

Graphene Battery for fast charging Electric Vehicles: A Review

Shashidhara B¹, Ezhilarasan Ganesan², Sudhakaran P³

¹Research Scholar Jain Deemed to be University, Assistant Professor, Electrical and Electronics Engineering, Ballari Institute of Technology & Management, Karnataka, India

²Professor, Electrical and Electronics Engineering, Jain Deemed to be University, Karnataka, India

³Associate Professor, New Horizon College of Engineering, Karnataka, India

Abstract

Rapidly charging Graphene batteries offer a promising solution for powering electric vehicles, promising faster recharge times and enhanced energy storage capabilities. This study proposes prospects for Graphene-based batteries as a solution for fast charging in electric vehicles (EVs). With the increasing demand for EVs and the necessity for efficient charging infrastructure, there is a growing need for batteries that can be rapidly charged without compromising performance or safety. Graphene, with its exceptional electrical conductivity and high surface area, holds promise for addressing these challenges. The major objective of this manuscript is to develop a fast-charging graphene battery for electric vehicles with the aim of significantly reducing charging time without compromising on battery performance or longevity. In this paper, explore the design, fabrication, and testing of a graphene-based battery optimized for fast charging applications in EVs. We examine the electrochemical performance, including charge/discharge rates, cycling stability, and energy density, of the graphene battery compared to traditional lithium-ion counterparts. Furthermore, we assess the feasibility of integrating graphene batteries into EV platforms and evaluate the potential impact on driving range, charging time, and overall vehicle performance. The results demonstrate the viability of graphene-based batteries as a compelling solution for enabling fast charging in electric vehicles, paving the way for widespread adoption of this transformative technology in the automotive industry.

Keywords: *Chemical Vapor Deposition, Energy Storage System, Electric Vehicles, Graphene Battery, Large Scale Grapheme, Lithium-Ion Battery, Thermal Management,*

1. Introduction

The development of alternative energy-powered cars, particularly electric vehicles, has increased recently with the goal of establishing the shift away from combustion engines and reducing the amount of fossil fuels used in the automotive industry [1]. The usage of Li-ion batteries in EVs has increased significantly in recent years, including hybrid and full-electric models. Precise tracking of the battery's SoC and SoH in an EV is essential for determining the car's range (which works similarly to a conventional vehicle's fuel gauge) and for keeping an eye on the battery system's general health [2]. The increasing population, modernization, and energy consumption of the world will pose significant challenges and environmental issues for future generations. Sustainable developments in energy-producing and -storing technologies are required to allay these worries [3]. Rapid charging is a crucial component of electric cars and portable gadgets, which has spurred intense study. The reduction of hours to minutes for charging energy storage devices that depend on reversible redox reactions is already a reality [4]. Utilizing renewable energy sources to address climate change requires energy storage [5]. The rapid rise in the world's energy demand will lead to a considerable increase in the growth of new energy generation. The market for batteries worldwide reached a value of \$21 billion in 2014, with \$9 billion coming from electric cars. With an average annual growth rate of 10%, the global market for rechargeable batteries is predicted to reach \$35 billion by 2020, with electric cars accounting for \$15 billion of that total. Batteries for new energy electric vehicles have a massive potential market and assist lower CO₂ emissions. However, because of its high stability, light weight, and vast surface area, graphene has attracted interest in the energy sector. Graphene is garnering global attention due to its potential use in energy storage, conversion, and transmission. Regarding whether graphene technology can actually advance the development of energy technologies, there is still a great deal of dispute [6].

Energy is a fundamental human need for survival and growth in every part of the planet at all periods [7]. But as a result of overusing coal, oil, and natural gas, environmental pollution is getting worse and there is a lack of energy, which has become one of the biggest issues facing humanity [8]. These problems have reportedly been resolved by a wide range of clean, sustainable, and highly effective energy conversion and storage technologies, such as batteries,

supercapacitors, capacitors, wind and wave energy converters, and thermoelectric generators [9]. Compared to graphite, graphene has a larger theoretical capacity. There has been a lot of interest in using carbon-based substances, like graphene and graphite, as substitute negative electrode materials [10]. Lithium batteries appear to be the perfect option for many everyday applications that make our lives more comfortable, but there are still a lot of things that could be done better, such as specialised energy, external heating, overcharging/discharging, and short work times [11].

The primary overall problem pertains to the production and advancement of effective electrode materials that offer extended periods of high energy density and high specific capacity, together with extended life and cycling time, robust protection, and affordable cost [12]. This paper also covers recent advances in GA synthesis for a variety of rechargeable lithium battery types' interlayer, electrode, and separator applications. Regarding graphene-based materials in lithium-air, lithium-sulfur, and LIBs, there are a ton of fascinating and significant review studies available [13, 14], some of which provide information on grapheme foams and aerogels. The three distinct types of LBs electrochemical performance is affected by pore size and volume, shape, specific surface area, and GA—all of which are ignored in their manufacturing processes and environments. In order to close this gap, the current study summarises available data and discusses the variables influencing electrochemical performances [15].

(a) Research Gap

One significant research gap in the improvement of rapid charging graphene batteries for EVs lies in achieving optimal performance and safety at scale. While graphene-based batteries exhibit promising properties in laboratory environments, transitioning these findings to large-scale production presents numerous challenges. Ensuring consistent performance across mass-produced batteries while maintaining rapid charging capabilities is crucial for their viability in electric vehicles. Additionally, addressing concerns related to cycling stability and safety, particularly regarding heat generation during rapid charging, remains paramount. Research efforts focused on optimizing manufacturing processes, enhancing cycling stability, and developing effective thermal management systems are essential for realizing the potential of graphene batteries in the EV market.

2. Graphene Batteries: High-Power Density Energy Storage with Enhanced Stability and Reversibility

Both the cathode and anode graphene electrodes are present in the graphene batteries. Graphene exhibits the maximum thermal conductivity (3000 Wm⁻¹k⁻¹) and inherent mechanical strength (1060 Gpa) [16]. The graphene battery produces a higher power density than a traditional lithium

ion battery because of the quick surface response that takes place in both electrodes. The high

electrical conductivity and porous shape are two characteristics that contribute to the increased power density. A few high-performance energy-storage technologies that exhibit promise due to their elevated energy density include superconductors, LIBs, and Li-ion capacitors (LICs). Unfortunately, the cost of existing LIBs is too high and their power density makes them unsuitable for large-scale applications. The primary electrode reaction feature of LIBs is intimately linked to these problems of high cost and low power density. Furthermore, because of the significant potential distinction between the cathode and anode, it maintains a high energy density. The literature suggests that, depending on the weight of the cathode and the specific capacity or electrochemical characteristic of graphene batteries assessed at the voltage range of 0.01 to 4.3 V at a current density of 0.05 A g⁻¹, the cathode delivers a capacity of approximately 170 mAh g⁻¹, or 100% utilisation, while the anode delivers a capacity of 430 mAh g⁻¹, or 80% utilisation.. Because graphene batteries' charge/discharge profiles do not change much after multiple cycles of charging and discharging, the electrochemical procedure in these batteries is extremely reversible, and their performance is superior to that of LIBs and superconductors.

2.1. Structure and Properties of Grapheme Battery

A layer of graphite that is 0.34 nm thick and one atom thick is known as the graphene nanostructure [17]. As can be observed in Fig. 2, the basic concept underlying changing to investigate the electrical dislocations using the graphene structure. The movement of C atoms within the unit cell is the main process responsible for the continuous development of nanostructure graphene. It took a lot of labor to create a nanostructure array with regulated size, shape, functionality, and crystallinity. These materials find extensive usage in fields such as optics, electronics, solar energy harvesting, electrochemical energy conversion and storage, and many more. Consequently, the enhanced characteristics of graphene have led to the compositing of several inorganic nanostructures, as the next sections shall demonstrate.

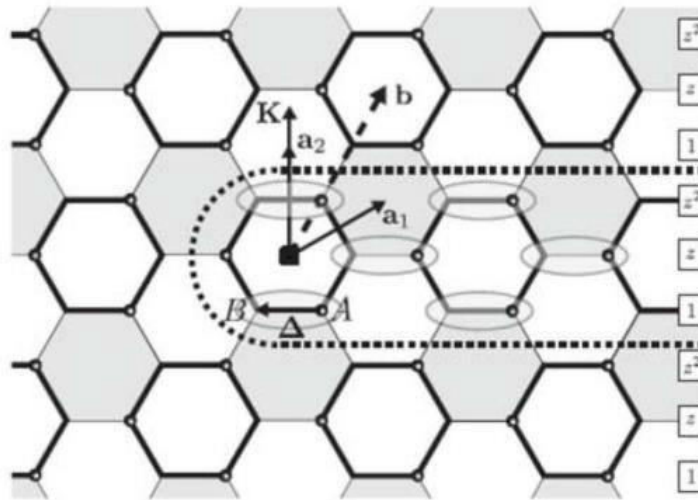


Fig 1: The electronic structure and dislocations in graphene

Graphene exhibits a number of intriguing features, excellent charge mobility (230,000 cm²/Vs), high power (130 GPa), and a robust specific surface area (2600 m²/g), and up to 2.3% visible light absorption [17]. This has succeeded in igniting the scientific community's interest in learning more about the potential uses of graphene. Because of this, a thorough understanding of graphene's application in fuel cells and batteries is necessary, including knowledge of its mechanical, chemical, electrical, and physical properties.

2.2. Exploring 3D Graphene: Varieties, Synthesis Methods, and Characteristics

Amidst a plethora of 3D nanostructures, 3D graphene has garnered significant attention owing to its multifaceted structural characteristics [18]. Understanding the differences between 2D and 3D graphene is essential to understanding 3D graphene. Based on layers and electrical characteristics, graphene, which is made up of monolayer C-atoms finely prearranged in a 2D honeycomb lattice with sp² hybridization, can be divided into several 2D forms. But 3D graphene develops into a sophisticated 3D network structure as opposed to its 2D cousin. 3D graphene is produced using a variety of methods and has uses in solar cells, electrochemistry, and hydrogen storage, among other fields. This section delineates different types of 3D graphene, prevalent fabrication methods, and underscores its pivotal electrochemical properties. Three-dimensional graphene materials fall into two categories: microscopic (less than 100 μm) and

macroscopic (more than 100 μm). The term "microscopic 3D graphene" refers to a variety of

formations, including hollow, floral, coral-like, honeycomb, strutted, crumpled, and printed shapes at the micron scale. Macroscopic 3D graphene consists of sponges, films, fibers, mill spheres, integrated templated, randomly template, uneven films, and vertical arrays. Fig 3 shows the Graphite (2D graphene) layered into a 1D nanocarbon tube, wrap it around 0D fullerene, and stack the layers to create 3D graphite.

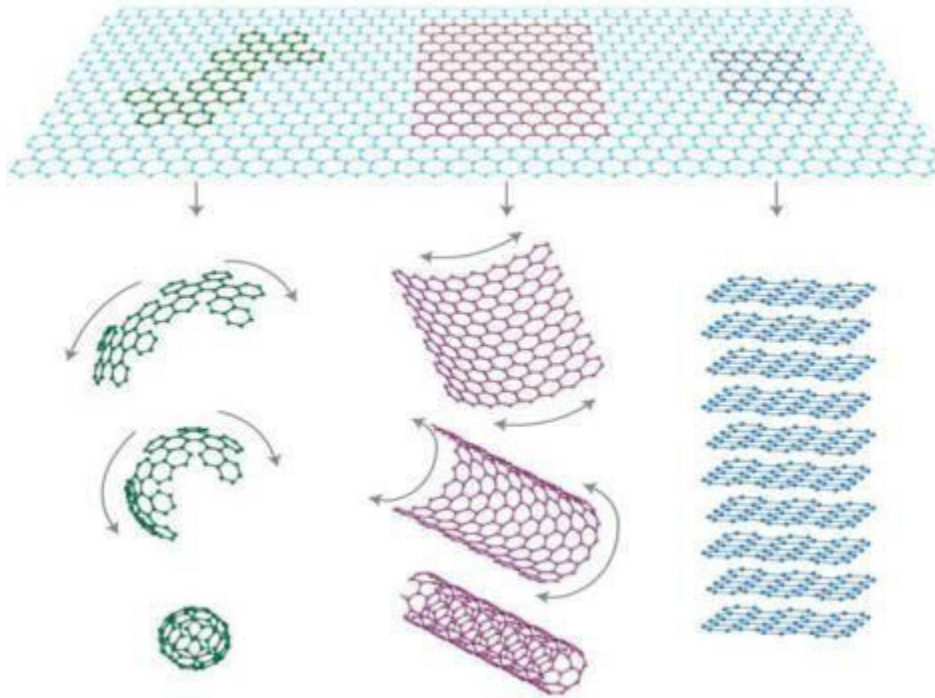


Fig 2: Graphite (2D graphene) layered into into a 1D nanocarbon tube, wrap it around 0D fullerene, and stack the layers to create 3D graphite [17]

2.3. . Graphene Aerogel Application in Li-Ion Batteries

2.3.1. Graphene Aerogels in Anodes for Li-Ion Batteries

LIBs' power density and cycle presentation are significantly by the properties, both chemical and physical, of the anode and cathode [19]. Typically, a LIB's two electrode materials are layered solids that have intercalated Li^+ ions that may be stored. Graphite's excellent Coulombic efficiency and longer cycle performance make it a popular commercial anode material for LBs. Graphite has a theoretical specific capacity of 372 mAh/g, or about one tenth of that of Li,

because it can store up to 1 Li for every 6 C- atoms among its graphene layers. Typical graphite

materials with an intercalation-type structure have low Li storage capacities because of the restricted Li-ion storage compartments within the sp^2 hexagonal C configuration. Because of its two-dimensional structure and higher capacity than graphite, graphene has recently been studied as a potential anode matter in LIBs. Li adsorption over the carbon sheet's two sides, Li intercalation in the material's pores or Li binding on graphene fragments' hydrogen-terminated ends in materials containing C are thought to be the causes of the increased capacity of graphene-based materials.. Assuming that Li ions may be adsorbed on both sides of the graphene sheets, forming two layers of Li for each graphene sheet and Li_2C_6 , theoretical capacity estimations of 744 mAh/g are predicted. Reduced graphene oxide (RGO) has a lesser surface area than 2D monolayer graphene, but is more commonly described in the literature due to its simpler production procedure. Over 10 years ago, unaltered graphene foam produced by annealing and freeze-drying Augmented reality served as the LIB's anode.. The reversible ability of 800 mAh/g at 50 mA/g was found by annealing graphene at 400 °C; this is much higher than the reversible capacities of graphene annealed at 600 °C and 800 °C. According to research, the temperature of annealing influences the ability by changing the reduction degree at 400 °C, which increases the amount of carboxyl groups with functions on graphene sheets that are capable of reacting electrochemically with Li ions in a reversible manner. The transportation and communication industries have seen a transformation thanks to LIBs' extended cycle life, high gravimetric energy density, and lightweight design.

2.4. . Anode Material for Lithium-Ion Batteries Based on Graphene

Graphene seems to be a promising material for the negative electrodes of LIBs. Graphene and graphite are similar in that they have faster charge-discharge cycles, greater electrical conductivity, and a larger capacity to store Li ions [20]. Fast charging is made possible by graphene's capacity to speed up both the electron and Li-ion intercalation and deintercalation into the electrode's constituent parts. The battery's reversible specific capacity may be raised by graphene, which also lengthens its lifespan. Because of its superior mechanical flexibility, graphene could be used to create flexible LIBs. Lithium ions have many routes to the anode substrate thanks to the graphene layer. Graphene is a perfect substrate for minimizing significant volume fluctuations and limiting the production of fragments from materials that undergo

conversion due to its unique 2D structure, remarkable mechanical stability, and flexibility.

Graphene appears to have the potential to greatly enhance battery-type electrode performance for LIBs, either as a conductive and flexible two-dimensional support or as extraordinary active materials. Most of the time, half cells having a highly broad cut-off voltage range of 0.01 to 3.0 V and very high specific capacities were used to evaluate graphene electrodes. Even with its potential, functional Li-ion cells do not fully exhibit attributes like increased efficiency. It is advised that electrode material have a charging upper limit of less than 0.3 V. For the purpose of studying high-voltage anodes or gaining a fundamental understanding of the maximum delithiation capacity, the voltage range can be extended up to 3.0 V. Examples of nanocomposites include C-coated nano-silicon encapsulated in C-nanotubes, nano-silicon encapsulated in carbon shells from metal-organic frameworks, Si nanodots scattered in MOF- derived nanoreactors, and interconnected porous SiC networks [21]. In these cases, the composite material is still nanometer in size after compositing Si and C. Fig. 4 shows the graphene-based nanocomposite that was utilized as the LIB anode material.

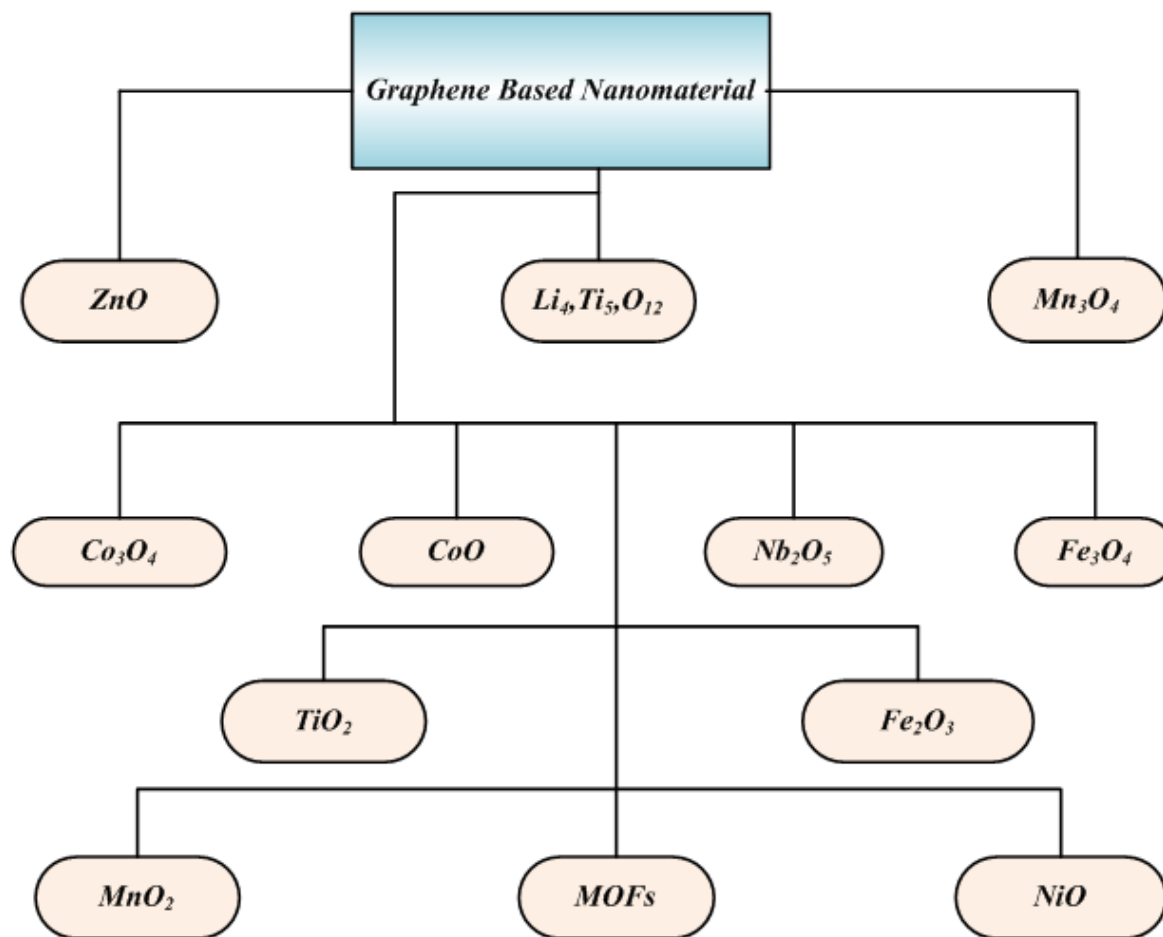


Fig 3: Nanocomposite based on graphene as LIB anode materials

2.5. Model and Description of High-Energy Density Graphene Battery Energy Conversion

In a recent work, large-scale graphene preparation and its application in electro-catalytic processes were examined. In a lab context, graphene-Pt electrodes were utilized to assess the material's potential for high-efficiency electric vehicle batteries [6]. Through the use of graphene's special structure, the study clarified the relationship among graphene and Pt catalysts and produced a highly de-centralized, stable, and active catalyst. Additionally, the researchers explored modifications and doping of the graphene nano-energy system to reduce reliance on Pt in battery applications. They produced functionalized graphene with high specific surface area, conductivity, and thermal conductivity via surface modification and graphene doping during electro-catalytic processes. Integration of graphene electrodes with current collectors and electrolytes facilitated the creation of nanographene electrodes for EV batteries. As part of their work, a model was established to analyse porous graphene, taking into account variables such as surface functioning, pore size dispersion, and specific surface area. This made it possible to assess the battery's specific capacitance, power density, and cycle performance quantitatively.

2.6. Epitaxial Growth Techniques: CVD for Large-Scale Graphene Production

The ability to produce high-quality, uniform graphene in large quantities is now necessary for novel graphene applications [20]. One method for producing significant amounts of graphene on a range of substrates is the epitaxial graphene growth. Chemical vapor deposition, silicon carbide (SiC) sublimation, and molecular beam epitaxy (MBE) are the main methods used in this approach. Two methods are used to feed carbon: in the first, the carbon is provided as a gas, and in the second, it is found in the substrate. The carbon atoms are placed on the substrate using a beam in the third technique. Moreover, various metal substrates, such as Ni /hexagonal boron nitride sheets, can be employed in the CVD and MBE processes. The key points of each technique that has been discussed are then reviewed. Using solid, liquid, or gaseous precursors, CVD is a commonly used technique for depositing or developing thin, crystalline, or amorphous

films. There are several kinds of CVD procedures, including as hot filament, low and atmospheric pressure, thermal, cold wall, hot wall, and plasma-enhanced (PECVD) techniques. Graphene is usually formed directly on a transition metal substrate in CVD by means of

hydrocarbon gas exposure results in carbon saturation at elevated temperatures. Substrates include semiconductors like germanium and zinc oxide, insulators like sapphire, and transition metals like copper, nickel, platinum, cobalt, and iridium. The most widely utilised precursor is methane, while research has also looked at acetylene, ethanol, benzene, and ethane as potential substitutes. Transition metals are essential to the deposition of graphene, and their methods vary depending on their solubility. For instance, carbon atoms dissolve in nickel to produce a solid solution, which then separates to form graphene, but in copper, they absorb and crystallise on the surface.

2.7. Lithium-Ion Batteries and Graphene

Graphene presents a large potential window and significant surface plasticity for functionalization, functioning as building blocks to generate various materials in the field of LIBs [22]. In addition, this material's layered structure and strong conductivity make it an excellent matrix for creating hybrids with anode and cathode materials. By improving conductivity, electron transport, and mechanical qualities, these hybrid materials can improve the final material's electrochemical performance. This is a crucial piece of information to support the creation of novel electrode configurations and LIB kinds. Real LIBs are primarily made of graphite, which is the anode electrode and is obtained by reversibly intercalating Li ions in the interlayer spaces; the positive electrode is typically lithium metal oxide, and is divided by an electrically insulating but ion-conductive separator that is submerged in an organic electrolyte that conducts ions. However, new materials are required to meet the demands of high-performance devices, leading to their downsizing and usage in new, varied applications including aerospace, military, and automotive applications, improving their mass capacities (Whkg⁻¹) and energy densities (WhL⁻¹). Because of its characteristics, graphene can improve the LIB's overall electrochemical performance. In order to meet development goals through electric cars, portable gadgets, and large-scale power grids, next-generation energy storage and conversion technologies are desperately needed [23]. The field of ubiquitous computing has been made possible by the application of miniature computers for autonomous intelligence that are just a few hundred micrometers thick and less than one square millimeter in size [24]. Electrochemical processes serve as the foundation for the operation of electrochemical devices used in energy

conversion and storage [25].

2.8. Synthesis of Graphene

2.8.1. Epitaxial Growth on Silicon Carbide

SiC is heated to extremely high temperatures (low pressure) during the epitaxial growth process to transform the substance into graphene [26]. The dimension of the SiC substrate dictates the dimensions of the product. The conductivity and thickness of the graphene can also be influenced by the substrate's composition. Weak antilocalizations in the graphene produced by the epitaxial process are absent from peeled/Scotch-taped graphene. However, it has been demonstrated that mixing graphene combined with other materials for the anode can lower a number of safety issues and enhance LIB performance [27].

2.8.2. Epitaxial Growth on Metal Substrate

This method seeds graphene's epitaxial growth using the atomic structure and source of a substrate made of metal. Typically, the thickness of graphene produced on ruthenium is not uniform [26]. Conversely, the graphene produced on iridium exhibits good organization, homogeneous thickness, and peel ability. However, graphene on iridium exhibits ripples in contrast to other substrates. The presence of these long-range ripples aids in the development of tiny gaps in graphene's electronic band structure, or Dirac cone.

2.8.3. Graphite Oxide Reduction

Historically, the initial technique for synthesizing graphene was decrease in graphite oxide. Synthesis of reduced graphene oxide in a single layer. At times, a little amount of graphene flakes combined with distributed carbon powder can be heated to separate graphite oxide. Graphite is converted into graphene oxide by employing potent oxidizing agents, which allows for chemical exfoliation [26]. Single-layer graphene sheets are created by further chemically reducing the graphene oxide with hydrazine during high temperature annealing. However, because many functional groups and imperfections are present, the grade of graphene produced by reducing graphite oxide is worse than that of graphene created by the Scotch-tape approach.

2.9. Three-Dimensional Bi-continuous Ultrafast-Charge and -Discharge Bulk Battery

Electrodes

An innovative development in energy storage technology is the creation of 3-dimensional bicontinuous ultrafast electrodes for charging and discharging bulk batteries. In response to the increasing demand for rapid charge and discharge rates in electrical energy storage devices, conventional batteries often sacrifice energy capacity. However, the bi-continuous electrode concept offers a solution by combining the battery's power density with the supercapacitor's rate performance [28]. The work design allows for extraordinarily rapid charge/discharge rates with minimum capacity loss by utilizing a self-assembled Nano architecture made up of an electrolytically active material sandwiched by effective ion and electron transport routes. This electrode design addresses key challenges in battery performance, including ion transport, electrochemical reactions, and electron conduction, leading to ultrafast while keeping significant energy storage capacity, including discharge and charge capabilities. The fabrication process involves intricate techniques such as electrode position through complex three-dimensional structures, ensuring the formation of interconnected pathways for rapid ion transport and efficient utilization of the electrode material. This transformative approach holds significant promise for advancing portable and distributed power technologies, offering a pathway towards high-performance energy storage systems for diverse applications.

2.10. Fabrication of Graphene Batteries

The main function of graphene in batteries is as a flexible electrode [29]. Currently, exfoliation of graphite oxide, the modified Hummers' method, epitaxial growth, and chemical vapour deposition are the four main production processes utilised to manufacture graphene.

2.10.1. Hummers' Method and Exfoliated Graphite Oxide

Graphene is usually produced by the Hummers' technique. In order to effectively oxidise and scrape the graphene layers off of graphite oxide, KMnO_4 and NaNO_2 are dissolved in concentrated H_2SO_4 . Depending on the needs of the application, the Hummers method can be altered in a variety of ways [29]. Graphene sheets were initially created by mechanically exfoliating them with scotch tape. A more cost-effective version of this process constantly exfoliates graphite using a three-roll mill setup. After that, graphite is spread out on an adhesive that is positioned

between the feed and the centre of the rolls. Pure graphene is produced by burning the resin layers in a muffle furnace at 500 °C after exfoliation.

2.10.2. Chemical Vapor Deposition

In order to coat a substrate, chemical vapour deposition (CVD) involves either heating carbon to a vapour or lowering ambient pressure [29]. Metal serves both a substrate and a catalyst for the formation of graphene. The procedure consists of three main stages: (i) the metal film's carbon diffusion; (ii) chilling the thin metal film to remove the carbon due to its decreased solubility; and (iii) the surface creation of graphene layers. Compared to CVD, another method known as PECVD offers benefits such direct growth on nanostructures or a plastic substrate.

2.10.3. Epitaxial Growth

Epitaxial growth is a microfabrication technology that can be used to create graphene films on a large scale [29]. Because SiC is flexible and contains carbon, it is used as an insulator substrate in epitaxy, allowing the carbon (graphene) to be preserved after the silicon is removed or melted. Nevertheless, achieving a consistent thickness across a greater surface area remains challenging, and the substrate bonding influences the electrical characteristics of the synthesised graphene layers. Using alternative substrates will eliminate these problems. The most crucial need for practical applications in High energy density LIBs have been the relentless pursuit of fast charging as the demand for EV charging times to drop rapidly increases. The integration of graphene balls (GB) as a coating material for LIB anodes and cathodes, forming a three-dimensional popcorn-like structure, presents a breakthrough solution enabling high-capacity [30] Ni-rich layered cathodes.

3. Extreme Fast Charging of Electric Vehicles

The technological landscape of XFC for EVs amidst the backdrop of escalating environmental concerns and the imperative to transition away from petroleum-based transportation [31]. With a focus on addressing the limitations of current lithium-ion battery technology and the critical need for robust EV charging infrastructure, the paper outlines the motivation behind XFC stations and the advantages they offer over traditional charging methods. It looks at power electronics converter topologies that are appropriate for XFC stations, with a focus on the design of the AC to DC front-end stage and DC to DC converter architectures that are specifically designed to

satisfy the demanding specifications of automobile traction batteries. The study also assesses the

viability and advantages of using SSTs in XFC stations to effectively convert medium voltage to low voltage while maintaining the required galvanic isolation. Lightweight, extended cycle life, and high gravimetric energy density of LIBs have transformed the transportation and communication industries [32].

3.1. EV Charging Model

The quantity of electric current passing through the distribution network's conductors rises as a result of the widespread use of EVs. Ensuring that electric vehicle batteries can be recharged when needed by the EV operator is essential for proper charging infrastructure planning [33]. Because of our demand for electricity, people are using fossil fuels and gasoline, which is having a negative impact on the environment and the economy [34]. In general, elemental sulfur is used as the cathode material in LSBs, which are the most promising possibilities for next-generation ESSs. This is due to the batteries' enormous specific capacity, excellent energy density, plenty of reserves, reasonable price, and environmental friendliness [35]. In this regard, the current idea aims to ascertain the highest power that ought to be installed in every CS in order to ensure that the electric supply is available when the user of non-conventional mobility needs it. The properties of the scattered loads must therefore be expressed mathematically. The link between voltage and the total quantity of active and reactive power in the feeder is represented mathematically by the load model. The Cym Dist software, which is used in this work, allows the load to be simulated using two distinct approaches: polynomial and exponential. The exponents, on the other hand, illustrate the proportionate percentage of each load type, whereas the coefficients indicate the load type represented by, for example, constant impedance, constant power, and constant current. Eqs. (1) and (2), respectively, are the active and reactive power expressions found in the polynomial model (ZIP).

$$P = P_o(p_1\bar{V}^2 + p_2\bar{V} + p_3) \quad (1)$$

$$Q = Q_o(q_1\bar{V}^2 + q_2\bar{V} + q_3) \quad (2)$$

When the supply voltage in Equations equals one p.u., V_0 , P_o , and Q_o stand for the voltage as

well as the reactive and active powers, respectively. The parameters in equations (1) and (2)

indicate how the load behaves as it gets closer to 1, either as a constant impedance, a steady continuous current. The p.u. is the independent parameter V of (3). voltage supply. As seen in (3), V will likewise equal 1 if the real supply current is equal to the value V_0 .

$$V = \frac{V}{V_0} \tag{3}$$

Table 1 below displays the coefficients that define the polynomial static model. In conclusion, since the power electronic components in the electric chargers replicate the load that the electric car represents on the grid by incorporating a harmonic current source that replicates the non-linear characteristic using a 12-pulse bridge and a 3-phase converter. This is on top of the implied increase in current from this.

Table 1: EV charge static load model parameters for fast charger

Power	Coefficient	Parameter
Active power	p_1	-0.1326
	p_2	0.1816
	p_3	0.9495
Reactive power	q_1	–
	q_2	–
	q_3	–

3.2. Modeling of Electrical Driving Systems

To operate a BLDC motor, electrical driving systems convert DC current (shared from DC bus lines) into a roughly equivalent AC current [36]. A MOSFET is used in this study's electrical

drive systems as the key switch. The types of charging ports for EVC are displayed in Table 2.

The MOSFET will always trip when the gate input drops to zero, regardless of whether current is flowing through the device positively or negatively. If the current flows through the internal diode and is negative, the switch closes when the current drops to zero. (no gate signal, or $g = 0$).

The terminal voltage V_{ds} is given as

The terminal voltage V_{ds} is given as

$$V_{ds} = \begin{cases} iR_{on} & , \text{ on-state} \\ iR_d - V_f + L_{on} \frac{di}{dt} & , \text{ off-state} \end{cases} \quad (4)$$

Where, i is the MOSFET's current, R_{on} is the switch-on resistor, R_d is the fly-wheel diode resistor, and L_{on} is the parasitic inductance.

Table 2: Types of charging ports for EVC [35]

Type	Current (Amp) Type	Time (h)	Recharge (%)	Power (kW)
Slow	17 AC	8	100	4-8
Semi-fast	33 AC	1.150	50-90	22
Fast	64 AC	0.500	50-90	50
Ultra-fast	250-400 DC	0.170	50-90	350
Change-Battery	AC-DC	0.033	100	-

3.3. EV Charging Systems

The charging time is the most notable feature for electrical vehicle charging. As a result, multiple standardized charging levels were created for charge at varying power levels. The CS are categorized as AC and DC charge stations and are separated into three types. [37]. An overview

of the various power and current capacity on the EVCS requirements may be found in Table 1.

One of the primary challenges to the broad adoption of EVs is the extended charging duration. Electric cars require significantly more time to charge than cars with internal combustion engines. However, end users see this position with distrust. But with technology advancing quickly, it's anticipated that soon EV charging times will match those of internal combustion engine vehicles. Furthermore, it ought to be feasible to localize the CS and reduce fast charging's effects on the grid. Thus, there is a need for innovative hybrid charging stations that are sourced locally. In these conditions, the proper and optimal size of locally provided energy-supplied charging stations is required.

Table 3: Power and current levels on the standards for the EVCS

Levels	Maximum power rating (kW)	Maximum current rating (A)
AC Charging	60-120	250
DC Charging	100-200	400

3.4. EV Battery Thermal Management Systems (BTMS)

The battery temperature is raised and the possibility of thermal escape is decreased by an EV's BTMS, which significantly prolongs the LIB pack's life [38, 39]. The ability to maintain the LIB pack's temperature among 15 and 35 °C, being lightweight, compact, and energy-efficient, being reasonably priced, being able to regulate the battery cells' temperature evenly throughout the pack, and having adequate ventilation in case toxic fumes leak from a lithium-ion battery fire are just a few of the features that make up a good battery temperature monitoring system (BTMS) [40]. The automotive industry uses a variety of Battery Thermal Management Systems (BTMS) types, including as systems based on liquid, air, thermoelectric elements, PCM thermal management, and hybrid technology. When compared to other passive cooling techniques like PCM and heat pipe BTMS types, air and liquid-based cooling are the most often used BTMS types in EVs because the cooling capacity can be dynamically adjusted based on the battery's thermal load. Fig. 5 shows the subcategories for every system.

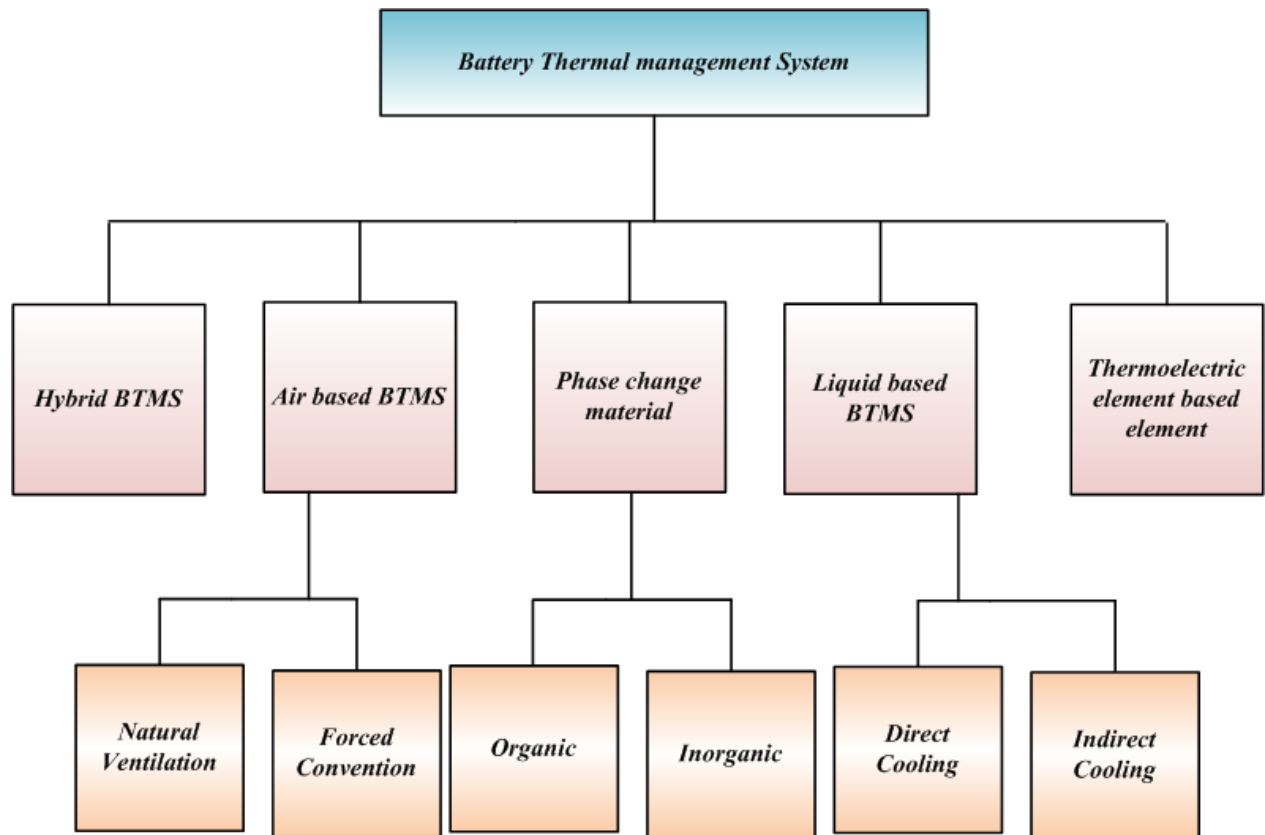


Fig 4: Various BTMS varieties are used with EV lithium-ion battery packs

3.5. . Air based BTMS Air based

In addition to having BTMS is a non-viscous, direct, low-risk coolant that has several benefits over liquid, PCM, and thermoelectric based BTMS. They are also more cost-effective, lightweight, small, require less maintenance, and have excellent reliability [21]. The energy required to run the TEC, TEG, or pump system reduces the EV's range when using active cooling battery management systems (BTMSs), which include those using BTMS based on liquid and thermoelectric thermal management [22]. This efficiency difference, meanwhile, is only noticeable under low heat load circumstances. Extreme heat load conditions, like high ambient temperatures or excessive charge and discharge rates, cause air-based battery management systems (BTMSs) to consume more energy than their liquid and thermoelectric equivalents. However, since a large number of PCMs are required to guarantee that the heat produced by the LIB pack is balanced by the PCM Capacity for Latent Heat, the majority of

PCM BTMSs will turn out to be noticeably heavier [40].

4. Physicochemical Basics of Fast Charging

Large current densities necessary for fast battery charging result in large over potentials at various battery components [41]. Battery failure occurs due to a physicochemical reaction that occurs when these excess potentials surpass specific limitations. Lithium plating at the negative electrode, usually graphite, is the most well-known mechanism that results in cell failure. Evolution of oxygen at oxide cathode active materials like NCM and other layered oxides is one type of degradation process that can also happen at the cathode. A battery cell's voltage at the anode $\tilde{\mu}_{e^-}^c$ and cathode v , correspondingly, is determined by the variations in the electrons' electrochemical potentials in the cell, as stated by

$$V = -\frac{1}{F}(\tilde{\mu}_{e^-}^c - \tilde{\mu}_{e^-}^a) = V_{oc} + \Delta\phi^c + \Delta\phi^a \tag{5}$$

Here, F stands for the Faraday constant, and $\tilde{\mu}_i$ for the species i electrochemical potential which is the total of the species' chemical potential $\tilde{\mu}_i$ and electrical potential $z_i F \phi$ plus the charge number z_i , which is determined by

$$\tilde{\mu}_i = \mu_i + z_i F \phi \tag{6}$$

Lithium ions are moved inside $\tilde{\mu}_{Li}$ and raised from the cell's equilibrium state during battery operation. An over potential, which is created in the cell by a raised $e^- \tilde{\mu}_{e^-}^a$ or $\tilde{\mu}_{e^-}^c$ at the anode or cathode contacts, correspondingly, is required to promote this kind of transport. The cumulative over potentials required to drive solid-state dispersion within the corresponding active anode or cathode material (AM a $\Delta\phi$ or $\Delta\phi$ AM c), the excessive capacity to promote charge exchange between the electrolyte and electrode (CT a $\Delta\phi$ CT c $\Delta\phi$), furthermore to the excess potential that proposes ionic transport in a porous electrode's electrolyte phase (EL c $\Delta\phi$ or $\Delta\phi$ EL a) can be combined to determine the total over potential at every battery electrode, $\Delta\phi^c$ or $\Delta\phi^a$.

$$\Delta\phi^c = \Delta\phi_{AM}^c + \Delta\phi_{CT}^c + \Delta\phi_{EL}^c \tag{7}$$

$$\Delta\varphi^c = \Delta\varphi_{AM}^a + \Delta\varphi^a + \Delta\varphi^a \quad (8)$$

Electronic conductivities in active materials are frequently significantly higher than ionic conductivities. Ionic transport is hence the main source of any over potentials $\Delta\phi_{AM}^a$ or $\Delta\phi_{AM}^c$. Due to solid-state dispersion, this results in a gradient of μLi^+ inside the active material. This gradient is caused by the cell current for the period of discharging or an applied current for the period of charging. Charge transfer occurs at the contacts between the electrodes and electrolyte; this process also needs a driving force $\Delta\phi_{CT}^c$ which lessens. Since most of the CAMs in LIBs are made of high-voltage materials that are more stable than normal solid electrolyte inter phases will occur as a result of side reactions between electrolytes at the interface. Therefore, migration in liquid electrolytes is usually disregarded, but migration alone is responsible for transport in solid electrolytes. Achieving rapid charging has been regarded as one of the most important avenues for the growth of EVs in the market and, consequently, battery research [42]. The air quality is affected when electric vehicles penetrate [43]. The most promising substance for LIB's anode to enable quick charging is likely $\text{Li}_4\text{Ti}_5\text{O}_{12}$ (LTO), a boron-doped graphene anode, and a hierarchically porous carbon anode [44, 45].

Table 4: A number of active substances and their variations for use in fast-charging systems [41]

Active Material	Material Limitation	Modifications to Materials for High-Rate Applications	Active Material Loading	Performance
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Graphene	Unstable SEI layer as a result of the graphite's expansion and contraction, which raises the ICL; metallic lithium deposition is	Somewhat oxidized graphite that preserves strong electrical conductivity but has expanded d-spacing	9.1 mg cm ⁻²	The capacity value did not significantly decline from the value recorded at 0.1C to 10C; instead, it remained rather close to the
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	produced by slow low lithiation voltage and intercalation kinetics.				Q0.1C until 50C.
Li	Li dendrite growth occurs during cycling due to the fragile SEI layer; most Li anodes can only be cyclably operated at low current levels.	Thin silicon wafer ([20–30] μm) is used to pretreat the surface of the Li anode, creating a thin, highly ionically conductive LixSi coating.	Thin, highly ionically conductive LixSi layer is produced via Li anode surface preparation using thin silicon wafer ([20–30] μm).		Approximately 390 mA h g ⁻¹ specific capacity at 2 mA cm ⁻² (150 cycles).

5. Conclusion

In conclusion, the review underscores the promising possibilities of graphene-based batteries as a viable solution for achieving rapid charging in electric vehicles, offering faster recharge times and enhanced energy storage capabilities without compromising performance or safety. As the demand for EVs continues to rise alongside the need for efficient charging infrastructure, the development of fast-charging graphene batteries represents a significant step forward in advancing the adoption of EVs reducing dependence on fossil fuels. Through continued research and development efforts, graphene-based batteries hold the promise of revolutionizing the automotive industry by enabling faster charging, extended driving ranges, and overall enhanced

vehicle performance. Future work in this field could focus on optimizing the scalability and cost-

effectiveness of graphene production methods for battery applications, and further enhancing the electrochemical performance and stability of graphene-based batteries under rapid charging conditions. Additionally, research efforts could explore novel electrode designs, electrolyte formulations, and system-level optimization strategies to continue improving the efficiency, safety, and reliability of fast-charging graphene batteries for electric vehicles.

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