International Journal of Power Electronics and Drive System (IJPEDS)
Vol. 16, No. 3, September 2025, pp. 1429~1437
ISSN: 2088-8694, DOI: 10.11591/ijpeds.v16.i3.pp1429-1437

Navigating the future of energy storage: insights into lithium-ion battery technologies

Kalagotla Chenchireddy[1], Perattur Nagabushanam[2], Radhika Dora[1], Vadthya Jagan[3], Shabbier Ahmed Sydu[4], Varikuppala Manohar[5]
[1]Department of Electrical and Electronics Engineering, Geethanjali College of Engineering and Technology, Hyderabad, India
[2]Department of Electrical and Electronics Engineering, Vallurupalli Nageswara Rao Vignana Jyothi Institute of Engineering and Technology, Hyderabad, India
[3]Department of Electrical and Electronics Engineering, Vignana Bharathi Institute of Technology, Hyderabad, India
[4]Department of Engineering, University of Technology and Applied Sciences, Al-Mussanah, Oman
[5]Department of Electrical and Electronics Engineering, Dr. Paul Raj Engineering College, Andhra Pradesh, India

Article Info

Article history:

Received Dec 31, 2024
Revised May 25, 2025
Accepted Jun 3, 2025

Keywords:

Charge/discharge rates
Energy storage
Life cycle
Lithium-ion batteries
Sustainability

ABSTRACT

Lithium-ion batteries are now considered essential technology for a wide range of contemporary applications due to the growing need for effective and sustainable energy storage solutions. The various lithium-ion battery chemicals that are covered in detail in this paper are lithium iron phosphate (LFP), lithium nickel manganese cobalt (NMC), lithium nickel cobalt aluminum oxide (NCA), lithium-ion manganese oxide (LMO), lithium-ion cobalt oxide (LCO), and lithium titanate oxide (LTO). Based on critical performance metrics such as energy density, life cycle, charge/discharge rates, cost, and operational temperature range, each kind is assessed. Additionally, the paper discusses the future potential of lithium-ion technologies, with a focus on advancements in energy density, safety, sustainability, and recycling. By assessing the strengths and limitations of various lithium-ion chemicals, this paper seeks to provide valuable insights into the rapidly evolving field of battery technology, highlighting their indispensable role in the transition to sustainable energy systems. Lithium-ion batteries have the potential to significantly enhance the efficiency and dependability of energy storage systems in a variety of applications with further research and development.

Corresponding Author:

Kalagotla Chenchireddy
Department of Electrical and Electronics Engineering, Geethanjali College of Engineering and Technology
Hyderabad, India
Email: chenchireddy.kalagotla@gmail.com

1. INTRODUCTION

The global transition toward sustainable transportation is driving rapid advancements and widespread adoption of electric vehicles (EVs). When economies address the urgent problems of air pollution and climate change, EVs provide a viable method to cut carbon emissions and decrease reliance on fossil fuels. The energy storage system is at the center of this shift, and lithium-ion batteries are setting the standard thanks to their remarkable energy density, efficiency, and long-term dependability [1]. Lithium-ion batteries have supplanted conventional options as the industry standard for EVs because they combine high energy density with increased driving range capabilities, two features that are critical to mass-market appeal [2]. This technology confirms its position as a flexible solution across modes of transportation by powering a wide variety of electric vehicles, including automobiles, trucks, buses, and motorbikes. Therefore, the future success of the electric vehicle (EV) market depends critically on continuous breakthroughs in lithium-ion battery technology [3]. Lithium-ion battery chemistry is diverse, with several types tailored to meet the demands of specific applications. For example, lithium nickel manganese cobalt oxide (NMC) batteries are widely utilized in passenger cars and are renowned for having a high energy density. Because of its extended life cycle and safety, lithium iron phosphate (LFP) batteries are especially well-suited for heavy-duty purposes like electric buses [4], [5]. In the meantime, lithium nickel cobalt aluminum oxide (NCA) batteries have a high energy density but have issues with heat management that need to be resolved in order to improve safety [6]. Beyond these prevalent chemicals, emerging technologies such as lithium titanate oxide (LTO) and solid-state batteries are gaining traction. LTO batteries, with their rapid charging capabilities and long-life cycle, are often deployed in specialized applications like fast-charging electric buses and military vehicles [7]-[9]. Solid-state batteries, though still in the experimental phase, hold the potential to revolutionize EVs by offering higher energy density and enhanced safety, albeit with current challenges in scaling production and reducing costs [10], [11].

Despite the advantages of lithium-ion batteries, challenges persist. High material costs, concerns over the environmental impact of mining key materials like cobalt, and issues related to battery recycling pose hurdles to the widespread adoption of EVs. Moreover, technological advances are needed to improve energy density, extend battery lifespan, and ensure thermal stability while reducing overall costs. This paper will examine the major types of lithium-ion cells used in EVs, their performance characteristics, and the challenges associated with each chemistry [12]-[15].

Figure 1 shows the parts of lithium-ion battery. The structural and chemical composition of lithium-ion batteries plays a critical role in determining their performance, particularly in electric vehicles (EVs). Four basic parts make up a conventional lithium-ion cell: the separator, cathode, electrolyte, and anode. The capacity, effectiveness, and safety of the battery's energy storage system are all determined by these constituent parts. A thorough understanding of these components is fundamental for assessing various battery Chemicals and their appropriateness for EV applications.

Anode: graphite is a common material for the anode and is ideal for storing lithium ions during charging. Lithium ions go from the cathode to the anode and intercalate inside the graphite structure as the battery charges. The energy density, charging rate, and overall efficiency of the cell are all directly impacted by the anode material selection. New technologies, such as silicon-based anodes, are being developed for commercial usage, but they aim to increase energy density and capacity.

Cathode: lithium metal oxides, such as lithium nickel manganese cobalt oxide (NMC), lithium iron phosphate (LFP), or lithium nickel cobalt aluminum oxide (NCA), often make up the cathode. As the source of lithium ions, the cathode material determines key battery characteristics, including voltage, capacity, and safety. Each type of cathode material offers unique trade-offs: NMC provides high energy density; LFP is prized for safety and durability, and NCA excels in energy storage but requires careful thermal management. Electrolyte: lithium ions are moved more easily between the anode and cathode during charge and discharge cycles thanks to the electrolyte. Typically, it consists of a lithium salt dissolved in an organic solvent, which significantly affects the cell's ionic conductivity and operating temperature range. The electrolyte's chemical stability is also crucial for safety, as instability can lead to thermal runaway and other risks. Separator: During battery operation, only lithium ions are permitted to flow through the separator, a microporous membrane that physically separates the anode and cathode. Preventing short circuits that might cause overheating or other safety risks is its primary function. The thermal stability and permeability of the separator's material directly affect the battery's safety performance.

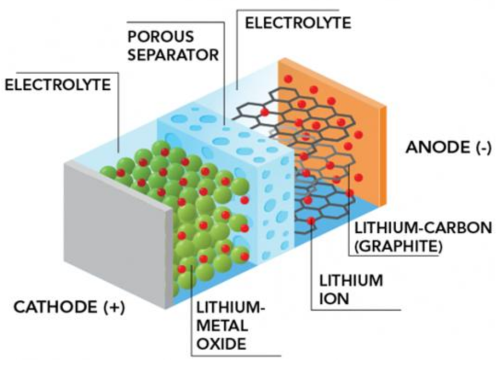


Figure 1. Parts of lithium-ion battery

The transfer of lithium ions via the electrolyte between the cathode and anode is the central process of the electrochemical processes that occur within a lithium-ion cell. Lithium ions move from the cathode to the anode during charging and back again during discharging, releasing energy in the process. This basic function is the same for all lithium-ion chemicals, but the performance of the battery is affected by the materials selected for each component. Every type of lithium-ion cell, including NMC, LFP, NCA, and others, finds a special way to balance the factors of cost, life cycle, safety, and energy density. Depending on the demands, such as long-range for passenger vehicles, quick charging times, or durability needed for heavy-duty applications like electric buses, the proper chemistry for an EV may be chosen. For instance, because of its high energy density, NMC is frequently used for passenger cars, whereas LFP is preferred for commercial and public transportation vehicles where lifespan and safety are top concerns. Emerging technologies, including solid-state batteries and advanced anode materials like silicon, seek to further enhance lithium-ion cell performance. The key objectives of these developments are to boost energy density, shorten charging periods, enhance thermal stability, and lengthen battery life. As research progresses, the structure and chemistry of lithium-ion cells will continue to evolve, steering the future of electric vehicles toward greater efficiency and sustainability.

2. TYPES OF BATTERIES & ITS CELL SPECIFICATIONS

2.1. Lithium iron phosphate (LFP)

Figure 2 shows the LFP cell. Due to their outstanding safety, extended life cycle, and general stability, LFP batteries are especially well-suited for energy storage systems (ESS). Compared to conventional lithium-ion batteries, LFP batteries offer a low energy density, but they excel in thermal and chemical stability, significantly reducing the risk of thermal runaway. This safety advantage makes them ideal for applications where longevity and reliability are prioritized over high energy density, such as residential energy storage and grid-level ESS. Additionally, LFP batteries are more environmentally friendly due to their reduced reliance on rare metals like cobalt and nickel, contributing to lower production costs. Higher energy density chemicals may be chosen in EVs that have longer driving ranges due to their lower energy density. Despite this, LFP's ability to handle up to 4,000–5,000 cycles make it one of the best options for applications requiring high durability and safety [16]-[20].

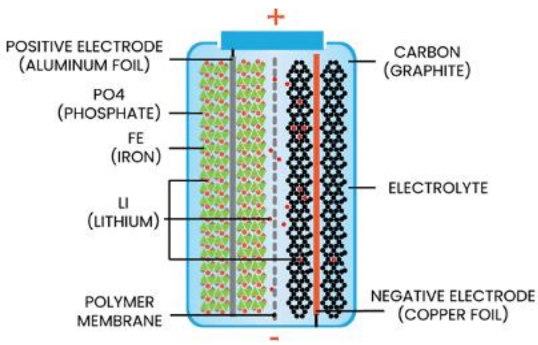


Figure 2. LFP cell

2.2. Lithium nickel manganese cobalt oxide (NMC)

Because of its high energy density, lithium nickel manganese cobalt oxide (NMC) batteries are used in the production of EVs and enable greater ranges. One of the main benefits of this chemistry is its ability to balance energy density and power by adjusting the ratio of manganese, cobalt, and nickel. Because of its adaptability, NMC batteries may be used in a wide range of settings, such as electric cars and power equipment. However, NMC batteries are relatively expensive due to the high cost of nickel and cobalt, and they can be more prone to thermal runaway under stress compared to LFP. The life cycle of NMC batteries is generally moderate, ranging from 1,000 to 2,000 cycles, which is lower than LFP but acceptable for high-performance applications where energy density is prioritized [21], [22].

2.3. Lithium nickel cobalt aluminum oxide (NCA)

Figure 3 shows the NCA cell. Similar in energy density to NMC batteries, lithium nickel cobalt aluminum oxide (NCA) batteries provide an edge in terms of overall energy production and power delivery. Because of these features, NCA batteries are a well-liked option for high-performance electric cars, particularly long-range variants like those made by Tesla. NCA batteries are perfect for applications that need the most energy storage possible in a small package because of their high energy density and significant power capacity. However, NCA batteries are more costly due to their reliance on elements like cobalt and aluminum. They also often have a shorter life cycle than LFP batteries and are more prone to overheating, which means that advanced battery management systems are required to preserve performance and safety [23]-[25].

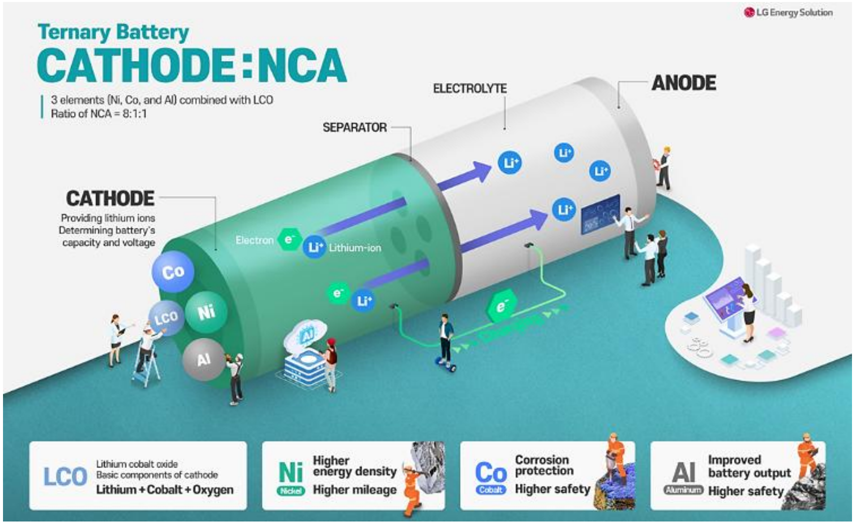


Figure 3. NCA cell

2.4. Lithium-ion manganese oxide (LMO)

Figure 4 shows the LMO cell. In comparison with NMC and NCA batteries, lithium-ion manganese oxide (LMO) batteries have a lower energy density, but they are renowned for their exceptional thermal stability and safety. LMO batteries have the benefit of having a high current output, which makes them perfect for devices like power tools and medical equipment that need brief bursts of power. Due to its lower energy density, LMO batteries are less prevalent in electric cars; nevertheless, they can occasionally be mixed with other chemicals, like as NMC, to form hybrid battery systems [26]-[28]. In a range of applications, these systems can provide a balanced approach by optimizing for power, safety, and energy density. The life cycle of LMO batteries is generally moderate, and their cost is relatively lower because of the reduced reliance on expensive materials like cobalt and nickel.

Figure 4. LMO cell

2.5. Lithium-ion cobalt oxide (LCO)

In addition to its excellent energy density, LCO batteries are highly prized for their suitability for portable gadgets like laptops, cameras, and cell phones. However, LCO batteries have a relatively short life cycle and lower thermal stability compared to other chemicals, such as LFP and NMC, which limits their suitability for applications requiring extended longevity and enhanced safety. The use of cobalt, a costly and environmentally contentious material, further limits the widespread use of LCO batteries in larger applications [29]-[31]. Their sensitivity to high temperatures and potential for thermal runaway also requires stringent safety measures, especially in consumer electronics. Consequently, LCO batteries are primarily used in applications where compact size and high energy density are crucial, but where safety and long life cycle are less critical. This makes them well-suited for consumer electronics, where portability and power are prioritized over extended durability and thermal stability.

2.6. Lithium titanate oxide (LTO)

Lithium titanate oxide (LTO) batteries stand out for their outstanding safety, extended life, and quick charging times. Grid storage, electric buses, and military operations are just a few of the uses for LTO batteries that demand rapid power supply because to their substantially improved thermal stability and quicker rates of charging and discharging. LTO is one of the most resilient lithium-ion chemicals on the market because of its life cycle, which may surpass 10,000 cycles. But because of their lower energy density, LTO batteries are less suited for uses where weight and size are critical, such in electric passenger cars [31]-[35]. The higher cost of production also limits their use in consumer markets, but for specialized applications that demand extreme durability and fast power response, LTO is a superior option.

3. COMPARATIVE ANALYSIS OF LITHIUM-ION BATTERY CELL SPECIFICATIONS

LFP, NMC, NCA, LMO, LCO, and LTO are the six popular types of lithium-ion batteries that are comprehensively compared in Table 1. Key performance characteristics, including as energy density, life cycle, charge/discharge rates, cost, and operating temperature range, are used to evaluate each type of battery [36]-[41]. Table 1 shows the comparative analysis of lithium-ion battery cell specifications.

Table 1. Comparative analysis of lithium-ion battery cell specifications

Battery type	Life cycle	Charge	Discharge	Cost	Temperature range
LFP	3,000–5,000	1 C	1 C to 3 C	Low	-20 °C to 60 °C
NMC	1,000–2,000	0.5 C-1 C	0.5 C to 3 C	Moderate	20 °C to 45 °C
NCA	500–1,000	1 C	1 C to 3 C	High	-20 °C to 45 °C
LMO	700–2,000	5 C	1 C to 5 C	Moderate	-20 °C to 50 °C
LCO	500–1,000	0.5 C-1 C	0.5 C to 1 C	High	0 °C to 45 °C
LTO	7,000–10,000	10 C	5 C to 10 C	High	-40 °C to 55 °C

3.1. Life cycle

The term "life cycle" refers to a battery's resilience to repeated cycles of charging and discharging. With a remarkable life cycle of 7,000 to 10,000 cycles, LTO is unique and ideal for applications like grid energy storage that need regular cycling. Additionally, LFP has a 3,000–5,000 lifetime cycle, which is advantageous for ESS The longer cycle lifetimes of NCA and LCO, which range from 500 to 1,000 cycles, limit their long-term use in high-demand situations.

3.2. Charge and discharge rates

The charge and discharge rates are essential for determining how quickly a battery can be charged or deliver power. LTO performs exceptionally well at quick charge rates of up to 10 C, which makes it perfect for usage like electric buses that need an instantaneous power supply. Additionally, LMO enables 5 C high discharge rates, making it appropriate for high-drain applications and power tools. In contrast, LFP, NMC, and NCA have more moderate charge/discharge rates, typically around 1C, balancing performance and energy storage capacity. Cost considerations are vital when selecting battery technology for specific applications. LFP is the most cost-effective option, primarily due to its absence of cobalt, which is often associated with higher costs in other chemicals such as NCA and LCO. NMC falls into the moderate cost category, making it an attractive choice for many EV manufacturers. Despite its great performance, LTO is generally more expensive than other options, which makes it less desirable for applications where cost is a factor.

3.3. Temperature range

The operational temperature range is another crucial factor influencing battery performance and safety. LTO demonstrates remarkable stability in extreme temperatures, operating efficiently from -40 °C to 55 °C, which makes it suitable for diverse climatic conditions. Additionally, LFP performs well throughout a broad temperature range, from -20 °C to 60 °C. On the other hand, LCO has a limited operational range of 0 °C to 45 °C, which could restrict its use in colder environments.

The future of lithium-ion battery technologies is set to undergo significant advancements as the demand for efficient energy storage solutions continues to surge. A primary focus will be on enhancing energy density through innovations in materials, such as solid-state electrolytes and advanced cathode compositions, which could result in lighter and more compact batteries suitable for electric vehicles (EVs) and portable electronics. Additionally, the emphasis on sustainability is prompting research into alternative, eco-friendly materials that reduce dependence on cobalt and other rare earth metals, paving the way for greener battery options with lower environmental impacts. Safety will remain a top priority, with future developments likely to focus on improving thermal stability and incorporating advanced safety features through enhanced battery management systems (BMS) and inherently safer chemicals, such as LFP and LTO. Furthermore, the industry is expected to aim for longer life cycles and faster charging capabilities, utilizing innovations in microstructured materials and novel electrode designs to facilitate rapid charging without compromising longevity. The integration of smart technologies into battery systems will also enhance performance, enabling real-time monitoring and adaptive charging strategies that extend battery life. Finally, as the volume of lithium-ion batteries in circulation increases, efficient recycling methods and second-life applications will become increasingly crucial, promoting a circular economy by recovering valuable materials and minimizing waste. All of these developments will be crucial in determining how lithium-ion batteries are used in the future, increasing their performance and sustainability, and promoting their acceptance in a variety of industries.

4. CONCLUSION

In conclusion, lithium-ion batteries are essential to contemporary energy storage technologies and have a big impact on a lot of different industries, like renewable energy and electric cars. The advancement of lithium-ion battery technology will be crucial in resolving issues with energy density, safety, and environmental impact as the need for effective and sustainable energy storage grows. It is anticipated that continuous advancements in materials science, battery management systems, and recycling techniques will improve the efficiency, durability, and sustainability of these batteries. In addition to offering enhanced energy storage capacities, lithium-ion technologies have the potential to support worldwide sustainability programs by lowering dependency on rare minerals and encouraging recycling and circular economy principles. Lithium-ion batteries will gradually contribute to a more sustainable energy environment as these developments take place, opening the door for a cleaner and more effective energy future.

FUNDING INFORMATION

The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Kalagotla Chenchireddy	✓	✓	✓		✓			✓		✓			✓	
Perattur Nagabushanam		✓				✓		✓	✓		✓	✓		
Radhika Dora	✓		✓	✓		✓	✓			✓	✓		✓	✓
Vadthya Jagan		✓	✓		✓			✓	✓		✓			
Shabbier Ahmed Sydu					✓		✓			✓		✓		✓
Varikuppala Manohar	✓			✓		✓		✓		✓		✓	✓	

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo: **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflicts of interest to disclose.

DATA AVAILABILITY

The data availability is not applicable to this paper as no new data were created or analyzed in this study.

REFERENCES

[1] V. R. Rikka *et al.*, "Tailoring micro resistance spot welding parameters for joining nickel tab to inner aluminium casing in a cylindrical lithium ion cell and its influence on the electrochemical performance," *Journal of Manufacturing Processes*, vol. 49, pp. 463–471, Jan. 2020, doi: 10.1016/j.jmapro.2019.12.014.

[2] S. T. Plunkett *et al.*, "Enhancing thermal safety in lithium-ion battery packs through parallel cell 'current dumping' mitigation," *Applied Energy*, vol. 286, p. 116495, Mar. 2021, doi: 10.1016/j.apenergy.2021.116495.

[3] G. J. Offer, V. Yufit, D. A. Howey, B. Wu, and N. P. Brandon, "Module design and fault diagnosis in electric vehicle batteries," *Journal of Power Sources*, vol. 206, pp. 383–392, May 2012, doi: 10.1016/j.jpowsour.2012.01.087.

[4] P. T. Coman, D. Petrushenko, E. C. Darcy, and R. E. White, "Electrical-thermal modeling and electrical design optimization of fuses in a nickel bus-plate for a Li-ion battery pack," *Journal of Energy Storage*, vol. 86, p. 111226, May 2024, doi: 10.1016/j.est.2024.111226.

[5] H. Wang *et al.*, "A comparative analysis on thermal runaway behavior of Li (Ni Co Mn) O2 battery with different nickel contents at cell and module level," *Journal of Hazardous Materials*, vol. 393, p. 122361, Jul. 2020, doi: 10.1016/j.jhazmat.2020.122361.

[6] S. Liu, X. Liu, R. Dou, W. Zhou, Z. Wen, and L. Liu, "Experimental and simulation study on thermal characteristics of 18,650 lithium–iron–phosphate battery with and without spot–welding tabs," *Applied Thermal Engineering*, vol. 166, 2020, doi: 10.1016/j.applthermaleng.2019.114648.

[7] J. Tangmongkhonsuk, N. H. Fuengwarodsakul, B. Kerdsup, and M. Masomtob, "Study on effect of terminal placement in low voltage Li-ion 18650 battery pack," in *2024 21st International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON)*, IEEE, May 2024, pp. 1–6. doi: 10.1109/ECTI-CON60892.2024.10594910.

[8] K. Smith, G.-H. Kim, E. Darcy, and A. Pesaran, "Thermal/electrical modeling for abuse-tolerant design of lithium ion modules," *International Journal of Energy Research*, vol. 34, no. 2, pp. 204–215, Feb. 2010, doi: 10.1002/er.1666.

[9] L. H. Saw, Y. Ye, and A. A. O. Tay, "Integration issues of lithium-ion battery into electric vehicles battery pack," *Journal of Cleaner Production*, vol. 113, pp. 1032–1045, Feb. 2016, doi: 10.1016/j.jclepro.2015.11.011.

[10] R. Kizilel, R. Sabbah, J. R. Selman, and S. Al-Hallaj, "An alternative cooling system to enhance the safety of Li-ion battery packs," *Journal of Power Sources*, vol. 194, no. 2, pp. 1105–1112, Dec. 2009, doi: 10.1016/j.jpowsour.2009.06.074.

[11] R. Gopalakrishnan *et al.*, "Electrochemical impedance spectroscopy characterization and parameterization of lithium nickel manganese cobalt oxide pouch cells: dependency analysis of temperature and state of charge," *Ionics*, vol. 25, no. 1, pp. 111–123, Jan. 2019, doi: 10.1007/s11581-018-2595-2.

[12] S. Wilke, B. Schweitzer, S. Khateeb, and S. Al-Hallaj, "Preventing thermal runaway propagation in lithium ion battery packs using a phase change composite material: An experimental study," *Journal of Power Sources*, vol. 340, pp. 51–59, Feb. 2017, doi: 10.1016/j.jpowsour.2016.11.018.

[13] H. Yan, K. C. Marr, and O. A. Ezekoye, "Thermal runaway behavior of nickel–manganese–cobalt 18650 lithium-ion cells induced by internal and external heating failures," *Journal of Energy Storage*, vol. 45, p. 103640, Jan. 2022, doi: 10.1016/j.est.2021.103640.

[14] A. Hussain, C. Y. Tso, and C. Y. H. Chao, "Experimental investigation of a passive thermal management system for high-powered lithium ion batteries using nickel foam-paraffin composite," *Energy*, vol. 115, pp. 209–218, Nov. 2016, doi: 10.1016/j.energy.2016.09.008.

[15] S. Mukane, P. Mane, and A. Gaddam, "Performance and analysis of battery thermal management system used in electric vehicles (EVS)," *Materials Today: Proceedings*, vol. 45, pp. 2690–2696, 2021, doi: 10.1016/j.matpr.2020.11.527.

[16] N. Kumar *et al.*, "In-depth evaluation of micro-resistance spot welding for connecting tab to 18,650 Li-ion cells for electric vehicle battery application," *The International Journal of Advanced Manufacturing Technology*, vol. 121, no. 9–10, pp. 6581–6597, Aug. 2022, doi: 10.1007/s00170-022-09775-z.

[17] S. P. Verma and S. Saraswati, "Numerical and experimental analysis of air-cooled Lithium-ion battery pack for the evaluation of the thermal performance enhancement," *Journal of Energy Storage*, vol. 73, p. 108983, Dec. 2023, doi: 10.1016/j.est.2023.108983.

[18] R. Luca *et al.*, "Current imbalance in parallel battery strings measured using a hall-effect sensor array," *Energy Technology*, vol. 9, no. 4, Apr. 2021, doi: 10.1002/ente.202001014.

[19] U. F. Shaikh, A. Das, A. Barai, and I. Masters, "Electro-thermo-mechanical behaviours of laser joints for electric vehicle battery interconnects," in *2019 Electric Vehicles International Conference (EV)*, IEEE, Oct. 2019, pp. 1–6. doi: 10.1109/EV.2019.8892972.

[20] R. Dora, V. Jagan, N. R. Varma, K. Swathi, G. S. Rao, and K. Chenchireddy, "Electric vehicle charging station with hybrid energy sources," *E3S Web of Conferences*, vol. 616, p. 03035, Feb. 2025, doi: 10.1051/e3sconf/202561603035.

[21] M. Klein, S. Tong, and J. W. Park, "In-plane nonuniform temperature effects on the performance of a large-format lithium-ion pouch cell," *Applied Energy*, vol. 165, pp. 639–647, Mar. 2016, doi: 10.1016/j.apenergy.2015.11.090.

[22] W. D. Connor, S. G. Advani, and A. K. Prasad, "Adaptive thermal control of cell groups to extend cycle life of lithium-ion battery packs," *Applied Sciences*, vol. 13, no. 8, p. 4681, Apr. 2023, doi: 10.3390/app13084681.

[23] A. García, J. Monsalve-Serrano, J. Marco Gimeno, and J. M. Hernández Egea, "Experimental measurement and modeling of the internal pressure in cylindrical lithium-ion battery cells under abuse conditions," *Journal of Energy Storage*, vol. 103, p. 114288, Dec. 2024, doi: 10.1016/j.est.2024.114288.

[24] J. Schöberl, M. Ank, M. Schreiber, N. Wassiliadis, and M. Lienkamp, "Thermal runaway propagation in automotive lithium-ion batteries with NMC-811 and LFP cathodes: Safety requirements and impact on system integration," *eTransportation*, vol. 19, p. 100305, Jan. 2024, doi: 10.1016/j.etran.2023.100305.

[25] Y. Merla, B. Wu, V. Yufit, R. F. Martinez-Botas, and G. J. Offer, "An easy-to-parameterise physics-informed battery model and its application towards lithium-ion battery cell design, diagnosis, and degradation," *Journal of Power Sources*, vol. 384, pp. 66–79, Apr. 2018, doi: 10.1016/j.jpowsour.2018.02.065.

[26] J. Hu, T. Liu, Q. Tang, and X. Wang, "Experimental investigation on thermal runaway propagation in the lithium ion battery modules under charging condition," *Applied Thermal Engineering*, vol. 211, p. 118522, Jul. 2022, doi: 10.1016/j.applthermaleng.2022.118522.

[27] S. Lee *et al.*, "In-depth analysis of the degradation mechanisms of high-nickel, low/no-cobalt layered oxide cathodes for lithium-ion batteries," *Advanced Energy Materials*, vol. 11, no. 31, Aug. 2021, doi: 10.1002/aenm.202100858.

[28] V. Adiyya and V. Manohar, “Impact of nickel strip configurations on resistance and voltage drop in lithium ion battery packs,” *International Journal of Innovative Science and Research Technology (IJISRT)*, pp. 2133–2138, Oct. 2024, doi: 10.38124/ijisrt/IJISRT24SEP1190.

[29] J. Taylor, A. Barai, T. R. Ashwin, Y. Guo, M. Amor-Segan, and J. Marco, “An insight into the errors and uncertainty of the lithium-ion battery characterisation experiments,” *Journal of Energy Storage*, vol. 24, p. 100761, Aug. 2019, doi: 10.1016/j.est.2019.100761.

[30] A. Barai, K. Uddin, W. D. Widanage, A. McGordon, and P. Jennings, “A study of the influence of measurement timescale on internal resistance characterisation methodologies for lithium-ion cells,” *Scientific Reports*, vol. 8, no. 1, p. 21, Jan. 2018, doi: 10.1038/s41598-017-18424-5.

[31] B. Aktekin *et al.*, “Understanding the capacity loss in LiNi 0.5 Mn 1.5 O 4 –Li 4 Ti 5 O 12 lithium-ion cells at ambient and elevated temperatures,” *The Journal of Physical Chemistry C*, vol. 122, no. 21, pp. 11234–11248, May 2018, doi: 10.1021/acs.jpcc.8b02204.

[32] G. Satyanarayana, D. R. Sudhakar, V. M. Goud, J. Ramesh, and G. A. Pathanjali, “Experimental investigation and comparative analysis of immersion cooling of lithium-ion batteries using mineral and therminol oil,” *Applied Thermal Engineering*, vol. 225, p. 120187, May 2023, doi: 10.1016/j.applthermaleng.2023.120187.

[33] T. Grün, K. Stella, and O. Wollersheim, “Influence of circuit design on load distribution and performance of parallel-connected Lithium ion cells for photovoltaic home storage systems,” *Journal of Energy Storage*, vol. 17, pp. 367–382, Jun. 2018, doi: 10.1016/j.est.2018.03.010.

[34] V. A. Marcis, A. V. J. S. Praneeth, L. Patnaik, and S. S. Williamson, “Analysis of CT-CV charging technique for lithium-ion and NCM 18650 cells,” in *2020 IEEE International Conference on Power Electronics, Smart Grid and Renewable Energy (PESGRE2020)*, IEEE, Jan. 2020, pp. 1–6. doi: 10.1109/PESGRE45664.2020.9070505.

[35] V. G. Sree Sai, R. Divya and M. G. Nair, "Navigating the smart grid landscape: A Comprehensive Review of Recent Advances," 2025 Fourth International Conference on Power, Control and Computing Technologies (ICPC2T), Raipur, India, 2025, pp. 734-739, doi: 10.1109/ICPC2T63847.2025.10958759.

[36] O. Apata, "Energizing change: Policy innovations for a low-carbon future," 2025 33rd Southern African Universities Power Engineering Conference (SAUPEC), Pretoria, South Africa, 2025, pp. 1-6, doi: 10.1109/SAUPEC65723.2025.10944336.

[37] M. Ben Youssef, I. Jarraya, M. A. Zdiri, and F. Ben Salem, “Support vector regression-based state of charge estimation for batteries: cloud vs non-cloud,” *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 34, no. 2, p. 697, May 2024, doi: 10.11591/ijeecs.v34.i2.pp697-710.

[38] M. S. A. Mustazal, M. A. M. Ariff, and S. N. Ramli, “An extensive review of energy storage system for the residential renewable energy system,” *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 18, no. 1, pp. 242–250, 2019, doi: 10.11591/ijeecs.v18.i1.pp242-250.

[39] B. Srujana and K. Chenchireddy, “Electric vehicle charging and temperature monitoring system,” in *2024 5th International Conference on Electronics and Sustainable Communication Systems (ICESC)*, IEEE, Aug. 2024, pp. 54–57. doi: 10.1109/ICESC60852.2024.10689817.

[40] B. Ramesh, K. Chenchireddy, D. S. Nivedh, B. Akanksha, A. S. Reddy, and D. S. Yadav, “Hybridization of solar and battery in standalone,” in *2023 7th International Conference on Electronics, Communication and Aerospace Technology (ICECA)*, IEEE, Nov. 2023, pp. 388–393. doi: 10.1109/ICECA58529.2023.10395329.

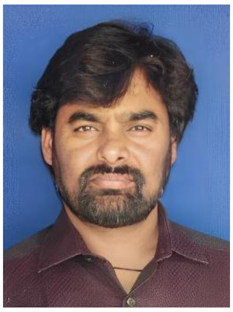
[41] N. R. Babu, K. Chenchireddy, V. H. V. Reddy, D. Samhitha, P. Apparao, and C. pavan Kalyan, “Case study on Ni-MH battery,” in *2023 2nd International Conference on Applied Artificial Intelligence and Computing (ICAAIC)*, IEEE, May 2023, pp. 1559–1564. doi: 10.1109/ICAAIC56838.2023.10140812.

BIOGRAPHIES OF AUTHORS

Dr. Kalagotla Chenchireddy was born in Andhra Pradesh State, India, in 1990. He received his B.Tech. and M.Tech. from JNTU Hyderabad, India, in 2011 and 2013, respectively, and he completed a Ph.D. degree in the Electrical Engineering Department from Karunya Institute of Technology and Sciences, Karunyanagar, Coimbatore, TN, India in 2024. He is presently working as an Associate Professor in Geethanjali College of Engineering and Technology, Hyderabad, India. He has presented technical papers in various National and International Conferences. He published Research papers in various Scopus and Web of Science Index Journals. His area of interest includes power electronics, power quality, and multilevel inverters. He is a regular reviewer of ISA transactions, cybernetics and systems SCIE journals, IJPEDS, and IJAPE. He can be contacted at email: chenchireddy.kalagotla@gmail.com.

Dr. Perattur Nagabushanam completed Ph.D. (EEG for medical applications- ML and DL algorithms for EEG signals) in the year 2020, was Co-PI in DST DST-funded project of 48 Lacs (DST/TSG/ICT/2015/54G, 2nd May 2016), and qualified GATE exam in the years 2019, 2018, 2013, 2010. He has 39 Scopus publications, including 7 SCI-indexed publications, 8 Scopus journal publications, 24 IEEE Scopus-indexed conference publications, and 2 book chapters. He also completed 6 MOOC NPTEL-Courses, completed 3 AICTE ATAL Courses to his credit. He had been involved as a coordinator in organizing training programs/workshops. He had served as an exam coordinator and as the Eduserve Software Coordinator. GATE coaching coordinator in the department for more than 8 years. His research areas include EEG for medical applications, electrical power systems. He has 13 years of teaching and 2 years of industry experience. He is presently working as an Assistant Professor in the EEE Department, VNR VJIET, Hyderabad. He can be contacted at email: nagabushanamphd14@gmail.com.

Dr. Radhika Dora is currently serving as Professor and Head of the Department (HOD) of Electrical and Electronics Engineering. She earned her B.Tech. degree in electrical and electronics engineering from Jawaharlal Nehru Technological University, Ananthapur (JNTUA) in 2000, followed by a master's degree in electrical power engineering from Jawaharlal Nehru Technological University, Hyderabad (JNTUH) in 2007. Her academic journey led to a doctoral degree in electrical and electronics engineering from JNTUH in 2017. Her research interests are centered around addressing critical issues in electrical engineering, focusing on power quality problems and mitigation, renewable energy generation, and electric vehicle design. She can be contacted at email: drradhikadora.eee@gcet.edu.in.



Dr. Vadthya Jagan was born in Telangana State, India, in 1985. He received his B.Tech. degree in Electrical and Electronics Engineering from C.V.R. College of Engineering, Hyderabad, Telangana State, in 2007, and M.Tech. degree in Electric Drives and Power Electronics from the Indian Institute of Technology Roorkee, Uttarakhand, India, in 2011. From August 2011 to July 2013, he worked as an Assistant Professor at Sharda University, Greater Noida, Uttar Pradesh. Then, he completed a Ph.D. degree in the Electrical Engineering Department from the Indian Institute of Technology Roorkee, Uttarakhand, India, in 2018. He worked as an Associate Professor from July 2018 to August 2023 at Vignana Bharathi Institute of Technology (VBIT), Hyderabad, Telangana State, India. Presently working as a Professor in the EEE Department, VBIT, since September 2023. Currently, he is working on the RPS project titled "Analysis, Design and Implementation of an Extreme-Boost Quasi Z-source Inverter Topologies," sanctioned by AICTE. His current research interests include power electronics, development of novel topologies on Z-source inverters and DC-DC converters, and solar photovoltaic systems. He can be contacted at email: jagan.iitr@gmail.com.

Dr. Shabbier Ahmed Sydu is a distinguished researcher and scholar with a strong academic background in the field of Electrical and Electronics Engineering. He obtained his Ph.D. from Sri Satya Sai University of Technology and Medical Sciences, India, where his research focused on advancing the integration of solar and wind energy into existing power systems. Before his doctoral studies, he earned a Master of Technology degree from JNTU Kakinada, India, where he furthered his expertise in power electronics and drives. He completed his Bachelor of Technology degree from Acharya Nagarjuna University, where he laid the foundation for his career in engineering. He can be contacted at email: shabbier.sydu@utas.edu.om.

Varikuppala Manohar is presently a PG student in the Power and Industrial Drive Department, Dr. Paul Raj Engineering College, Andhra Pradesh, India. He completed his B.Tech. from the Teegala Krishna Reddy Engineering College and a diploma (electrical and electronics engineering) from the Govt Polytechnic College. He has presented technical papers in various national and international journals and conferences. His area of interest includes power electronics, power quality, and electric vehicle technologies. He developed a hybrid vehicle at Teegala Krishna Reddy Engineering College, Hyderabad. He can be contacted at email: manoharvarikuppala143@gmail.com.