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Selection of Optimal Lithium Battery Technology for Backup Power Supply of Automatics Systems in Railway Transport

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Abstract

The article presents the results of the research into batteries based on lithium technology. An analysis of all the most widely represented lithium battery technologies was carried out with an assessment of their main parameters. The research was aimed at studying the performance characteristics of the six most common technologies for the production of chemical power sources using lithium, which are currently the most developed and are manufactured on a mass production scale. A comparative analysis showed that the features of each of them should be taken into account in order to optimize the choice of parameters for batteries with different technologies when solving various industrial and household problems, since this approach will make it possible to further use their differences with the greatest efficiency. The most suitable areas for practical application of each type of lithium battery are given, taking into account the individual characteristics of their performance. Also, from a practical point of view of highly efficient use of electrical energy storage devices, as a constant consumer of especially large volumes of energy carriers, the transport industry is considered, which has a great interest in improving technologies in order to improve the quality of equipment, increase the safety of the transportation process and the economic efficiency of the type of activity being carried out. This analysis was carried out using the example of their use in backup power supply systems for railway automatics devices. The advantages of replacing backup power sources based on the traditional method of storing electrical energy using lead-acid batteries with batteries made using lithium technology are shown. At the same time, to determine the appropriate technology, the specifics of the application conditions were first taken into account, since this type of energy source belongs to the category of guaranteed energy supply. The research results obtained allow us to compare lithium batteries to identify selection criteria for specific tasks based on their performance characteristics.
KEY WORDS: *batteries, current sources, power supplies, railway automatics, performance analysis*

1. Introduction

For any branch of the national economy, regardless of whether it is manufacturing or household sphere, energy sources are needed. The transport sector is not an exception to this postulate, but rather even a confirmation of it. For the transport sector, the issue of energy sources is vitally important and in many ways is decisive in such issues as efficiency, safety and environmental friendliness [6]. At present, it is no secret that carbon-containing energy carriers such as oil, natural gas, hard and brown coal, oil shale, peat will come to an end at some point, since they are non-renewable energy resources. This moment is not so far from us and is predicted to be in the attainable future. In addition, no one can ignore the issues related to environmental pollution and the greenhouse effect from products obtained in the process of burning carbon-containing sources.

Currently, the issue of meeting the needs for energy supply is facing the challenge of finding alternative renewable energy sources. These include the use of solar, wind, water, geothermal, coastal wave energy and other types. At the same time, a very important issue arises about the accumulation of the received electricity, which will make it possible to solve many modern problems of energy redistribution during the day, autonomy of power supply, environmental friendliness and obtaining sources with high quality of electricity. It is necessary to take into account that energy consumption is constantly increasing, especially in recent decades, so the dynamics of growth in the implementation of new generation energy systems must exceed the rapid growth in demand in order to be able to partially or completely replace traditional carbon-containing energy carriers in the future. It is worth considering what type of energy systems to give preference to, since compared to gasoline internal combustion engines, the efficiency of which is about 25-30%, and diesel engines with an efficiency of 40%, which even when using a turbocharger or fuel injection system, the efficiency rises to 55%, the efficiency of electric motors with a capacity of up to 100 kW is at the level of 75-90%, and over 100 kW - 90-97%, which is a high indicator of energy efficiency.

Railway transport, like any other industry, is critically dependent on power supply. And the issue is hidden not only in the provision of power to power units, but also in the stable operation of the transportation process control systems, which is possible only with guaranteed power sources. The safety of railways directly depends on the stability and reliability of energy sources. To ensure the reliability of the supply of critical loads, backup power is usually provided. Subsequently, when a failure occurs in the main power source, the load is switched to a backup or emergency power source, thereby ensuring the normal operation of the connected loads. In this regard, the issue of choosing technologies for backup power supply of electrical circuits for ensuring control and monitoring of railway automation systems is an urgent problem [1].

2. Analysis of the Problem State and Task Setting

In general, batteries used in railway transport can be divided into three types: fast (H), medium (M) and long (L) discharge. The first are used as starter batteries to start internal combustion engines of diesel locomotives, cooling sections, carriages, diesel trains and stationary engines. The second are widely used as the main power source in passenger cars and refrigerated sections at low speeds and at stops when the generator stops supplying power to them. The third are used as a backup source in uninterruptible power supplies with the main AC power supply or as a buffer with the main DC power source in signaling, centralization and blocking (SCB) and communication equipment, as well as in low-voltage circuits for the auxiliary needs of substations and other stationary objects of railway transport. When the main power source is operating, the battery is in charging mode and is used in the event of a failure or temporary disconnection of the source. The use of storage batteries is determined by the desire to have an independent source in case of any accidents and failures in primary circuits, in case of power supply failures associated with lightning strikes, equipment failure or an accident. This is a guaranteed power source, thanks to which traffic safety standards are met in the event of the absence of main power supply lines.

The requirements for backup power supply sources for railway signalling systems, which receive power from them in abnormal and emergency situations, are extremely important to ensure a stable and reliable power supply, so they come from the conditions imposed by the system load: guaranteed safe and normal performance of operations, including railway crossings, signal lights, operation of turnouts and blocking systems. These signalling systems are usually connected to the internal electrical network of the railway.

Safe operation of railway automation and telemechanics equipment requires stability and reliability of their power supply systems. Reliable and uninterrupted operation of automation and telemechanics systems and devices is one of the most important factors determining the safety of train traffic. High requirements for the reliability of power equipment are imposed because railway automation and communication devices are classified as especially important first-category power consumers. One of these requirements is to ensure uninterruptible power supply to automated systems. This requirement is met by a backup power source, which is a battery. Batteries act as backup sources and ensure complete continuity in the power supply of automation devices.

Despite the fact that lead-acid batteries, which are still in use today, have a slight decrease in discharge voltage and high efficiency, they are morally and technically obsolete and, in addition, have a number of disadvantages that make their operation labor-intensive and difficult. Such features include: low energy density of the battery, which determines its large weight; the problem of battery resistance to deep discharges - the service life of batteries is sharply reduced when discharged by more than 80%; high maintenance requirements - the electrolyte level must be constantly monitored (low electrolyte density leads to sulfation, and high density causes rapid corrosion of the electrodes, therefore, a sharp decrease in performance), charged in a special, well-ventilated room, and labor protection requirements must be strictly observed; up to 30% of electricity is lost during charging; the battery must not be left in the cold when it is discharged; incomplete one-time charge return by the battery at high discharge currents. According to the conditions of use of lead-acid batteries in railway automation systems, the maintenance technology provides for checking their condition once every 4 weeks at stations and crossings and every 2 weeks on sections. It should be noted that lead-acid batteries are not subject to repair, but 100% of batteries are subject to recycling, of which 98% of components are reused.

Lithium-ion batteries (LIB) have a number of advantages, the most significant of which are their high specific capacity and discharge current density, high discharge voltage, no "memory effect", high charging currents and minimal self-discharge. A lithium battery consists of a specific number of elements, so it can be easily repaired by replacing those elements that have failed. The use of such batteries can significantly reduce operating costs, since their service life is from 10 to 15 years, which is 2-3 times longer than that of lead-acid batteries. When using LIB, there is no need to monitor the level, temperature and density of the electrolyte, unlike lead-acid batteries. In addition, they do not emit by-products during electrochemical reactions into the environment and do not require a special storage place. These batteries are also highly stable at low temperatures. However, for lithium batteries, the recycling rate is no more than 5-7%, while only about 50% of the components can be reused [16]. However, the continuity of technologies should be noted as a positive trend, as evidenced, for example, by the development of approaches to optimizing and extending the service life of electric vehicle batteries, which, in particular, are proposed to be used as a stationary energy storage device in a residential building [2, 5].

As microprocessor systems are increasingly used with the development of railway automation systems, the requirements for power supply reliability are increasing significantly. An example of a power transfer device is the Micro ECO Operation, the response time of which is approximately 25-56 ms [11]. Such a short transition time ensures that subsequent equipment continues to operate normally. Long switching times often lead to malfunction or disconnection of connected loads, causing failures in the operation of subsequent loads (e.g. signaling systems) and, as a result, in the movement of trains.

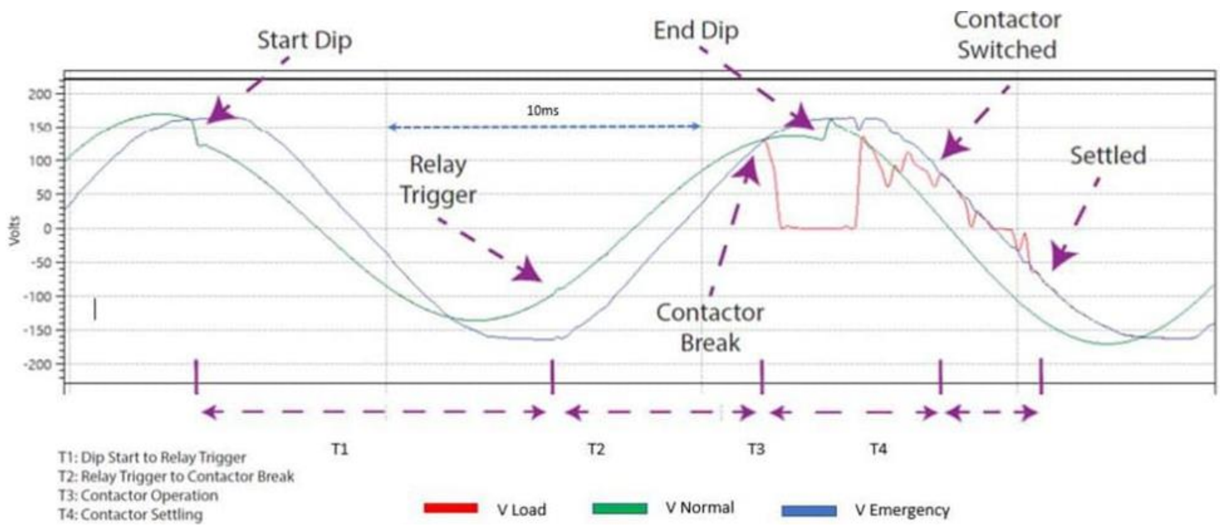

Fig. 1 Time dependence of the device operation Miro ECO Operation

Currently, UPS solutions for railway signalling and blocking systems as backup power sources instead of traditionally used diesel generators have become increasingly popular, which significantly affects the cost of installing the entire system and, since it takes up significant space, the specific power of the system. An example of the organization of such a system is shown in fig. 1. The optimization is aimed not only at eliminating the backup diesel-electric generator (and the associated greenhouse gas emissions and noise), but also at increasing the level of redundancy by adding a battery pack.

All independent power supply networks can be used in the backup power supply scheme. Using a UPS converter, it is possible to organize power supply networks of different frequencies. If a fault occurs in one of them, the UPS is able to redirect the load through the other. In the event of a failure in both independent networks, the battery unit of the UPS that has accumulated energy will provide power to the entire system. Thanks to this approach, UPS systems ensure a safe and continuous flow of rail traffic. The highest possible throughput and the readiness of the system to carry out the transportation process at any time are of great importance, since the railway infrastructure is used non-stop. This makes signaling systems reliable and precise transit management key factors in the profitability of the railway system.

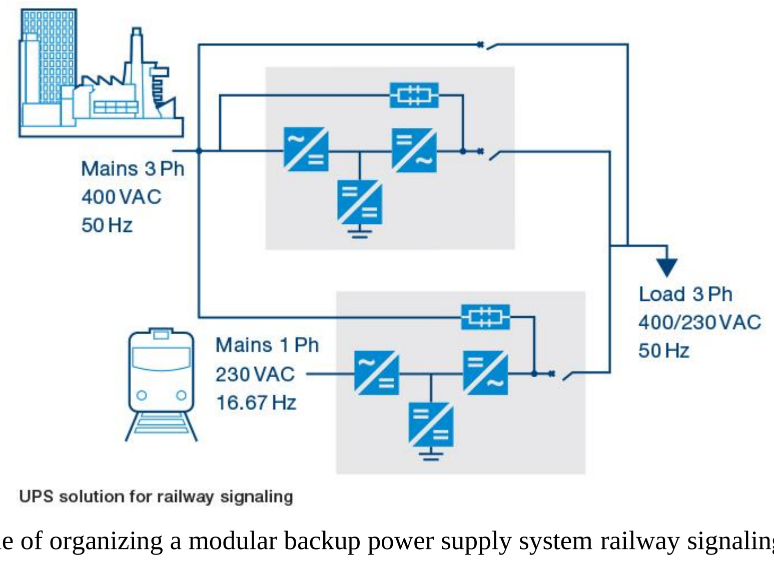

Fig. 2 An example of organizing a modular backup power supply system railway signaling and interlocking

Therefore, given the role that UPS plays in ensuring the continuity of the transportation process, a particularly important task in choosing UPS systems is the correct selection of lithium technology that will take into account operating conditions that concern not only load characteristics, but also environmental conditions.

3. Features of Using Lithium Batteries

LIBs are a major breakthrough in the world of technology, primarily due to their cost-effectiveness, environmental friendliness and efficiency. And according to the different electrolyte materials used in lithium-ion batteries, they are divided into liquid (LIB) and polymer (PLB). Let's consider the first of them.

The cost-effectiveness of LIB is that it allows to significantly reduce operating costs compared to traditionally used lead-acid and alkaline batteries. This effect is based on three features. Firstly, LIB have a high resource 2-3 times higher than the best lead-acid batteries, and up to 6 times higher than alkaline batteries. This fact of increasing the service life is already completely economically justified, despite their higher cost. Secondly, LIB are completely sealed, as a result of which the absence of harmful and hazardous substances is guaranteed during operation. In addition, LIB do not require maintenance throughout the entire service life. In total, this allows to dramatically reduce the costs of LIB maintenance, since the combination of these properties eliminates the purchase of consumables, and also allows to refuse the use of specialized charging rooms and reduce the costs of paying for the labor of service personnel. Third, LIBs have a higher energy efficiency, expressed as the ratio of the energy expended during their charging to the energy removed during their discharging. The higher efficiency of LIBs, combined with a highly efficient charger equipped with a pulse converter, allows for energy savings of about 30-40% [19].

The environmental friendliness of LIBs is that they are environmentally safe products at all stages of the life cycle - during production, operation and disposal [3]. Replacing lead-acid or alkaline batteries with LIBs is an opportunity to get rid of harmful emissions during operation and charging of the battery, solve the problem of accelerated corrosion due to the creation of an aggressive environment, and improve the state of the air environment.

The efficiency of LIB is based on high energy indicators, which allow creating effective solutions in any field of application, both in stationary and mobile installations. High energy density (about 200 Wh/kg and 220 kWh/m^3) allows achieving weight and volume savings. The LIB charging process is fully automatic and does not require personnel monitoring. This is possible due to the use of a battery control and management system together with the LIB, which continuously monitors the state of individual cells and the battery as a whole, and in case of emergency conditions ensures disconnection of the power circuit.

For mobile applications where the battery does not serve as a counterweight, the use of LIB allows for increased load capacity or additionally increased mileage from a single charge, since a battery made of LIB with equal energy capacity has 2-3 times less weight than a lead-acid or alkaline battery. For example, in electric carts, due to the reduced weight of the battery, the useful load capacity of the cart increases by 10-30%.

One of the key properties of LIB is a relatively fast charging time. From a purely practical point of view, even when charging with a nominal current of 0.5C, the full charge time does not exceed 4 hours (for traditional batteries - 8 hours). At the same time, during the first two hours, when the DC charging stage lasts, the battery manages to charge by 85-90%. In many cases, such a fast, although not full, battery charge allows, by changing the operating schedule of the equipment, to reduce its fleet, which in turn leads to significant cost savings.

In addition, LIBs also allow for much faster charging – the maximum charging current can be 3C, but the feasibility of constantly using such a charging mode should be economically justified, since it can contribute to a reduction in battery life.

The design features and classification of lithium-ion batteries also include the fact that they can be divided into high-power, high-capacity and intermediate, occupying a place between the two classes. The essence of this division is that even taking into account the use of the same electrochemical process, the battery itself, as a final product, can be manufactured differently. If the conductive base of the electrode, represented by aluminum foil on the positive electrode and copper on the negative, is made thinner in one case and more electrode mass is applied, and in the other, everything is done vice versa, then the resulting characteristics of such products will differ significantly. The greater the ratio of active electrode masses participating in electrochemical reactions to passive ones not participating in them, the higher the specific characteristics of the final product. However, the thinner the copper foil, the less current it can pass without overheating. And vice versa, the thicker the layer of electrode mass, the greater its resistance. That is, a battery with a thinner conductive base and a thicker layer of electrode mass will have high indicators of stored energy, but low power, and vice versa. Therefore, to further reduce resistance, active materials with a smaller particle size are used.

Thus, by changing the thickness of the electrodes, foil, separator and materials of the positive and negative electrodes, particle sizes, it is possible to obtain a battery with different maximum discharge currents and/or different capacities in the same size of the final product.

4. Comparative Analysis of Lithium Batteries

The differences between different technologies directly affect the performance of each battery, such as energy density, life cycle and service life, depth of discharge, safety, self-discharge rate, operation at sub-zero temperatures, thermal runaway, environmental safety, stable power supply and voltage. It should be noted that the parameters are interrelated, since the battery life depends not only on its design features, but also on the operating conditions [9]. It is possible and necessary to test the parameters and capabilities of lithium batteries experimentally, but since such studies are associated with a very large amount of time, a more productive way in this case is to turn to an open resource with lithium battery tests from companies, scientific laboratories and researchers that can be trusted [10, 14].

Table shows a comparison of the most significant parameters of lithium technologies.

Table

Varieties of lithium technology batteries

PARAMETER	TYPES OF BATTERIES OF LITHIUM TECHNOLOGY					
	LCO	LMO	NMC	NCA	LFP	LTO
Nominal voltage, V	3.6	3.7 (3.8)	3.6 (3.7)	3.6	3.2 (3.3)	2.4
Standard operating voltage range, V	3.0-4.2	3.0-4.2	3.0-4.2	3.0-4.2	2.5-3.65	1.8-2.75
Specific energy, Wh/kg	150-200	100-150	150-220	200-260	90-120	70-80
Charge speed	0.7-1C Max	0.7-1C Typ, 3C Max	0.7-1C	0.7 Typ	1C Typ	1C Typ, 5C Max
Discharge rate	1C Max	1C Typ, 10C Max, 30C Pulse	1C Typ, 2C Max	1C Typ	1C Typ, 25C Max, 40C Pulse	10C Max, 30C Pulse
Depth of discharge	80-90%	80-90%	80-90%	80-90%	100%	100%
Life span (cycles)*	500-1000	300-700	1000-2000	500	1000-2000	3000-7000
Temperature, ºC (max)	150	250	210	150	270	270
Operating tempe-rature range, ºC	-10…+60	0…+45	-20…+55	-10…+60	-30…+60	-30…+45
Thermal runaway	high charging	high charging	high charging	high charging	stable	safest Li-ion battaries
Safety	low	low, but safer than LCO	moderate	low	highest	safest
Price	high	moderate	high	high	moderate	highest

*the parameter is specified for a loss of 20% capacity

Fig. 3 shows the theoretical capacity and potential range of different cathode materials used in LIBs [13].

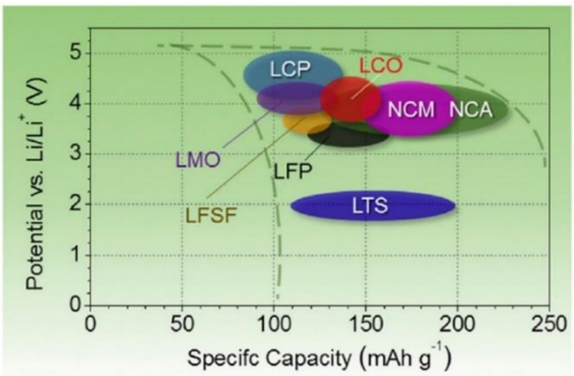

Fig. 3 Theoretical capacity of lithium-ion battery (LIB) cathode material by type

LCO (lithium cobalt with $LiCoO_2$ cathode) batteries contain a graphite anode and a cathode made of lithium cobalt oxide. The cathode in such models has a layered structure. And its greatest advantage is high energy capacity (up to 200 Wh/kg) and light weight, which allows for compact and capacious batteries. That is why LCO batteries are found in the vast majority of smartphones, laptops, photo and video cameras and other gadgets for which compactness is important. The lithium cobalt electrochemical system is distinguished by high specific energy capacity, but offers average indicators of specific power, safety and service life. The maximum charge and discharge rate of LCO batteries is 1C, that is, one full capacity in one hour. Anything faster can lead to problems. Among the biggest disadvantages of this technology is their unsafety, as the batteries can catch fire from mechanical impacts or during rapid charging/discharging, and also do not tolerate negative temperatures well and overheat in the heat. And an important factor is the price, which is quite high for these products due to the fact that cobalt is a rare mineral, so its use costs about 2 times more than nickel, 15 times more than aluminum and 1000 times more than manganese. The disadvantages also include a short service life and limited capabilities under load. A lithium-cobalt battery cannot be charged or discharged at a current higher than its C-rating. Forced fast charging or connecting a load higher than this value will lead to excessive stress and overheating.

LMO (lithium-manganese-oxide with $LiMn_2O_4$ and Li_2MnO_3 cathodes) batteries have lower energy capacity and shorter service life than LCO. But there are advantages. Firstly, such batteries are cheaper, since manganese is 1000 times cheaper than cobalt. And secondly, lithium-manganese spinel is used in the cathode of such batteries. This is a three-dimensional crystalline structure, which, compared to the layered cobalt structure, improves the flow of ions on the electrode through microchannels, which significantly reduces internal resistance and increases the output current, giving a significant advantage in power. Due to such structural features, the LMO charge rate is 3C, that is, 3 times faster than LCO, and the discharge current is generally ten times higher than its capacity and is at the level of 10C. That is why LMO batteries are used in equipment that requires high current strength, where it is necessary to produce high power in a short period of time. At the same time, they have an average specific energy capacity with a fairly large resource. It is assumed that they can be used for user purposes for 5 years, since they stably withstand up to 1000 full charge/discharge cycles. The features of this type of batteries include self-balancing due to high thermal stability. If the voltage reaches maximum peaks, the element emits heat so as not to exceed the threshold values. Due to this effect, such models can be used with minimal control. They are used to power expensive power tools, in light electric transport, and medical equipment. The disadvantages include the inability to charge at sub-zero temperatures.

NMC (lithium-nickel-manganese-cobalt-oxide with $LiNiMnCoO_2$ cathode) batteries combine the high energy capacity of LCO and the high power of LMO batteries. This is one of the new most successful versions of the lithium-ion electrochemical system, which is a combination of nickel, manganese and cobalt (NMC) in the cathode. Their development was aimed at combining the advantages of previous types. The combination of these metals allows you to compensate for each other's shortcomings and fully use their strengths [4]. Therefore, they are distinguished by: significant specific electrical capacity, chemical stability, frost resistance, high current output. The secret of this technology is the combination of nickel and manganese. Nickel is known for its high specific energy, but poor stability. Manganese is famous for its low resistance, due to the spinel structure. And the combination of these metals enhances each other's strengths. Its main advantage is its balance, since its energy capacity is 220 Wh/kg, which is even higher than that of LCO, and its service life is not inferior to LCO and is in the range of 1000 to 2000 cycles. In addition, the usual charge rate is up to 1C, but the discharge rate is 2C, which is 2 times higher than LCO [8]. The situation with operating temperatures and safety is identical to LCO, and the cost is about the same. Among all technologies, it has the lowest heating level. This is one of the most popular technologies. NMC batteries are used in cases where the issue of autonomous power supply concerns primarily the power of the source and its ability to operate energy-intensive systems [12]. They are used mainly in electric bicycles, medical equipment, electric cars and in industry.

NCA (lithium-nickel-cobalt-aluminum-oxide with $LiNiCoAlO_2$ cathode) batteries are manufactured using a complex and expensive technology that allows producing long-lasting and energy-intensive batteries for medical equipment, industrial installations and power units. This type of battery is not widely used by consumers due to its high cost. The main problem with this type of battery is the high risk of battery explosion when used under constant loads and high temperatures. The only advantage of NCA technology is its highest energy capacity. In all other parameters, NCA batteries are inferior to other lithium batteries.

LFP (lithium iron phosphate with $LiFePo_4$ cathode) batteries simultaneously combine two technological breakthroughs - safety and power. These batteries have a significant advantage in terms of service life compared to other lithium battery manufacturing technologies, lower toxicity, withstand overcharging and voltage drops in the power grid well, they have low self-discharge and special resistance to low temperatures, which allows them to be used outdoors. They have good electrochemical properties and low internal resistance. At the same time, they are able to withstand high current values and supply a load of 25C. However, they have low energy capacity, therefore, it is necessary to allocate a lot of space for installing the battery pack. Therefore, such batteries are used in large electric transport, such as electric buses, as uninterruptible power supplies or as energy storage systems in portable or stationary devices where high load currents and endurance are required. Their disadvantage is a higher price.

LTO (lithium titanate oxide with anode $Li_4Ti_5O_{12}$) batteries are the most durable. At the same time, they are impeccable in terms of safety, temperature resistance, and power. They have a significant speed of both charge and discharge, which makes this type of batteries especially interesting. However, they also have serious drawbacks, firstly, this is the lowest of all energy capacity and the highest cost. Despite the fact that this technology has a low nominal cell voltage, the battery can be charged very quickly and provide a high discharge current of 10C, that is, 10 times higher than its capacity, as well as a large number of charge-discharge cycles, high safety and excellent characteristics at low temperatures (about 80% of capacity at a temperature of -30°C). However, at present, it still has a high cost and still low specific energy capacity. They are used in uninterruptible power supplies, electric power units, street lighting on solar cells.

For a more visual presentation and comparative analysis of the data presented in Table 1, we present the average assessment of batteries in graphical form in Fig. 4 [15].

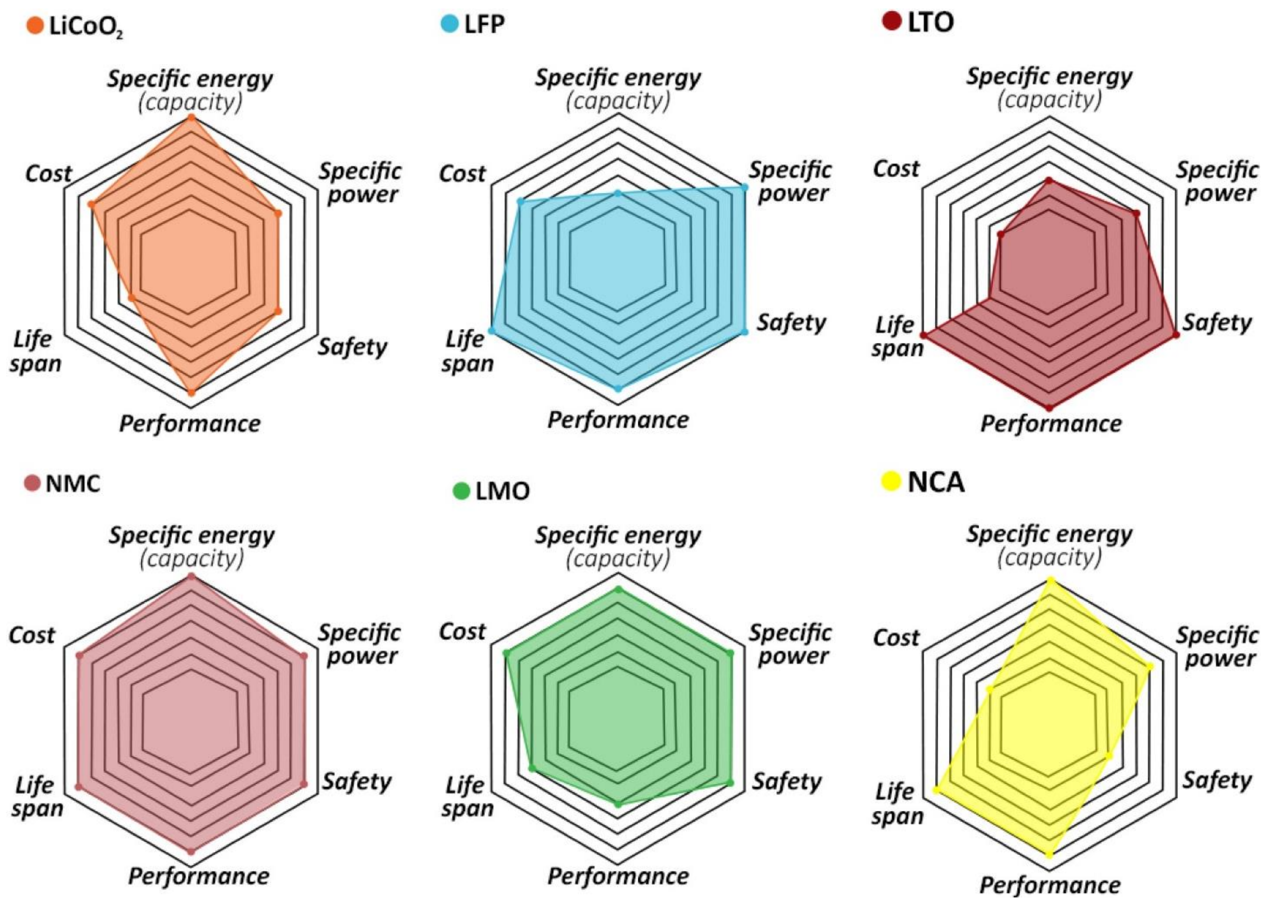

Fig. 4 Average rating of batteries with different lithium technologies

It should be noted that the last two types of LFP and LTO technology batteries are distinguished by unique electrochemical and physical stability of the material structure, which explains the high electrical performance and long service life. Due to the listed unique properties, these batteries are of great interest to powerful consumers in various industries, transport and backup power supply systems, where guaranteed power supply must be provided.

Also, NMC and LFP technologies are considered the most effective today and, depending on the tasks, a specific battery type is selected that is optimal for their implementation. The LFP battery is a clear leader in stability in the same price segment. However, lithium batteries of NMC technology may be the best option if priority is given to high output power. In turn, NCA have the highest specific energy capacity, but LMO and LFP are superior in specific power and thermal stability, and LTO have the longest service life [7, 17].

It is therefore obvious that a very wide range of possibilities is required to satisfy both the consumer battery market, where capacity is the top priority, and the industry, where battery systems with good load characteristics, a long service life and reliable safe operation are needed, with a single technological approach. Therefore, as an example, we can cite the successful combination in many cases of LMO batteries in combination with NMC technology to increase the specific energy capacity and extend the service life. This union, which is called LMO (NMC), allows achieving optimal results in terms of increasing the specific power, load characteristics and durability of the battery and thus using the strengths of both systems. It is these combined batteries that are used in most electric vehicles, which allows combining high acceleration capabilities of the electric motor with long autonomous operation. It should also be noted that LMO (NMC) technologies can be optimized for capacity or power.

5. Determining the Most Suitable Technology for Backup Power Supply of Railway Automation Devices

Reliable and stable power supply is the key to the efficient and safe operation of devices and systems whose operation depends on the stability and continuity of the supply of electrical energy. Critically important consumers include railway automation systems that ensure the implementation and verification of interdependencies and mutual exclusions in the transportation process, issuing orders and monitoring their implementation. Due to this, a minimum number of workers is involved, which significantly reduces the human factor, increases the speed of operations directly related to operational work, and increases the safety of such work. In the event of a power outage due to force majeure, transferring such a system to manual control is very difficult and implies a significant reduction in the number of operations performed. In this case, the insignificant staff intended for operational monitoring of the system state in real time will be able to perform only basic functions in manual control mode, which in turn will lead to the accumulation of a huge number of unfulfilled actions and will negatively affect throughput.

In this case, highly efficient operation is possible only with strict compliance with the criteria for power supply of critical infrastructure. As mentioned earlier, such systems in railway transport include automation systems that perform control, monitoring and analysis functions. Therefore, providing power to these systems is one of the most important tasks for railways as a whole. The requirements put forward by the conditions for supplying backup power supply determine that all automation systems must have three independent power sources: main, backup and autonomous source. In some cases, consumers can be additionally connected to batteries (input traffic light and crossing signaling), which provides a high guarantee of their continuity of operation.

The development of electric energy storage technologies with all their advantages gives reason to seriously consider the possibility of their use as the main backup source [18]. However, with all the variety of options presented, preference should be given to the most suitable in terms of operating mode. To do this, it is necessary to highlight the most significant criteria. These include: cost, reliability, safety, resource, environmental conditions, operating mode (load, switching frequency). Fig. 5 shows the percentage of the significance of these criteria in determining the most suitable technology for the accumulation of electric energy. It should be noted that reliability is of the greatest importance, which determines the readiness to provide electric power at any time. The least important is the operating mode, since the battery is in hot reserve and charge-discharge cycling does not occur.

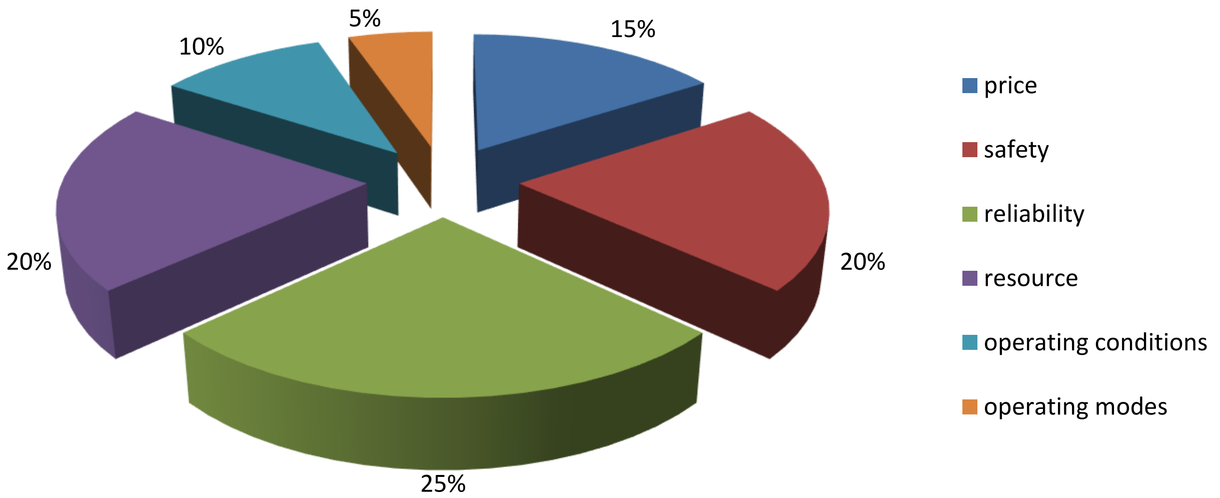

Fig. 5 Criteria for selecting electric energy storage devices for automatic control devices in railway transport

Thus, in case of application in automatic devices on railway transport it is necessary to select such lithium battery technology that could withstand environmental conditions, have a long service life, and maintain stable high energy consumption during the time of restoration work of the main power lines. As such technology, taking into account the choice of the optimal price, it is advisable to consider LFP batteries.

6. Conclusions

The main advantage of using lithium batteries is that they do not require maintenance, have low self-discharge and do not have the so-called "memory effect". However, it should be taken into account that if the conditions of their use are violated, they can cause a fire or explosion. To ensure safety, the following general rules must be observed: eliminate the possibility of a short circuit; do not allow the battery to overheat; do not use damaged batteries.

The use of modern lithium-ion batteries as a backup power source in UPS for railway automation and telemetry devices and systems allows to reduce the weight and dimensions of the battery by almost an order of magnitude, free up space, eliminate harmful working conditions that arise when servicing acid and alkaline batteries, and extend the service life several times.

The development of technologies in the field of electric energy accumulation provides an opportunity to take a new look at the systems of power supply organization. Due to significant technological progress and recent achievements in the development of batteries, it has become possible to organize backup power supply from reliable and stable sources. In addition, the advantages are directly related to the quality of electric energy, which is extremely important in view of the widespread use of microprocessor technologies in railway transport, which are extremely demanding on the purity and shape of the current in the network due to their sensitivity to power supply.

The considered types of LIB have their own personal individual features. Their diversity allows making the optimal choice for a specific task. Considering the conditions of using LIB as a backup power source for automation systems in railway transport, the most suitable are LFP type batteries.

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