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Battery Technologies in Electric Vehicles

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Improvements in Electric Battery Packs

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Restrictions on fossil fuels and related environmental pollution issues motivate many organizations and countries to set their focus on electric vehicles (EVs) rather than conventional internal combustion engine vehicles [1], [2]. EVs require an energy storage system to store converted electric power in another form of energy and then reconvert the stored energy to electric power whenever it is required. The energy stored can be converted to electric energy for various uses, such as movement, lighting, and heating (although accessories are supplied by a 12-V auxiliary battery; the auxiliary battery is supplied by the main battery pack or by recuperative energy). Fortunately, many electrical energy storage technologies are available, with some offered commercially while others are in the research and development stage [3], [4]. Electrochemical energy storage systems use various technologies [5], [6]. Energy storage systems, the heart of EVs, are composed of battery cells, battery modules, and a battery pack. Researchers work on various sections of battery packs to improve their performance [7]. These sections are illustrated in Figure 1. As shown in the figure, some EV battery technology developers are studying chemical materials to increase the capacity, power, energy density, safety, and cell voltage. In the past century, the most common batteries for EV applications were Pb–acid and Ni-based batteries [8]. In current use, Li-ion-based batteries are at the top.

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Ongoing research of battery technologies for EVs focuses on some promising next-generation battery technologies for EV applications, such as solid electrolyte or aqueous, Li-oxygen (O_2), and Li-S, along with solid-state batteries [9], [10]. Also, research efforts concentrate on the cell components to decrease the internal resistance of cells, provide thermal management conditions, improve performance, reduce the production cost,

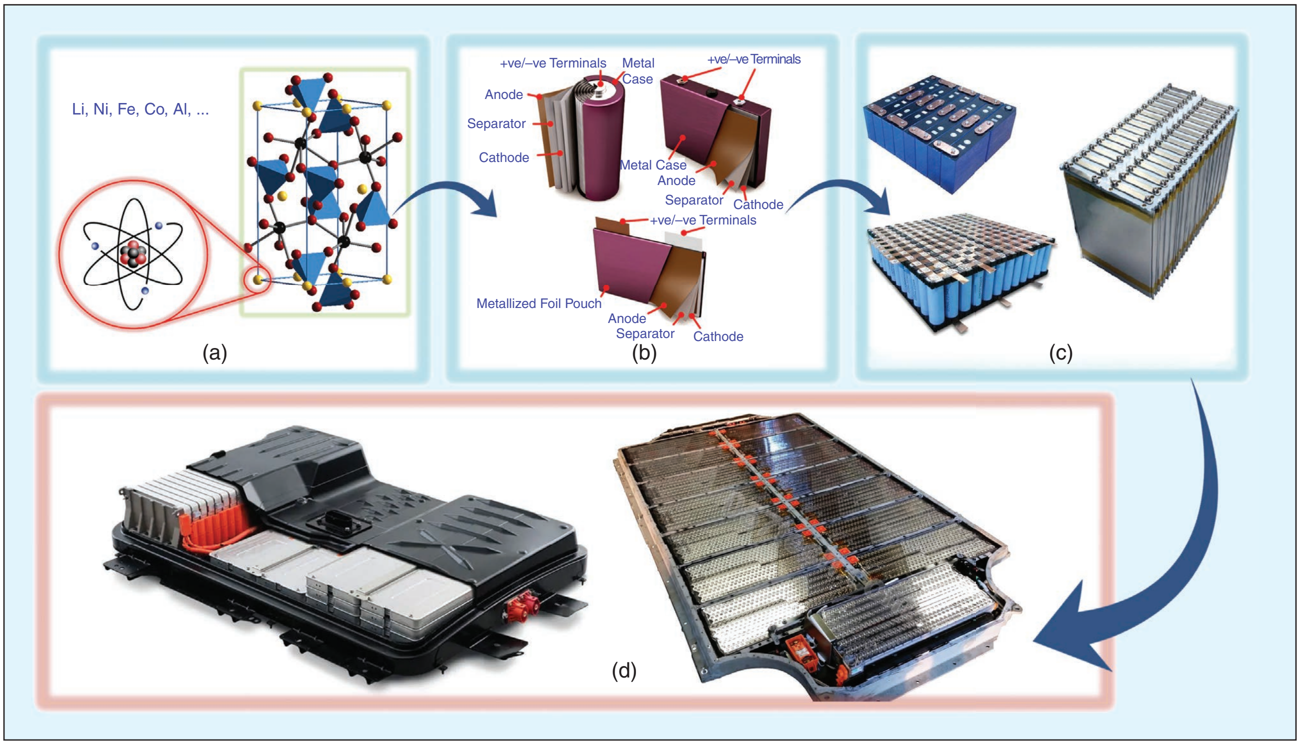


FIGURE 1 – The production structure of an onboard battery pack for EVs. The (a) chemical materials, (b) cell components, (c) series- and parallel-connected cells, and (d) battery pack. +ve: positive; –ve: negative.

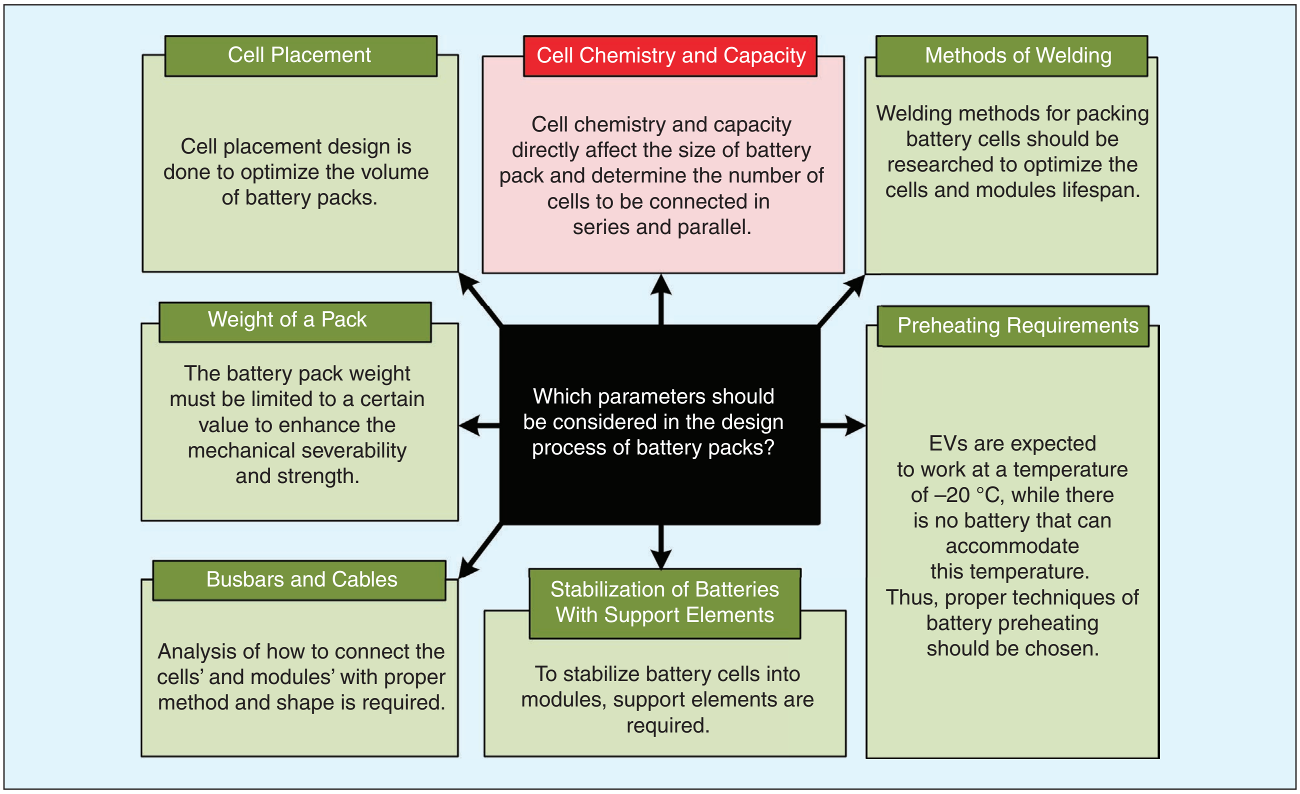


FIGURE 2 – The parameters to be considered in the battery pack design.

TABLE 1 – THE THREE TYPES OF LI-ION-BASED BATTERIES.

CELL TYPE	CYLINDRICAL CELL	PRISMATIC CELL	POUCH CELL
			
Produced by	Li-NMC, Li-NCA, and Li-LMO	Li-LFP	Li-LFP, Li-NMC, and Li-LTO
Features	✓ Proper cost performance and high manufacturability	✓ Better thermal management performance ✓ Easy heat exchange between the inside of the cells and the cooling system ✓ Easier design of cooling system [7], [19]	✓ Accidental swelling and bulging produces major safety concerns ✓ Being gradually marginalized due to safety problems [20]
Attractive among EV manufacturers	Tesla	Toyota, Volkswagen, and BYD	Chevrolet, Nisan, Hyundai, BAIC, Mazda, and General Motors [13]

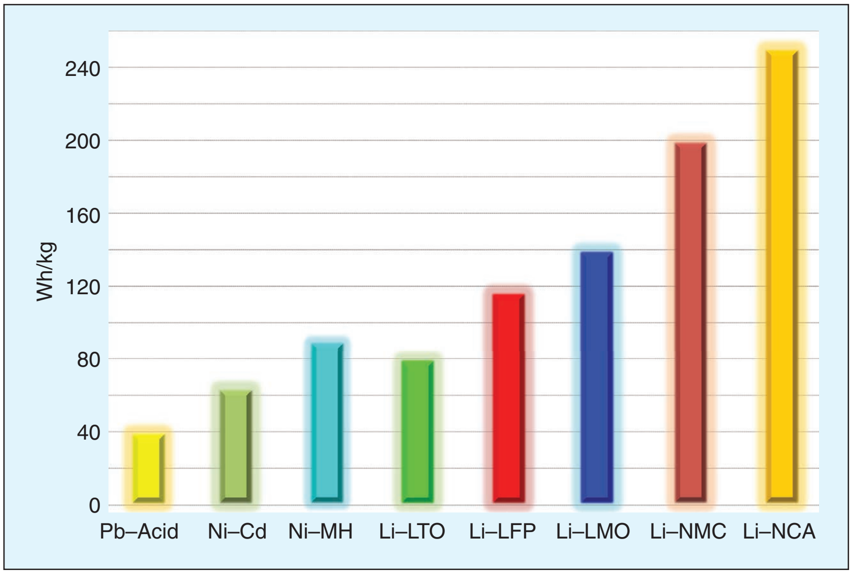


FIGURE 3 – A comparison of Li-ion-based batteries with Pb–acid and Ni-based batteries in terms of specific energy. MH: metal hydride.

facilitate fabrication, and support the stable operation of batteries [11], [12]. Eventually, the required high energy and voltage for EVs are obtained by connecting the selected cells in series and parallel [13]. Consequently, novel cell materials, cell components, and techniques of connecting cells can improve the voltage, capacity, weight, size, cost, thermal management, and safety of onboard battery packs, which are all required to upgrade the performance of EVs [14]. As a result, there are many fields involved in the movement toward improved EV battery pack technologies. Also, many different parameters should be considered during the design of battery packs. In this design, it is necessary to determine strategies for combining these parameters. In addition to choosing the proper cell chemistry and type in the battery pack design, some other parameters, shown in Figure 2, should be considered [7].

This article addresses the various technologies utilized by well-known EV manufacturers. We discuss the different approaches of various EV manufacturers to improve the performance of their battery packs. The advantages and disadvantages of the approaches are pointed out to enable better analysis of the performance of the EV battery technologies.

Basic Types of Battery Storage Technologies Used in EVs and Their Comparison

The chemistry of batteries distinguishes them in terms of their specific power rate, specific energy rate, lifecycle, cost, performance, and safety. In the early decades of the 20th century, Pb–acid and Ni-based batteries were utilized to power most automobiles. The oldest rechargeable battery technology is Pb–acid-based batteries. Ni-based batteries can provide better electrochemical characteristics, and they are lighter than lead-acid or Pb-acid batteries; on the other hand, their cost is approximately 10 times higher than that of lead-acid or Pb-acid batteries.

In many applications, Li-ion-based batteries are being replaced with lead and Ni-based batteries. Li-ion-based batteries are more expensive, but their low maintenance and high cycle count reduce their per-cycle costs. The main Li-ion-based battery types, based on their chemical composition, are $LiCoO_2$, $LiMn_2$ oxide (LMO), $LiNiMnCoO_2$ (NMC), LiFe phosphate (LFP), LiNiCoAl oxide (NCA), and Li titanate (LTO) [17]. Li-ion battery cells used onboard EV energy storage systems are also categorized into three types, as listed in Table 1: prismatic cell, cylindrical cell, and pouch cell [18]. The specific energy rate of Li-ion-based batteries, Pb–acid batteries, and Ni-based batteries are compared in Figure 3. It can be concluded that the energy rates of Li-ion-based batteries are higher compared to Pb–acid and Ni-based batteries. The advantages, disadvantages, and applications of the battery storage technologies are presented in Table 2. Li-based battery technologies have been dominating the EV onboard storage systems market, due to the features given in the table. But these batteries have some limitations and challenges, and to solve them requires better technologies. Battery technologies are advancing, and batteries under research have the potential to be the future large-scale commercial batteries for EV applications [13]. Future batteries theoretically work amazingly, but most of them do not meet the basic eight requirements, including high specific energy, high specific power, safety, a reasonable price, toxicity, long life, fast charging, and a wide function range, for an ideal battery. A limited load current and short cycle life often prevent them from being commercialized. Besides the eight requirements, a battery should have a

TABLE 2 – THE ADVANTAGES, DISADVANTAGES, AND APPLICATIONS OF THE BATTERY STORAGE TECHNOLOGIES [8], [10], [13], [15], [16].

CELL CHEMISTRY		ADVANTAGE	DISADVANTAGE	APPLICATION
Pb–acid		• Economically acceptable due to low price	• Low cycle count • Limited energy • Pb is toxic	• Lighting and starting in internal combustion engine vehicles • Golf carts • Wheelchairs • UPS
Ni based	Ni–Cd	• Ultrafast charging without considerable stress • High discharge current • Long service life • Work at high temperatures	• Cd is a toxic element • Memory effect; needs periodic full discharges	• UPS • Medical instruments
	Ni–MH	• Replacement for Ni–Cd batteries: provide higher energy	• Composed of mildly toxic metals • Slight memory effect	• Hybrid cars • Medical instruments • Industrial applications
Li-ion based	Li–NMC	• Can be designed based on application in terms of needed energy or power per cell • Increasing market due to high energy and power	• Expensive	• E-bikes • Medical devices • EVs
	Li–LFP	• High electrochemical performance with low resistance • Safe even when fully charged • Can tolerate high-voltage conditions for a long time with less stress • High thermal stability, cycle count, and current performance	• Low temperature reduces performance • High storage temperature reduces lifecycle • Highest discharge rate among Li-ion batteries (makes balancing problem with aging) • Low cell voltage reduces the battery energy	EVs and so on
	Li–LTO	• Fast charging • High discharge current • Highest cycle count and best thermal stability among Li-ion batteries • Excellent low-temperature performance (80% capacity at –30 °C)	• Low capacity • Expensive • Low charging and discharging voltage range	• UPS • Electric powertrains • Street lighting
	Li–LMO	• Low internal resistance (proper for high-current discharging and fast charging conditions) • Design flexibility for maximum delivered power, high lifecycle, and high capacity	• Expensive	• Electric powertrains • Medical devices
	Li–NCA	• Highest specific energy, high power, and high lifecycle count	• Lowest safety among Li-ion-based batteries	• Electric powertrains • Medical devices
Future batteries	Li–air	• Theoretical specific energy density is up to 2,000–3,000 Wh/kg, which is a high value	• Poor loading • Short life • Need to breathe clean air [21]	Potential for EVs
	Li–S	• High specific energy density of ≥2,500 Wh/kg • Wide operating temperatures • Good safety • Low production cost	• Poor loading and cycle life [22]	
	Li–metal	• Good loading capability • High specific energy • Rapid charging	• Lithium deposition is uncontrolled, which makes safety hazards	• Portable and industrial applications • EVs
	Solid-state Li-ion	• Wonderful specific energy density and safety • High potential for large-scale manufacturing and high lifecycle • Possibility of producing in a single large plate piece • Increasing the driving mileage significantly • Solving safety problems by reducing heat generation [23]		• Talked about for EVs • Wheeled mobility • Electrical energy storage • Under investigation by BMW, Hyundai, and Volkswagen

UPS: uninterruptable power supply; MH: metal hydride.

low self-discharge, long shelf-life, and capability of providing instant start-up whenever required. Meeting all the basic requirements is not easy, but researchers have not given up. Some of the future batteries may find specific markets, but some may not come out of laboratories. Therefore, the advantages, disadvantages, and applications of the most promising experimental batteries are also mentioned in Table 2.

Si anodes are a promising technology for Li-ion batteries, due to their considerably high capacity for storing Li. But Si anodes tend to shrink and expand during charging and discharging, which makes the system unstable. To reduce the amount of shrinkage and expansion, it is proposed to make batteries from a composite of Si and graphite to maintain their theoretical high capacity. However, the cycle life is still limited due to some problems in the structure [13], [25]. Therefore, more research and development are needed to make Si-based anode batteries commercialize to meet the market demand.

Figure 4 gives a performance summary of the five main battery chemistries through a hexagonal spider graphic of the onboard battery storage system of EVs. Also, Table 3 summarizes the performance of the five battery technologies for EVs. Although the power rate of the Li–LFP chemistry is the highest, there are no significant differences among the five chemistries. In the terms of safety, Li–NCA takes the lowest place. The safety of Li–NMC and Li–LMO is lower than that of Li–LFP and Li–LTO. In terms of performance, since Li–LTO is in the lead, it shows the best performance. In terms of the cycle life count, Li–LTO has the highest cycle life count, but it is the most expensive battery chemistry. Therefore, it cannot be added considerable things about the cycle life count and cost. Although Li–NCA has the highest capacity in EV applications, the cycle count and safety will gain more attraction compared to capacity.

Battery Technology Comparison of EV Manufacturers

Table 4 summarizes the characteristics of the utilized battery cell technologies of four well-known EV manufacturers (Tesla, Nissan, Chevrolet, and Kia). The table clearly shows that Tesla has elevated the power density of its battery cells while providing a 20% higher energy density by increasing the battery size (utilizing 21,700 cells instead of 18,650 cells) in its Model Y and Model 3. As a result, it can be concluded that Tesla attempts to increase the size of the batteries to increase the power, capacity, and control of heat generation over the previous ones. This results in higher power and capacity per pack, with fewer cells in the same pack size utilized for the previous cell generations.

While cylindrical batteries are attractive for Tesla, other large car companies, such as Chevrolet, Nissan, and Kia, have chosen a different laminated battery type. At present, the provided battery technology by Tesla has reached a high rate of production automation, lighter weight, and higher security and compliance, which is proper for mass production of batteries. Using this battery cell type by Tesla is the best choice. But many smaller batteries provided by Tesla must be wired in parallel and in series to provide the required power, energy, and voltage. This high number of battery cells in the pack requires a complicated battery management system (BMS), which has been acquired only by Tesla. The sheet shape of the laminated batteries makes them more suitable to conduct heat to the cooling system outside the batteries. Thus, they do not need a complicated cooling system and a complex BMS. But generally, the thin aluminum plastic film packing of the laminated batteries makes them more vulnerable to mechanical damage. Therefore, the batteries are prone to major damage in the case of critical circumstances and car accidents, which is the main defect of the cars.

Voltage and Power Level of Battery Packs of EV Manufacturers

The specifications of some onboard battery pack technologies used by some reputable EV manufacturers are provided in Table 5. This table shows that battery technology has been improving and helped with the advent of large battery packs with 50–150 kW. Although Tesla achieved ultrafast charging powers of 200–250 kW in models Y and S, with a 400-V pack voltage, the other EV manufacturers have been able to improve their power only by increasing the battery pack voltages to 600–800 V. The charging cables and busbars of the battery packs are large enough, and it is not possible to enlarge them. The charging power can be increased significantly by increasing the voltage without changing the conductor size and increasing the generation of heat [2], [26].

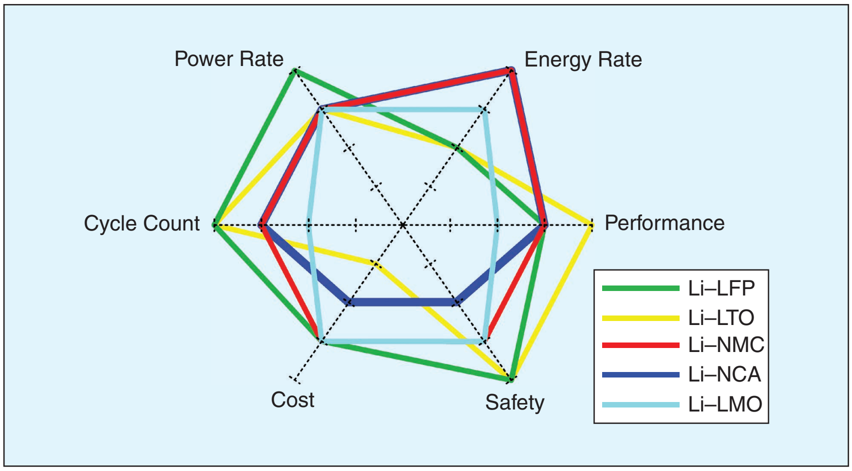


FIGURE 4 – A performance comparison of the five main Li-ion-based battery chemistries utilized in EVs.

An example of an improved battery charging profile by increasing the battery pack voltage is given in Figure 5. In the first configuration, the 400-V battery pack system is obtained from 100 series- and four parallel-connected battery cells. The 100 series-connected battery cells make the battery pack voltage around 400 V. Although the maximum conduction current of each cell is around 150 A, the charging current of the four parallel-connected battery cells is limited by the maximum current of the combined charging system (CCS) connector: 350 A. The increased-voltage battery pack 800-V system is composed of 200 series- and two parallel-connected battery cells. The charging current of this system is limited by the total maximum charging current of two cells, $2I_{\text{Cell,max}} = 300$ A, which is lower than the maximum current of the CCS, at 350 A. As a result, the maximum charging power of the standard battery pack system is increased by 71.43% by increasing its voltage to 800 V, without increasing the number of battery cells and the battery pack capacity. But on the other hand, it should be considered that the charging current of the batteries in the 800-V system is 150 A versus 87.5 A in the 400-V system. This maximum charging current increases the heat generation and thermal loss in the batteries, which can also reduce the lifetime of the batteries. Therefore, this thermal loss in the batteries should be managed by a well-designed thermal cooling system of the vehicle or a thermal capacity. However, increasing the voltage rate of the battery pack increases the number of battery channels in the BMS. For instance, in Figure 5, in the 800-V system, 200 voltage levels should be controlled and monitored, versus 100 voltage levels in the 400-V system. As can be seen in Table 5, some of the EV manufacturers, including Porsche, Hyundai, Kia, and Mercedes-Benz, increased their battery pack voltages to provide ultrafast battery charging stations. Increasing the voltage can provide many benefits, such as a significant reduction in the cross-sectional area and weight of busbars and

TABLE 3 – A PERFORMANCE COMPARISON OF THE FIVE WELL-KNOWN BATTERY CHEMISTRIES FOR THE ONBOARD STORAGE SYSTEM OF EVs.

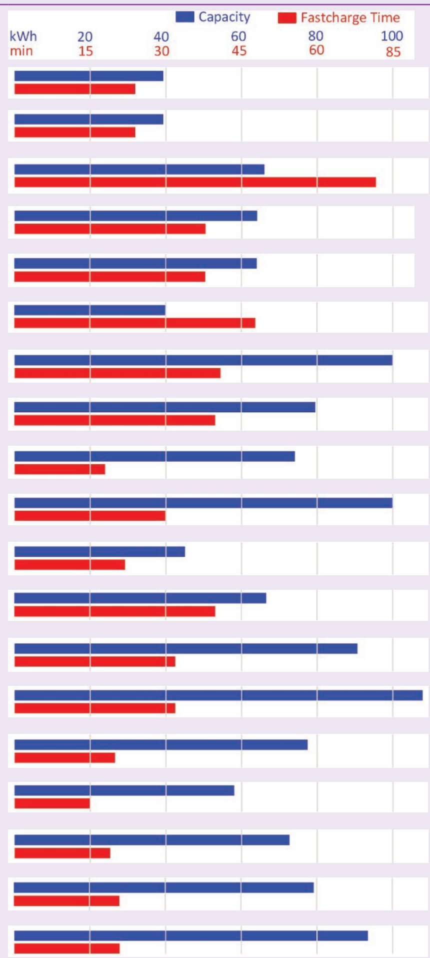
	BATTERY MANUFACTURERS [7], [13]	NOMINAL VOLTAGE (PER CELL)	TYPICAL OPERATING VOLTAGE RANGE (PER CELL)	SPECIFIC ENERGY (Wh/kg)	CHARGE (C RATE)	DISCHARGE (C RATE)	CYCLE LIFE COUNT	COST ($/kWh) [24], [25]	THERMAL RUNAWAY	OPERATING TEMPERATURE (°C)
Li–LFP	BYD, Valence, Lishen, and GS Yuasa	3.2 and 3.3 V	2.5–3.65 V	90–120	1C	1C; 25C in some cells	2,000 and higher	~580	270 °C; very safe even when fully charged	0–40
Li–LTO	LEC, EnerDel, CATL, Valence, Hitachi, Toshiba, and SAFT	2.4 V	1.8–2.85 V	50–80	1C; 2.8C maximum	10C; 30C for 5-s pulses	3,000–7,000	~1,005	One of the safest	−30–45
Li–LMO	Panasonic, Sony, Sanyo, LG Chem, Samsung SDI, CATL, BYD, and Lishen	3.7 and 3.8 V	3–4.2 V	100–150	0.7–1C; 3C maximum	1C; 10C possible for some cells; 30C for 5-s pulses	300–700	~360	250 °C; high charge increases it	–
Li–NMC	CATL, SK Innovation, Panasonic, Samsung SDI, LG Chem, and Hitachi	3.6 and 3.7 V	3–4.2 V or higher	150–220	0.7–1C (<1C shortens battery life)	1C; 2C possible for some cells	1,000–2,000	~420	210 °C; high charge increases it	0–40
Li–NCA	Panasonic, Tesla, CATL, and LG Chem	3.6 V	3–4.2 V	200–260	0.7C; fast charging possible	1C; high discharge reduces battery life	500	~350	150 °C; high charge increases it	–

TABLE 4 – THE SPECIFICATIONS OF THE BATTERY CELL TECHNOLOGIES UTILIZED IN SOME RECENT WELL-KNOWN EVs.

	TESLA				
	MODELS S AND X	MODELS Y AND 3	2018 NISSAN LEAF ZE1	CHEVROLET BOLT	KIA e-NIRO
Cell type	Panasonic cylindrical 18650	Tesla and Panasonic or LG Chem Cylindrical 21700	AESC Pouch Sheet shaped 261 × 216 mm	LG Chem Ni-rich sheet shaped 300 × 110 mm	SK Innovations Sheet shaped 300.5 × 108.5 mm
Nominal voltage	3.8 V	3.6 and 3.7 V	3.65 V	3.75 V	3.75 V
Capacity	3.4 Ah	5 and 4 Ah	56.3 Ah	60 Ah	60 Ah
Voltage range	2.5–4.2 V	2.5–4.2 V	2.5–4.2 V	2.75–4.2 V	2.5–4.2 V
Discharging current	Continuous 5.5 A	Continuous 15 and 12 A	–	Continuous 120 A	Continuous 120 A
Weight (maximum)	48 g	69 g	914 g	850 g	899.3 g
Temperature range	–20~+60 °C	–20~+60 °C	–35~+45 °C	–10~+60 °C	–20~+60 °C
Dimensions	18.25 × 65.1 mm	21 × 70 mm	261 × 216 × 7.9 mm	300 × 110 × 15 mm	300.5 × 108.5 × 15 mm
Energy density (volumetric)	675 Wh/L	689 and 707 Wh/L	460 Wh/L	614 Wh/L	607 Wh/L
Energy density (gravimetric)	250 Wh/kg	300 Wh/kg	224 Wh/kg	243 Wh/kg	257 Wh/kg
Cost	US$185/kWh	US$170/kWh	US$236/kWh	–	–
Number of cells	S: 7,104 X: 8,256	4,416	192	288	294

TABLE 5 – A COMPARISON OF THE VOLTAGE AND POWER LEVEL OF THE ONBOARD BATTERY PACKS OF SOME WELL-KNOWN EV MANUFACTURERS.

	VOLTAGE	MAXIMUM ONBOARD CHARGER POWER	MAXIMUM FAST CHARGER POWER
Hyundai Kona SE	319 V	7.2 kW	100 kW
Kia Soul EV	327 V	7.2 kW	100 kW
Chevrolet Bolt EV	350 V	7.2 kW	55 kW
Hyundai Kona SEL	356 V	7.2 kW	100 kW
Kia e-NIRO 4	356 V	7.2 kW	100 kW
Nissan Leaf SL	360 V	6.6 kW	50 kW
Tesla Model X	350 V	17.3 kW, 72 A	145 kW
Tesla Model 3	360 V	11.5 kW, 40 A	120 kW
Tesla Model Y	340 V	11 kW	250 kW
Tesla Model S	400 V	11.5 kW, 48 A	200 kW
Volkswagen ID.3 Pro S	408 V	11 A	125 kW
Mercedes-Benz EQB	420 V	11 kW	100 kW
Mercedes-Benz EQS	500 V	7.4 kW	170 kW
Mercedes-Benz AMG EQS	500 V	7.4 kW	200 kW
Kia EV6	697 V	11 kW	233 kW
Hyundai Ioniq 5 Standard	800 V	11 kW	225 kW
Hyundai Ioniq 5 Long Range	800 V	11 kW	225 kW
Porsche Taycan 4S	800 V	11 kW	400 V:50 kW; 800 V:225 kW
Porsche Taycan 4S+	800 V	11 kW	400 V:50 kW; 800 V:270 kW



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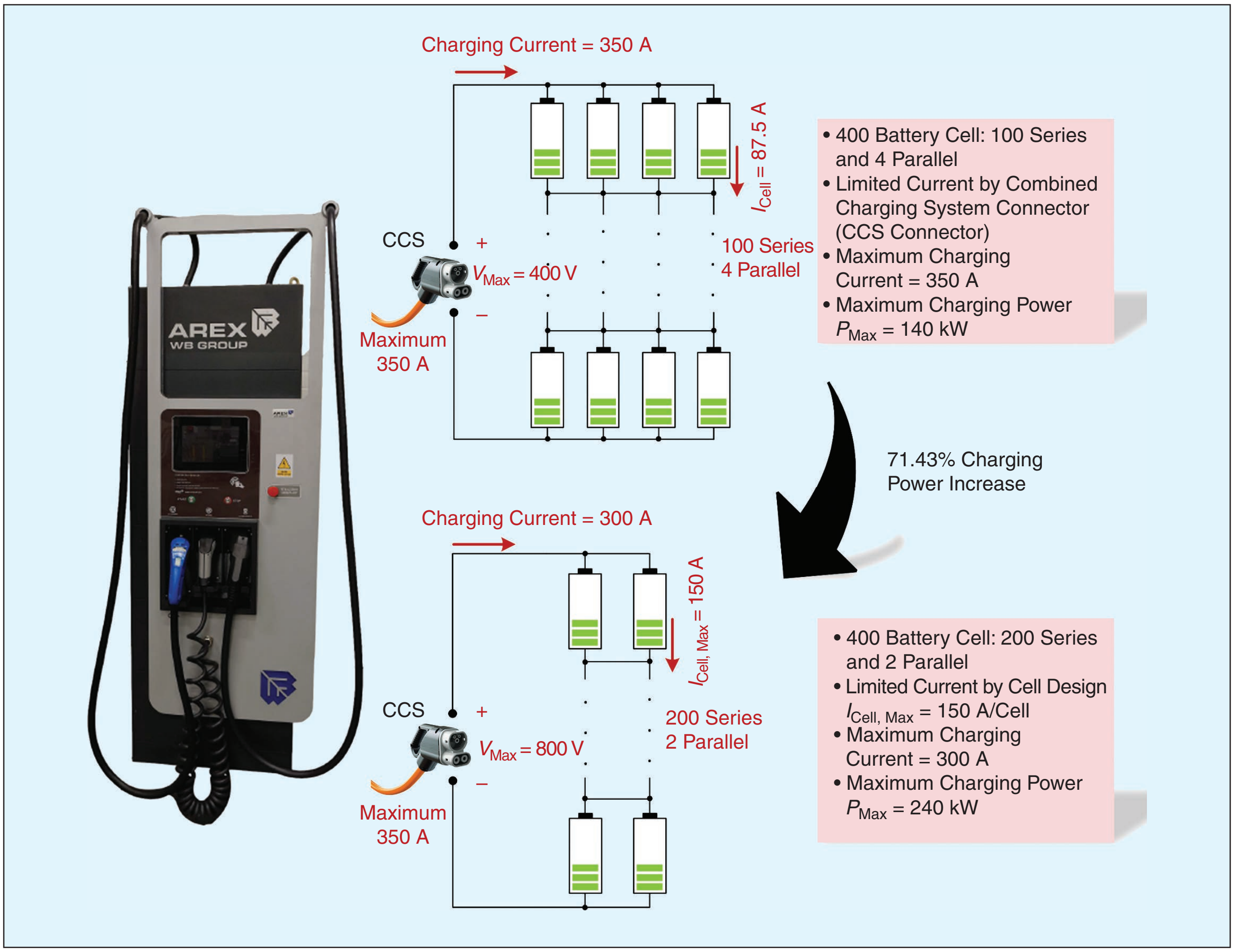

FIGURE 5 – The improved battery charging profile by increasing the battery pack voltage from 400 to 800 V. CCS: combined charging system.

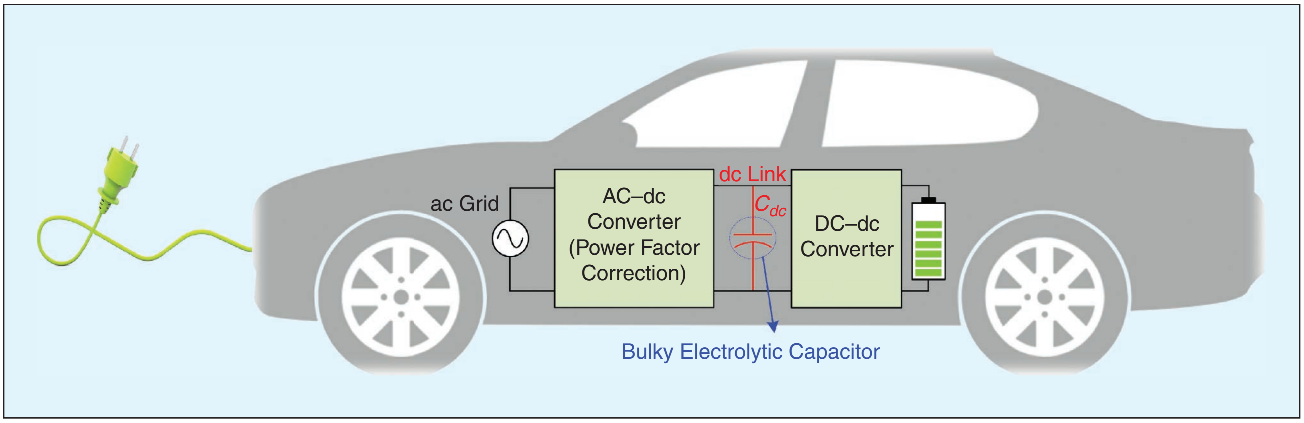

FIGURE 6 – The onboard EV charger.

cables to handle the same amount of power [27], [28]. For example, a cable to handle the 350-kW fast-charging power with a 350-V battery pack voltage should conduct a 1,000-A current with a reasonable temperature rise. A proper cable for this current should have a 300-mm^2 cross-sectional area, which will weigh 3.22 kg/m. Therefore, 5 m of the cable would have a 16.1-kg weight. While this high conducting current can be reduced, with an 800-V battery pack voltage, to 438 A, this requires a 125-mm^2 cross-sectional area, which weighs 1.4 kg/m, and its 5-m cable would have a 7-kg weight. Increasing the voltage to increase the power requires more thickness for the insulators of cables and busbars, but the relative impact is not considerable because the needed extra insulation is just a few millimeters in thickness, and its materials have about a 12.5% density compared to copper. Moreover, increasing the fast-charging power by increasing the voltage rather than the current would allow the same cooling

TABLE 6 – THE MAJOR CHALLENGES OF INCREASING THE BATTERY PACK VOLTAGE OF EVs.

POINT	CHALLENGE	SOLUTION
High voltages are more likely to make an arc and electrocution menace.	Increasing the battery pack voltage decreases the safety of passengers, especially in car accidents.	Increase the thickness of the insulators and the separation distance between conductors.
The total capacity of the series-connected batteries depends on the capacity of the weakest battery.	Increasing the number of series-connected batteries increases the impact of the weakest battery.	✓ Parallel connecting low-capacity batteries and then connecting in series can help to reduce the impact, but it still cannot solve the issue. ✓ Use a proper BMS, which monitors and manages the individual cells and regulates the charge and discharge of each cell to keep all cells at an equal state of charge and avoid overworking weaker cells. ✓ Perform a diagnostic battery cell test before inserting a cell in the battery pack. ✓ Additionally, it is important to have a regular checkup of the battery pack and replace weaker battery cells with new ones to maintain the high performance of the battery pack.
A little increase in the battery pack voltage requires modifying the circuit, parameters, and utilized components in the power electronics elements of the inverter, onboard charger, and dc–dc converter of the EV.	DC voltage link capacitors (shown in Figure 6) should tolerate the high voltage, while 450 V is the highest rate for commonly used capacitors.	✓ Connect some specific capacitors in series, but this would provide some leakage current issues. ✓ Use film and ceramic capacitors, but utilizing them to provide the high capacitance for the dc link will increase the cost of the power electronics circuits.
The switching frequency can be increased significantly to decrease the size of the magnetic components.	• The higher voltage could lead to higher dv/dt and higher electromagnetic interference problems compared to lower voltages. • The high switching capability of the utilized semiconductors should be considered.	✓ The electromagnetic interference issues can be solved with a proper shield and by providing fully resonant and soft-switching operations in power electronics converters [29], [30], [31]. ✓ The high-voltage-range Si carbide semiconductors, which have high-frequency switching capability, can be a proper choice. ✓ Using gallium nitride semiconductors for their uncommon availability for higher-than-650-V blocking voltage ranges would be challenging and require redesigning the power electronics converters.

system to be used without significant changes and save a significant portion of the conducting losses.

It should be considered that the battery pack voltage cannot be increased arbitrarily. By increasing the voltage from 300–400 V to 600–800 V, designers should modify all the devices utilized in the EV system: the conductors need more insulation, motors need more turn, dc–dc converters and the inverter need to be redesigned or use semiconductors with 1.2–1.7-kV blocking voltage rates, and so on. This will impact all components in different ways. For example, the volume of the onboard charger (Figure 6) or inverter will increase by 10% by increasing the voltage range. This 10% is a significant increment in the power electronics range, but it should be considered that the volume of the battery pack is 20–40 times more than the power electronics size, and this volume increment can be compensated easily by the saving in the battery pack voltage increase. In addition, the voltage level elevation can affect the structure of fuses and requires putting some insulators between fuses and increasing the separation distance between them, which increases the cost of the fuses. The major challenges of increasing the battery pack voltage to 800 V and the recommended solutions are presented in Table 6.

Conclusion

This article compared various types of previous, contemporary, and future battery technologies for EVs and presented their advantages and disadvantages. A battery pack designer should consider all aspects of the design. Currently, Li-ion-based batteries are the best selection for EV battery packs. But battery pack technology is improving, and next-generation battery technologies will be commercially available. Although some EV manufacturers have invested much in battery cell technologies, others do not rely on any revolutionary battery technology. They are trying only to rearrange the series and parallel connections of battery cells to increase the total voltage of their battery packs. The only reason is that they cannot increase the diameter of the conductor, which gets hot during fast charging. Considering all the discussed advantages and disadvantages of increasing the battery pack voltage from 350 to 800 V for reducing the charging time and managing the generated heat during battery charging, we can conclude that the reasonable progress achieved in EV technology is an evolutionary rather than a revolutionary step forward.

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Ongoing research of battery technologies for EVs focuses on some promising next-generation battery technologies for EV applications.

The chemistry of batteries distinguishes them in terms of their specific power rate, specific energy rate, lifecycle, cost, performance, and safety.

In many applications, Li-ion-based batteries are being replaced with lead and Ni-based batteries.

A battery should have a low self-discharge, long shelf-life, and capability of providing instant start-up whenever required.

Tesla has elevated the power density of its battery cells while providing a 20% higher energy density by increasing the battery size.

The charging power can be increased significantly by increasing the voltage without changing the conductor size and increasing the generation of heat.

Although some EV manufacturers have invested much in battery cell technologies, others do not rely on any revolutionary battery technology.

The reasonable progress achieved in EV technology is an evolutionary rather than a revolutionary step forward.