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COMPARATIVE ANALYSIS OF LITHIUM-IRON-PHOSPHATE AND SODIUM-ION ENERGY STORAGE DEVICES

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Abstract. *Energy storage is the process of accumulating, releasing, and managing energy using storage devices. Today, this principle of energy storage is playing an important role in energy supply, as renewable sources become more and more responsible for energy production. Moreover, since it is not possible to regulate the amount of energy from renewable sources, it is necessary to store energy during periods of lower demand or higher production, from sources such as solar and wind energy. Over the past century, a wide range of energy storage technologies have been developed, from large-scale hydroelectric power plants to advanced electrochemical storage. Hydroelectric power plants remain the main method of long-term energy storage due to their high capacity and durability. At the same time, lithium-iron-phosphate and sodium-ion batteries open up new opportunities for energy storage at the local level, making them promising for integration into modern power systems. In addition, the efficient use of energy storage can minimize the risks of electricity shortages during critical periods and ensure the stability of the power system. This is achieved due to the ability of energy storage to effectively level the load, compensate for fluctuations in renewable energy generation, and provide reliable backup power. In particular, $LiFePO_4$ and Na-Ion technologies demonstrate high energy efficiency, which allows them to be integrated into various segments of the power system – from household devices to large-scale industrial plants. Their use also helps to reduce the carbon footprint of the energy sector, which is important for achieving sustainable development goals. In this paper, we compare two types of electrochemical storage devices – $LiFePO_4$ and Na-Ion. Particular attention will be paid to their durability, energy efficiency, materials from which they are made, and technical characteristics. Also, their economic feasibility and prospects for implementation in commercial and domestic applications will be assessed.*

Keywords: sodium-ion batteries, lithium-iron-phosphate batteries, energy storage, charge monitoring

ANALIZA PORÓWNAWCZA URZĄDZEŃ DO MAGAZYNOWANIA ENERGII Z UŻYCIEM AKUMULATORÓW LITOWO-ŻELAZOWO-FOSFORANOWYCH I SODOWO-JONOWYCH

Streszczenie. *Magazynowanie energii to proces gromadzenia, oddawania i zarządzania energią za pomocą urządzeń magazynujących. Obecnie ta zasada magazynowania energii odgrywa ważną rolę w dostawach energii, ze względu na to, że źródła odnawialne stają się coraz bardziej istotne w produkcji energii. Ponadto, ponieważ regulacja ilości energii ze źródeł odnawialnych nie jest możliwa, konieczne jest magazynowanie energii w okresach niższego zapotrzebowania lub wyższej produkcji, ze źródeł takich jak energia słoneczna i wiatrowa. W ciągu ostatniego stulecia opracowano szeroką gamę technologii magazynowania energii, od wielkoskalowych elektrowni wodnych po zaawansowane magazyny elektrochemiczne. Elektrownie wodne (szczytowo-pompowe) pozostają główną metodą długoterminowego magazynowania energii ze względu na ich wysoką wydajność i trwałość. Jednocześnie akumulatory litowo-żelazowo-fosforanowe i sodowo-jonowe otwierają nowe możliwości magazynowania energii na poziomie lokalnym, co czyni je obiecującymi do integracji z nowoczesnymi systemami energetycznymi. Ponadto efektywne wykorzystanie magazynów energii może zminimalizować ryzyko niedoborów energii elektrycznej w krytycznych okresach i zapewnić stabilność systemu energetycznego. Osiąga się to dzięki wykorzystaniu magazynów energii do skutecznego wyrównywania obciążenia, kompensowania wahań w wytwarzaniu energii odnawialnej i zapewniania niezawodnego zasilania rezerwowego. W szczególności technologie $LiFePO_4$ i Na-Ion wykazują wysoką wydajność energetyczną, co pozwala na ich integrację z różnymi elementami systemu energetycznego - od urządzeń gospodarstwa domowego po duże zakłady przemysłowe. Ich zastosowanie pomaga również zmniejszyć ślad węglowy sektora energetycznego, co jest ważne dla osiągnięcia celów zrównoważonego rozwoju. W tym artykule porównano dwa rodzaje elektrochemicznych urządzeń magazynujących – $LiFePO_4$ i Na-Ion. S Szczególna uwaga zostanie zwrócona na ich trwałość, wydajność energetyczną, materiały, z których są wykonane oraz charakterystykę techniczną. Oceniona zostanie również ich ekonomiczna wykonalność i perspektywy wdrożenia w zastosowaniach komercyjnych i domowych.*

Słowa kluczowe: akumulatory sodowo-jonowe, akumulatory litowo-żelazowo-fosforanowe, magazynowanie energii, monitorowanie ładowania

Introduction

Ensuring access to a reliable, affordable energy grid is a challenge for modern societies facing population growth and the depletion of fossil fuels. In terms of energy storage, lithium-based batteries are currently the most widely used and developed, with high density, long service life, and relatively low weight. Such drives are widely used in portable electronics, computers, electric vehicles, mobile devices, and stationary energy storage systems. Despite the rapid growth in the use of this type of storage device, the use of lithium is limited in the earth's crust [19, 22]. Therefore, if the demand for lithium cannot meet the demand for production, this role may be taken over by sodium-ion storage, as sodium is much more abundant than lithium in the Earth's crust. Even despite their lower performance, they are attracting a lot of attention, as the technology is still under development, and it is likely that the density and durability of this type of storage will exceed lithium-iron-phosphate in the coming years [7, 28].

In the search for safer and more economical energy storage solutions, lithium iron phosphate ($LiFePO_4$) and sodium-ion (Na-Ion) have become two technologies that have attracted significant attention. However, lithium deposits are many times smaller than sodium deposits. However, sodium is more evenly distributed around the world and cheaper than lithium [3, 6].

At the same time, sodium-ion batteries have their own unique characteristics that make them promising for large-scale stationary storage. Unlike their lithium counterparts, Na-Ion batteries do not use scarce and geopolitically sensitive materials such as cobalt or nickel, which significantly reduces supply chain risks. In addition, recent advances in electrode materials, particularly layered oxides and Prussian blue analogy, have significantly improved energy density and charge retention in sodium-ion systems [5, 18].

Another major advantage of sodium-ion batteries is their better performance at low temperatures compared to lithium-ion cells [10, 33]. This feature makes them particularly attractive for applications in regions with harsh climates, where lithium batteries often suffer from reduced performance. In addition, the ability to use aluminium instead of copper as the current collector further reduces cost and increases recyclability, which reinforces their sustainability advantage over conventional Li-Ion technology [13, 15].

Nevertheless, commercialization of Na-Ion storage devices on a large scale is still challenging. Although laboratory prototypes show promising results, commercial production requires the development of efficient manufacturing processes and optimization of electrolyte formulations to improve cycling stability. The relatively lower energy density compared to their lithium-ion counterparts also means that sodium-ion batteries are more suitable for stationary storage and power grids rather than high-performance electric vehicles. However, ongoing research and growing investment in this area suggests that Na-Ion technology will play an increasingly significant role in the energy transition [16, 32].

These technologies work on a similar principle: the movement of ions, but with different chemical compositions and have significant differences in performance and application [19, 30]. In this research, we will review the key parameters of these drives, compare their advantages and disadvantages, and find out which type of drive is best suited for specific use cases.

With the advancement of technology, both types of drives are evolving rapidly, constantly offering more options for energy storage in the future [2, 37].

1. Materials of research

In this research, a comparative analysis of several types of batteries, including lithium-iron-phosphate ($LiFePO_4$) and sodium-ion (Na-Ion) energy storage devices, was conducted. For this purpose, we used data collected from scientific publications, technical documentation from leading battery manufacturers, and the results of experimental studies. The sources of information were battery technical data sheets, published scientific articles, laboratory tests, and generalized statistics reflecting the experience of using these technologies in various industries, such as renewable energy, electric transport, and stationary power systems [6, 31].

The information collected allows us to assess the main advantages and limitations of each type of battery, as well as to find out under what conditions and for what applications each type is most effective [11, 16].

2. Structure of batteries

To begin with, let's consider the structure of lithium-iron-phosphate ($LiFePO_4$) and sodium-ion (Na-Ion) drives [19, 40]. Lithium-iron-phosphate batteries are composed of (Fig. 1):

- cathode made of lithium-iron-phosphate;
- anode made of graphite or other carbon material;
- electrolyte, usually a liquid, gel or solid electrolyte based on lithium salts in a solvent;
- a separator made of microporous polymeric material such as polyethylene or polypropylene;
- a housing made of metal or polymer.

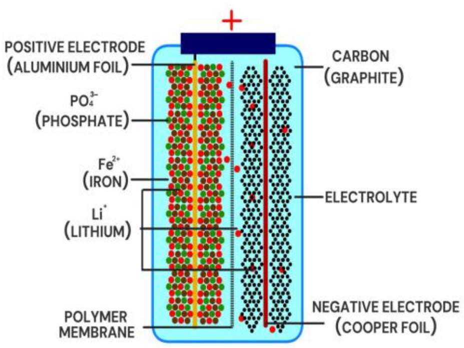

Fig. 1. Structure of the $LiFePO_4$ battery [35]

Lithium-iron-phosphate batteries use lithium-iron-phosphate ($LiFePO_4$) as the cathode material and a graphite carbon electrode with a metal substrate as the anode. Unlike other cathode materials, $LiFePO_4$ is a polyanionic compound consisting of more than one negatively charged element [29, 37].

A $LiFePO_4$ battery works on the same principle as other lithium-ion batteries: lithium ions move between the positive and negative electrodes during charging and discharging. However, phosphate is a non-toxic material, unlike cobalt oxide or manganese oxide, which makes it safer to use [36, 37].

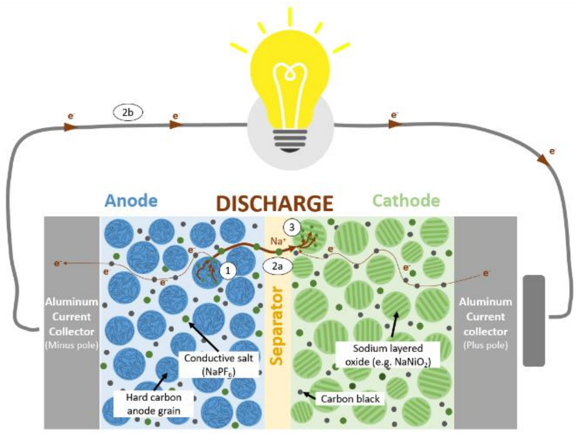

Fig. 2. Structure of the Na-Ion battery [5]

Let's consider the structure of sodium-ion (Na-Ion) batteries (Fig. 2) [8, 22]. This drive has a similar structure to a lithium-ion drive, but using sodium instead of lithium and consists of:

- a cathode made of a sodium compound;
- the anode is usually made of carbon materials such as solid carbon, graphite or other carbon structures [7];
- the electrolyte is liquid, containing sodium salts such as $NaPF_6$, $NaClO_4$ in an organic solvent;
- the separator, as in $LiFePO_4$, uses a microporous polymer polyethylene or polypropylene;
- the housing is usually made of metal or polymer.

The basic design of a sodium-ion battery is also almost identical to that of a lithium-ion battery. As shown in Fig. 2, a sodium-ion battery also consists of two active electrodes: an anode and a cathode, where energy is stored. A separator is located between the anode and cathode to prevent short circuits between the active materials [9, 24].

3. Comparative characteristics of $LiFePO_4$ and Na-Ion batteries

A comparison of the materials and characteristics of $LiFePO_4$ and Na-Ion batteries is presented at the Table 1 and Table 2.

From these tables, it can be concluded that $LiFePO_4$ batteries usually have a higher energy density, which makes them preferable for applications where compactness and high capacity are important [18, 23]. Sodium ion batteries are still inferior in this regard, but are being actively improved [12, 27]. It is expected that within two years their energy density will reach 160-180 Wh/kg, and in five years 200 Wh/kg, which will make them competitive. Also, both types of batteries support deep discharge without a significant impact on service life, but $LiFePO_4$ has a slight advantage due to its greater stability.

In terms of efficiency, $LiFePO_4$ batteries are characterized by high efficiency, with minimal energy losses during conversion. Sodium batteries are still some what inferior, but are also showing progress.

Also, $LiFePO_4$ batteries have a longer life cycle with more cycles before a significant decrease in performance. Sodium batteries do not yet reach such indicators, but every year the technology is being refined and the number of charge-discharge cycles is increasing [7, 41]. But at low temperatures, Na-Ion batteries are much better, making them ideal for cold climates. $LiFePO_4$ batteries can lose performance in such conditions, which is their disadvantage [14, 34] (Fig. 3).

Table 1. Comparison of materials between $LiFePO_4$ and Na-Ion battery

Type	Sodium-ion battery Na-Ion	Lithium-iron-phosphate battery $LiFePO_4$
Cathode Material	Layered oxides, Prussian blue, polyanions, etc.	Ternary materials, lithium iron phosphate, lithium manganese oxide, etc.
Anode Material	Amorphous carbon	Graphite
Electrolyte	Sodium hexafluorophosphate	Lithium hexafluorophosphate
Cathode Current Collector	Aluminum foil	Aluminum foil
Anode Current Collector	Aluminum foil	Copper foil
Separator	PP/PE	PP/PE

Table 2. Comparison of $LiFePO_4$ and Na-Ion battery characteristics

Specification of of batteries	Sodium-ion battery Na-Ion	Lithium-iron-phosphate battery $LiFePO_4$
Nominal voltage	3.0V	3.2V
Operating Voltage	2.8–3.5V	2.5–3.65V
Weight Energy Density	120–200 Wh/kg	150–220 Wh/kg
Volume Energy Density	180–280 Wh/L	200–350 Wh/L
Typical Cycle Life (@80%)	1000–3000 Cycles	3000–6000 Cycles
Calendar Life (@80%)	15–20 Years	8–10 Years
-20°C Capacity Retention Rate	>90%	60–70%
Temperature Range	-40°C to 60°C	-20°C to 50°C
Overdischarge Resistance	0V	2V
Depth of Discharge (DOD)	100%	100%
Charging Speed	Charged to over 80% in 15 minutes at room temperature	Charged to over 80% in 45 minutes at room temperature
Cost	Low	High
Thermal Runaway	350°C (662°F)	270°C (518°F)
Maximum Safe Charge	50–100%	100%
Safety	No risk of thermal runaway, Non-toxic	Can overheat and catch fire, Non-toxic
Environmental Impact & Recyclability	Simple recovery process	Complex separation of metals may be required
Memory Effect	NONE	NONE

One of the key advantages of sodium batteries is the significantly lower cost of sodium compared to lithium. For example, data from the Shanghai metallurgical market shows a striking 20-fold difference in the price of pure sodium and lithium compounds [16, 23]:

- Sodium carbonate costs approximately $290 per metric ton;
- Lithium carbonate (99.5% battery grade) has a much higher price of about $35,000 per metric ton (even after a significant decline since mid-2022).

At the moment, the demand for sodium in battery production remains insignificant, especially compared to the rapidly growing demand for lithium used in $LiFePO_4$ batteries [6, 17]. In 2022, prices for lithium-based battery packs showed growth for the first time in 12 years, reaching $151 per kWh. This was the result of high demand for batteries caused by the electrification of passenger transport, the production of electric industrial equipment, and the creation of energy storage systems [20, 28].

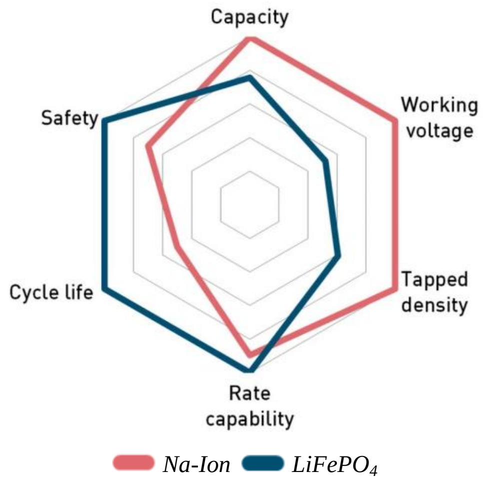

Fig. 3. Comparison Na-Ion and $LiFePO_4$ battery [26]

These factors indicate the economic attractiveness of Na-Ion batteries for energy systems, especially in cases where cost is a key criterion.

Advancements in production technology and cell chemistry have contributed to reducing manufacturing costs. Combined with global efforts to decrease fossil fuel consumption, $LiFePO_4$ battery technology has facilitated the electrification of billions of passenger and commercial vehicles.

A comparison of $LiFePO_4$ and Na-Ion, as illustrated in Fig. 3, highlights that each cathode material excels in different key aspects. Na-Ion benefits from a higher cell voltage, power density, and specific capacity, giving it a clear edge in volumetric energy density – an essential factor for achieving long driving ranges similar to those of internal combustion engine vehicles (e.g., 1,000 km on a single tank of fuel). In contrast, $LiFePO_4$ stands out for its longer cycle life, superior rate capability, and enhanced safety. The lower risk of thermal runaway in the event of mechanical damage makes $LiFePO_4$ particularly well-suited for commercial vehicles with frequent charging access (such as buses, forklifts, and scooters) and for stationary energy storage systems, often used in conjunction with solar farms or wind power plants.

4. Experimental performance of $LiFePO_4$ and Na-Ion

$LiFePO_4$ and Na-Ion test performance. In this section, we'll look at the practical performance of two types of storage devices in the 18650 form factor. As a prototype, we will use the HAKADI Sodium ion 18650 3.1V 1500 mAh and $LiFePO_4$ BATTERY CELL 18650-3.2V-1600 mAh, comparison of which is shown in Figures 3. From the characteristics, we can see that $LiFePO_4$ slightly wins over Na-Ion in terms of capacity. So, let's further analyse the charge discharge graphs of these drives and test them.

The graphs at Figures 4, 5, 6 and 7 show that sodium-based drives are able to discharge to a lower voltage than phosphate-based ones [3, 29], and in our case, to 1.55 volts with a high capacity gain. Instead, the $LiFePO_4$ drive can discharge up to 1.95 volts. Another important aspect is the efficiency of capacity utilization at different stages of discharge. The graphs show that sodium-ion batteries tend to have a more even distribution of capacity during discharge, while $LiFePO_4$ batteries show a more pronounced decline in the final stages. This means that although $LiFePO_4$ batteries may have a higher initial capacity, their performance at low levels of abuse may be less than that of sodium-ion batteries.

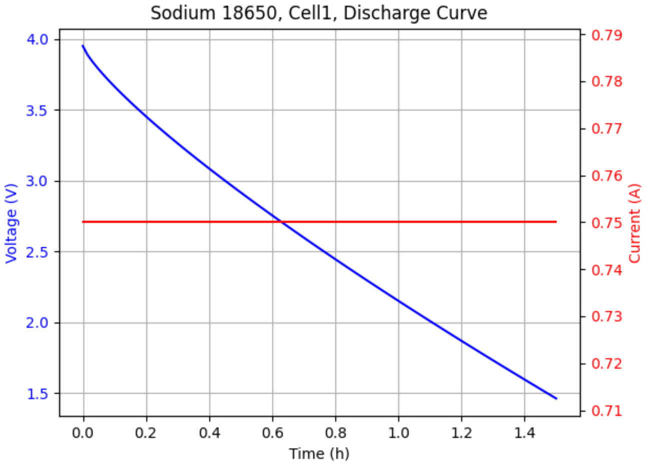

Fig. 4. Na-Ion battery discharge graph

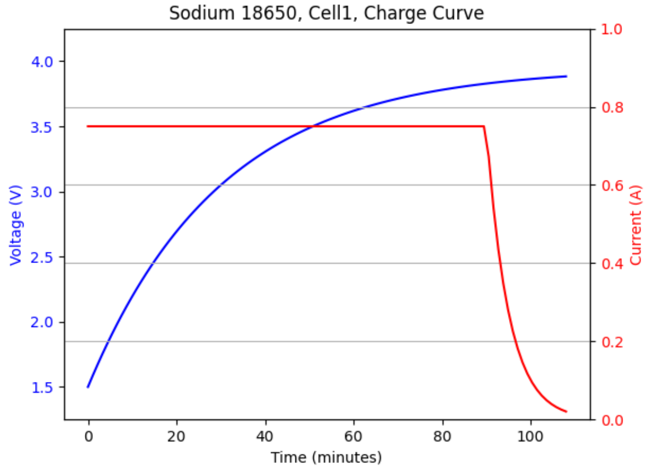

Fig. 5. Na-Ion battery charge graph

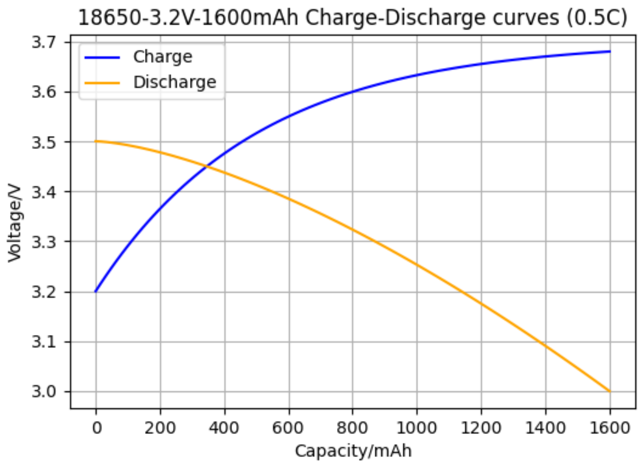

Fig. 6. Graphs of $LiFePO_4$ battery charge and discharge

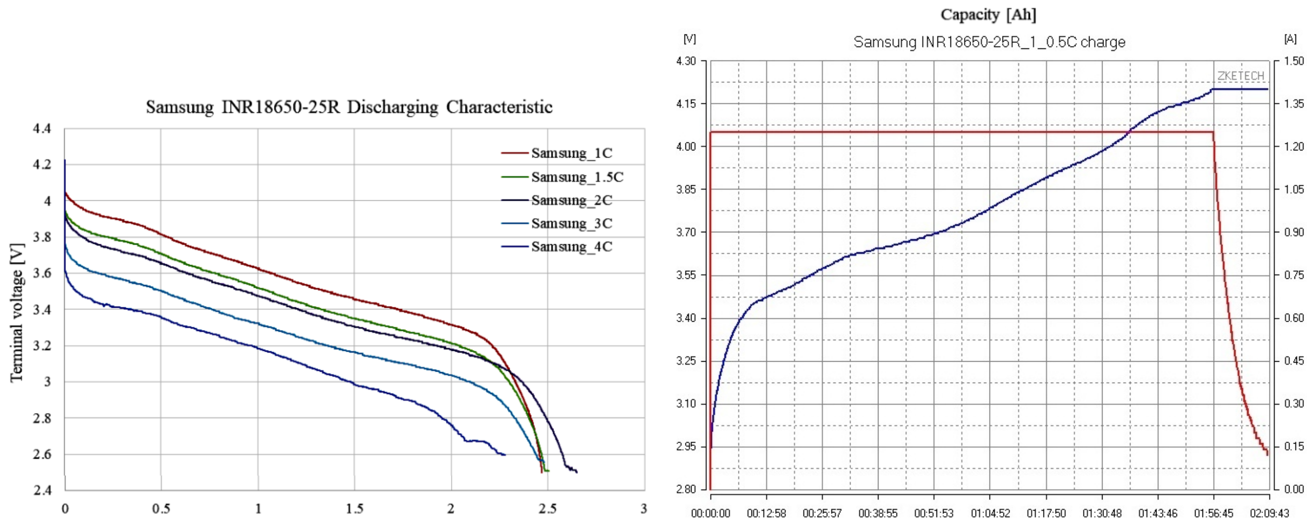

Fig. 7. $LiFePO_4$ battery charge and discharge graphs [20]

5. Comparison with Li-Ion

Since we used 18650 form factor drives for our test, we will compare them to lithium-ion drives in this size. Their chemical composition and design features are similar, as they use lithium as the key component that ensures high density. Sodium-ion batteries use sodium ions, which facilitates fast charging but reduces energy density due to the larger size of the ions [4, 13].

Both types of batteries have a similar design: anode, cathode, electrolyte, and separator. However, Na-Ion current collectors are made of aluminium, while Li-Ion current collectors are made of more expensive copper. Also, in comparison, sodium-ion batteries are more environmentally friendly due to the wide availability of sodium, as well as their lower environmental impact during production [21, 39]. They are safer because they do not explode in case of overheating. Lithium-ion batteries require more careful temperature control due to the risk of thermal overclocking. In the following, we will consider the practical performance of Li-Ion batteries, using the example of the Samsung INR18650-25R 3.7 V 2500 mAh battery [1, 25].

The graph above shows that the minimum discharge voltage is 2.5 V, and they also have a uniform distribution of capacity, just like sodium batteries, but different from lithium-iron-phosphate batteries. Also, I will distinguish by the charge discharge on the graph that the charge was up to 4.2 V, unlike sodium with a discharge of 3.95 V and phosphate 3.65 V in our case.

This reflects a general trend where lithium-ion batteries provide high energy density but require stricter control of charging processes to prevent material degradation. Sodium and phosphate batteries, on the other hand, have slightly lower energy density characteristics, but benefit from durability and safety, making them more suitable for stationary energy storage systems.

6. Conclusions

Sodium and $LiFePO_4$ batteries have their own unique advantages and disadvantages, making them suitable for different applications. Sodium batteries are a more cost-effective solution and offer better performance at low temperatures, while $LiFePO_4$ batteries offer higher energy density, longer life and increased safety. The choice between these technologies depends on specific application requirements, such as cost, performance, and environmental friendliness. In the future, we can expect improvements in both types of batteries, which will contribute to more versatile and sustainable energy storage solutions.

References

[1] Adaikkappan M., Sathiyamoorthy N.: Modeling, state of charge estimation, and charging of lithium-ion battery in electric vehicle: A review. Int. J. Energy Res. 46(5), 2021, 2141–2165 [https://doi.org/10.1002/er.7339].

[2] Al_Issa H. A. et al.: Correct Cross-Section of Cable Screen in a Medium Voltage Collector Network with Isolated Neutral of a Wind Power Plant, Energies 14, 2021, 3026 [https://doi.org/10.3390/en14113026].

[3] Al_Issa H. et al.: Assessment of the Effect of Corona Discharge on Synchronous Generator Self-Excitation. Energies 15(6), 2022 [https://doi.org/10.3390/en15062024].

[4] Bashir T. et al.: A review of the energy storage aspects of chemical elements for lithium-ion based batteries. Energy Mater. 1, 2021, 100019.

[5] Belik M.: Optimisation of energy accumulation for renewable energy sources. Renew. Energy Power Qual. J. 2021, 19, 205–210 [https://doi.org/10.24084/repqj19.258].

[6] Halko S., Suprun O., Miroshnyk O.: Influence of Temperature on Energy Performance Indicators of Hybrid Solar Panels Using Cylindrical Cogeneration Photovoltaic Modules. 2nd KhPI Week on Advanced Technology (KhPIWeek), Kharkiv, Ukraine, 2021, 132–136 [https://doi.org/10.1109/KhPIWeek53812.2021.9569975].

[7] Hannan M. A. et al.: Impact assessment of battery energy storage systems towards achieving sustainable development goals, J. Energy Storage 42, 2021, 103040 [https://doi.org/10.1016/j.est.2021.103040].

[8] Jamil M. et al.: Hybrid Anode Materials for Rechargeable Batteries – A Review of Sn/TiO2 Based Nanocomposites. Energy Rep. 7, 2021, 2836, 2836–2848 [https://doi.org/10.1016/j.egyr.2021.05.004].

[9] Karaiev O. et al.: Mathematical modelling of the fruit-stone culture seeds calibration process using flat sieves. Acta Technologica Agriculturae 24(3), 2021, 119–123 [https://doi.org/10.2478/ata-2021-0020].

[10] Khasawneh A. et al.: Optimal Determination Method of the Transposition Steps of An Extra-High Voltage Power Transmission Line. Energies 14, 2021, 6791 [https://doi.org/10.3390/en14206791].

[11] Komada P. et al.: The incentive scheme for maintaining or improving power supply quality. Przegląd Elektrotechniczny 5, 2019, 79–82 [https://doi.org/10.15199/48.2019.05.20].

[12] Kumar R., Goel V.: A study on thermal management system of lithium-ion batteries for electrical vehicles: A critical review. J. Energy Storage 71, 2023, 108025 [https://doi.org/10.1016/j.est.2023.108025].

[13] Lakshmi G. S. et al.: Battery Energy Storage Technologies for Sustainable Electric Vehicles and Grid Applications. Journal of Physics: Conference Series 1495, 2020, 012014 [https://doi.org/10.1088/1742-6596/1495/1/012014].

[14] Lezhenkin O. M. et al.: Investigation of the separation of combed heap of winter wheat. Journal of Physics: Conference Series, International Conference on Applied Sciences (ICAS 2020), Hunedoara, Romania, 20–22 May 2020, 1781, 12016 [https://doi.org/10.1088/1742-6596/1781/1/012016].

[15] Lezhniuk P., Buslavets O. Rubanenko O.: Balancing electricity generation and consumption in a system with renewable energy sources. 2nd KhPI Week on Advanced Technology (KhPIWeek), Kharkiv, Ukraine, 2021, 63–68 [https://doi.org/10.1109/KhPIWeek53812.2021.9570087].

[16] Makovenko E. et al.: Single-phase three-level qZ-source inverter connected to the grid with battery storage and active power decoupling function. 59th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON), Riga, Latvia, 12–13 November 2018, 1–6 [https://doi.org/10.1109/RTUCON.2018.8659843].

[17] Markowska K. et al.: Analysis and improvement of power quality in the onboard electrical power systems within a self-propelled floating crane. International Journal of Electrical Power & Energy Systems 161, 2024, 110179 [https://doi.org/10.1016/j.ijepes.2024.110179].

[18] Martinko D. et al.: Planning of the Optimal Performance of Household Photovoltaics and Battery Storage within Consideration of Investment Return. Przeglad Elektrotechniczny 100(1), 2024, 105–111 [https://doi.org/10.15199/48.2024.01.22].

[19] Miroshnuk O., Tymchuk S.: Uniform distribution of loads in the electric system 0.38/0.22 kV using genetic algorithms. Technical Electrodynamics 4, 2013, 67–73.

[20] Miroshnyk O. et al.: Investigation of Smart Grid Operation Modes with Electrical Energy Storage System. Energies 16, 2023, 2638 [https://doi.org/10.3390/en16062638].

[21] Patel T.: A Comparative Study of Lithium-ion and Sodium-ion Batteries: Characteristics, Performance, and Challenges. Friedrich Alexander-Universität Erlangen Nürnberg (FAU), 14 March 2023 [https://open.fau.de/handle/openfau/21891].

[22] Qawaqzeh M. et al.: The assess reduction of the expected energy not-supplied to consumers in medium voltage distribution systems after installing a sectionalizer in optimal place. Sustain. Energy, Grids and Networks 34, 2023, 101035 [https://doi.org/10.1016/j.segan.2023.101035].

[23] Qawaqzeh M. Z. et al.: Research of Emergency Modes of Wind Power Plants Using Computer Simulation. Energies 14, 2021, 4780 [https://doi.org/10.3390/en14164780].

[24] Rudola A. et al.: Commercialisation of high energy density sodium-ion batteries: Faradion's journey and outlook. J. Mater. Chem. A 9, 2021, 8279–8302 [https://doi.org/10.1039/D1TA00376C].

[25] Rudola A.: The Future of Clean Transportation: Sodium-ion Batteries [http://www.bridgeindia.org.uk].

[26] Sayahpour B. et al.: Perspective: Design of cathode materials for sustainable sodium-ion batteries. MRS Energy Sustain. 9, 2022, 183–197 [https://doi.org/10.1557/s43581-022-00029-9].

[27] Schwarz S.: Lithium Iron Phosphate – enabling the future of individual electric mobility, 2022 [https://www.e-motec.net/lithium-iron-electric-mobility].

[28] Shi N. et al.: State of charge estimation for the lithium-ion battery based on adaptive extended Kalman filter using improved parameter identification. J. Energy Storage 45, 2021, 103518 [https://doi.org/10.1016/j.est.2021.103518].

[29] Subramanyan K. et al.: Fabrication of Na-Ion full-cells using carbon-coated Na3V2(PO4)2O2F cathode with conversion type CuO nanoparticles from spent Li-Ion batteries. Small Methods 2022, 6, 2200257 [https://doi.org/10.1002/smtd.202200257].

[30] Szafraniec A. et al.: Magnetic field parameters mathematical modelling of windelectric heater. Przeglad Elektrotechniczny 97, 2021, 8, 36–41 [https://doi.org/10.15199/48.2021.08.07].

[31] Trunova I. et al.: The perfection of motivational model for improvement of power supply quality with using the one-way analysis of variance, Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu 6, 2019, 163–168 [https://doi.org/10.29202/nvngu/2019-6/24].

[32] Tymchuk S. et al.: Assess electricity quality by means of fuzzy generalized index. Eastern-European Journal of Enterprise Technologies 3(4(75)), 2015, 26–31 [https://doi.org/10.15587/1729-4061.2015.42484].

[33] Tymchuk S. et al.: Calculation of energy losses in relation to its quality in fuzzy form in rural distribution networks. Eastern-European Journal of Enterprise Technologies 1(8(73)), 2015, 4–10 [https://doi.org/10.15587/1729-4061.2015.36003].

[34] Battery Data online [https://calce.umd.edu/battery-data#Storage].

[35] First Phosphate. How the LFP Battery Works [https://firstphosphate.com/phosphate-industry/about-the-lfp-battery/#:~:text=How%20the%20LFP%20Battery%20Works,than%20one%20negatively%20charged%20element].

[36] FutureBatteryLab. The big beginner's guide to Sodium-Ion batteries [https://futurebatterylab.com/the-big-beginners-guide-to-sodium-ion-batteries].

[37] Identifying the pinch points in the LFP supply chain [https://firstphosphate.com/lfp-battery-strategy].

[38] Na-Ion battery online [https://www.hinabattery.com/en/index.php?catid=12].

[39] Samsung INR18650-25R datasheet [https://www.powerstream.com/p/INR18650-25R-datasheet.pdf].

[40] Sodium Ion Batteries: Performance Advantages and Broad Application Prospects in Extreme Temperatures. [https://www.LiFePO4-battery.com/News/sodium-ion-batteries-advantages.html].

[41] Sodium-Ion Battery Market [https://www.marketsandmarkets.com/Market-Reports/sodium-ion-battery-market-207269067.html].

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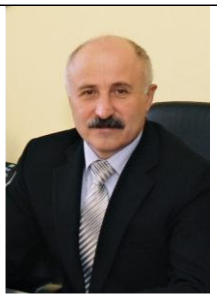

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