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Application and Development of Energy Storage Systems

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ABSTRACT
The global energy industry now is at a new stage – a stage of a large-scale transition that characterized by the widespread use of renewable energy sources and the reduction in the use of hydrocarbon-based fuels. A new trend in the development of the energy sector is already clearly visible – the generation of energy should be continuously connected with its parallel accumulation. This article examines the existing technologies of energy storage systems (ESS), the experience of successful domestic and foreign operation of systems, the prospects and potential of their development in the Russian Federation, as well as the associated risks.

Keywords: *Energy storage systems, Uninterrupted power supply unit, Battery, Power system, Battery, Power supply, Generation, Electricity.*

1. INTRODUCTION

In the modern world the energy sector is on the verge of important changes. One of the key milestones in these changes is the proliferation of energy storage systems and the reduction in storage costs. Through the introduction of these technologies, power plants will be able to optimize the operation of electrical equipment and networks, as well as consumers to balance the load and store energy for further use.

A breakthrough in the field of energy storage systems can become an incentive to expand the use of renewable energy sources (RES). This issue is especially relevant for the regions of Russia that are not technologically connected with the unified energy system of the country, for example, in the Far North and the Arctic [1–3].

ESS are widely used in many spheres of human life. Without efficient energy-intensive batteries it would be impossible to conquer the depths of water, explore space or introduce electric vehicles into everyday life.

According to the "McKinsey Global Institute" energy storage technologies are among the twelve most critical to the development of the global economy. «Bloomberg New Energy Finance» expects that the installed capacity of energy storage units around the world will reach 1095 GW*h by 2040, and the capacity will be about 2850 GW*h. According to forecasts, the world market leaders in this area will be the United States, China, Germany and India. The volume of investments will reach 662 billion USA dollars by 2040.

In Russia a new investment cycle in the energy sector is expected after 2022. The amount of investments can reach 500–700 billion USA dollars by 2035. At the same time practically all market participants will be able to benefit from the use of storage devices.

The development of energy storage technologies in the near future will increase the reliability of the operation of power systems, make them more flexible, smooth out consumption peaks, expand the zones of distributed generation, introduce a larger volume of renewable energy sources into production, create the possibility of a local transition to DC systems and eliminate the need for strict simultaneity of production and electricity consumption [4–7].

However, it is extremely important to assess all the possibilities of using ESS, the ways of their development and the nuances of successful operation.

2. CURRENT DEVELOPMENT TRENDS

There are a number of priority areas of application of ESS that forming the largest sectors of the domestic market and ensuring the achievement of the greatest effect for the economy. These include:

- Distributed energy systems, microgrids, smartgrids: the use of ESS in the power supply of isolated and remote areas, in residential energy supply systems, the use of ESS in the power supply system of industrial and commercial consumers, the use of ESS in electric transport and charging infrastructure, special service applications of ESS (mobile emergency power supplies, collective uninterruptible power supplies (UPS), services of improved electricity quality);
- New general scheme of energy systems: management of the daily schedule of consumption and generation, as well as the quality of electricity, rotating reserve of the power system and other system services;
- Hydrogen energy.

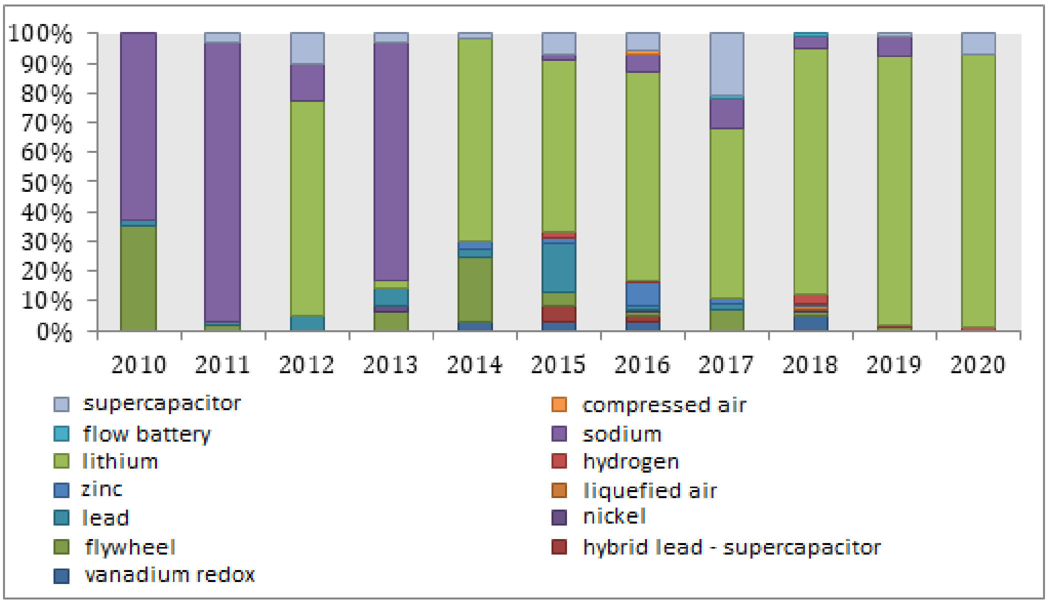

Figure 1 Structure of the introduced technology projects.

In the course of the analysis more than 1000 both implemented projects and those projects that are in the process of implementation were considered, according to the results a range of the most used technologies was identified (Figure 1).

The main types of ESS are presented in Table 1. The fields of application of ESS are classified by functions and types of consumers (Table 2) [8–11].

Navigant Research estimates that the market for electricity storage systems used in grid and system services will exceed 18 billion USA dollars, and the installed capacity will exceed 20000 MW by 2025 (Figure 2).

Table 1. Classification of electric power storage systems

Electric power storage systems				
Hydraulic storage systems (HSS)	Thermochemical batteries	Energy accumulator with hydrogen cycle	Li-ion	Supercapacitors
Underground compressed air storage	Energy storage by heating the substance	Conversion of hydrogen to methane	Ni-Cd	Superconducting systems
Liquid air storage system	Energy storage using materials with reversible phases	-	NaS	-
Inertial drives	-	-	LeadAcid	-

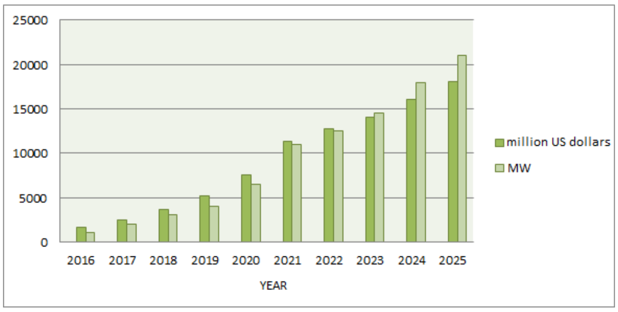

Figure 2 Forecast of growth of the world market of electric power storage systems and forecast of installed capacity of electric power storage systems in the world.

The main factors that will strengthen the market and develop the use of ESS will be:

- Cost reduction and massive expansion of generation zones based on renewable energy sources;
- Distribution and large-scale use of electric transport;
- Development of batteries based on lithium-ion technologies and reduction of their cost, as well as an increase in the need for generating and network capacities [12–16].

Priority ESS technologies on the horizon of 2021–2035 which Russia needs to rely on, belong to the following five groups:

- “Post-lithium” electrochemical technologies, which include technologies of sodium-ion, potassium-ion, magnesium-ion and other types of electrochemical batteries;
- Flow-through batteries in which the power source and the electrolyte are separated. This group includes redox-vanadium, zinc-bromide, zinc-iron and a number of others that differ in the type of current-forming reaction;
- Metal-air batteries, such as air-zinc and aluminum-air batteries, characterized by low costs for their production and high density of stored energy.

Table 2. Fields of application and functions of electric power storage systems

Functions	**Types of consumers of electric power storage systems**			
	National and regional power systems, from 500 kW*h	***Commercial and industrial enterprises, from 150 to 500 kW*h***	***Private and public electric transport, from 50 to 150 kW*h***	***Households and industrial equipment, from 10 to 50 kW*h***
The main source of energy	-	Own energy source for enterprises	Energy source for personal electric and hybrid transport	Own energy sources for households and industrial equipment
			Energy source for public electric and hybrid transport	
Emergency power source	Rotating power reserve for loading and unloading	Uninterruptible power supply for enterprises	-	Uninterruptible power supplies for households
		Источники аварийного питания предприятий		Emergency power sources for social facilities and equipment
Managing the consumption schedule	Smoothing the daily load schedule in power systems	Price Arbitrage	-	Price Arbitrage
	Smoothing out the annual unevenness of electricity consumption	Smoothing the consumption schedule		Smoothing the consumption schedule
	Unloading of power centers and cross sections	Improving the efficiency of own generation, including renewable energy		Improving the efficiency of own generation
Regulation of system parameters	Primary and secondary frequency control in the power system	Regulation of system parameters	Energy recovery on unconnected public transport	Energy recovery on equipment
				Electric transmission
		Launch systems		Launch systems

- Hydrogen technologies based on a combination of technologies for generating energy from gas and fuel cells that provide energy storage in synthetic chemical fuels;

- Gravity storage - solid-state accumulating power plants, the operation of which is based on the principle of lifting solid loads. Due to its high efficiency, this type of storage is considered as a potential technological leader of the domestic market of ESS.

3. PRODUCTION EXPERIENCE AND OPERATION

In Russia today there are more than 15 enterprises producing electrochemical storage devices and supercapacitors. Customers are mainly enterprises of the military-industrial complex, and therefore, in most cases, components for them are produced not in a ready-made form, but components for them. The only plant producing lithium-ion batteries in Russia is “Liotech”. The production volumes of “Liotech” exceed 1 GW*h and are even excessive in conditions of low demand in the domestic market. In addition, over the past two years, new production facilities have been launched in Russia in various areas of ESS: in the field of lithium-ion batteries – LLC “Enerzet” (NMC technology), in the field of hydrogen energy and fuel cells – LLC “InEnergy”. A landmark event is the start of production of modern supercapacitors by LLC “TEEMP”. The largest facilities in Russia, where ESS are operated, are the pumped storage power plant (PSPP): Zagorskaya PSPP-1 (capacity 1.2 GW), Kubanskaya PSPP (capacity 15.9 GW) and Zelenchukskaya HPP-PSPP (capacity 320 GW). There are also projects at the stages of implementation. It is planned to install a “network” system with a capacity of 584 kW*h at the Kosh-Agachskaya SES. At the Verkhnyaya and Nizhnyaya Burzyanskaya SES, installation and commissioning works are carried out on two hydraulic accumulating installations with a total capacity of 8000 kW*h. The manufacturing company LLC “Energy Storage Systems” has successfully completed tests of storage systems with a capacity of 400 kW*h, which allows you to adjust the load schedule and prevent the shutdown of gas piston units in the event of a sharp change in the load profile [17–19].

Electricity storage systems based on other technologies are also operated, some of which are shown in Table 3.

Table 3. Implemented ESS projects in the russian federation excluding PSPP

Location	Battery Type	Total rated power/ energy consumption	Purpose of the ESS	Commissioning
PS “Skolkovo”, Moscow region	Lithiumion	1200 kVA /1000 kW*h	Uninterruptible power supply	2012
PS “Psou”, Sochi	Lithium-ion	1500 kVA /2500 kW*h	Uninterruptible power supply, frequency control, peak power compensation	2013
PS “Volkhov-Severnaya”, St. Petersburg	Lithium-ion	1500 kVA /2500 kW*h	Parallel operation with a gas turbine plant to compensate for peak power, load schedule alignment, frequency control	2014
Charging station for electric vehicles, Ryazan, UES of Russia	Lithium-ion	22 kVA /100 kW*h	SNAP for electric vehicle charging station	2016
Republic of Tyva, Mugur-Aksy settlement	Lithium-ion	400 kVA /460 kW*h	Optimization of the operation of solar power plants and DES	2019

The American company “Tesla” has connected one of the largest lithium-ion batteries with a capacity of 150 MW and a capacity of 193,5 MW*h to the “Hornsdale” wind farm in South Australia. This direction is extremely promising and relevant. This is due to the fact that generation in Australia is increasingly based on renewable energy – wind and solar energy. “Tesla” is also implementing similar technologies in California, New Zealand, the United Kingdom, Hawaii and a number of Pacific islands.

The Japanese company “NGK Insulators” was one of the first to enter the world market with the technology of sodium sulfide batteries with liquid electrolyte. Today, the total capacity of «» installed worldwide is about 3 GW*h, and the world's largest battery network has been created in Japan.

This technology was also introduced in the UAE capital Abu Dhabi: fifteen battery systems were installed in ten different geographical locations of the city – with a total capacity of 108 MW, each of which is capable of providing the declared capacity for five to six hours.

The leading Korean company “LS Power” has commissioned the world's largest ESS facility «Gateway Energy Storage» with a capacity of 250 MW, based on lithium-ion batteries, in San Diego County, California.

The Chinese company “CATL” has developed a 100 MW*h battery storage system for the Luneng Haixi demonstration project, which is a combination of various types of power plants powered by renewable energy sources. This system is the world's first electrochemical energy storage with a virtual synchronous generator [20–22].

4. DEVELOPMENT RISKS

1. The main and most potential political risks for the development of the electrical industry market both in Russia and in the rest of the world are sanctions: restrictions and prohibitions aimed at undermining economic stability in countries, artificial slowdown in production, restriction or complete cessation of supplies of necessary material resources and a significant decrease in competitiveness in the market.

Due to the potential threats of sanctions against our country, dependence on the import of technologies and some types of strategic and scarce raw materials creates risks of not providing various sectors of the domestic economy with the necessary mineral raw materials and jeopardizes the dynamic and successful development of the ESS industry.

2. From the point of view of sociocultural risks, one of the barriers to the development of the ESS sector is the doubts of society due to the lack of a reference and sufficiently well-known successful practice of application in Russia. Due to the novelty of these technologies, consumers often lack sufficient awareness of the level of technical characteristics and compliance with the declared financial value of the product. The situation is negatively affected by the complexity of demonstrating the effectiveness of the use of ESS in small-scale domestic projects at the level of individual households or companies and the presence of an economic effect only as a result of the implementation of large-scale complex projects at the level of a microdistrict or a large industrial facility.

Another social problem, which is increasingly being written about by the world's leading media, is the artisanal extraction of raw materials in some countries of the world for the production of batteries, for example, cobalt and lithium. In the process of mining these metals, child labor is often used, workers are not adequately protected, not to mention environmental protection.

One of the trends in the development of the electricity storage market is the widespread use of electric vehicles in everyday life. According to the study, about half of the doubts about purchasing an electric car are based on the still low performance characteristics of batteries and the lack of a developed charging infrastructure for them. It is obvious that for the steady growth of the market, it is necessary to increase the level of technical literacy of the consumer in the field of electric vehicles. The solution may be the implementation of a set of introductory events.

3. The economic risks associated with the development of energy storage systems can be divided into two branches: internal, related to their production, and external, related to changes in the economic situation and market conditions.

Internal risk is a possible shortage of raw materials and a struggle for the raw materials market. «Deutsche Bank» estimates that the world's lithium reserves will last for about 185 years. The situation is somewhat different around cobalt, which is also in demand, more than half of the world production of which is concentrated in the Democratic Republic of the Congo, and almost all production of spherical graphite is concentrated in China.

Foreign economic risks can also be divided into two areas: risks of economic efficiency and risks of stagnation. It is assumed that storage facilities will replace most of the capacity reserve, but only if it turns out to be more cost-effective than maintaining generation reserves. In Russia, the maximum recorded actual load is slightly more than 158 GW, and the total nominal capacity of all power plants exceeds 240 GW – the stations are not used at full capacity.

To date, energy storage in ESS (the cost is 0,4 USA dollars per 1 kW*h) is more expensive than its production (the cost is 0,05 USA dollars per 1 kW*h). Stagnation risks are generally associated with a slowdown in the growth of the economies of states. The fall in the value of national currencies relative to world currencies inevitably leads to a sharp drop in demand for new technologies.

4. A significant legal barrier to the development of ESS, which is present in Russian legislation, is the absence of the concept of “electricity storage system” in industry regulatory legal acts regulating the rules and features of the wholesale and retail electricity and capacity markets. The absence of this definition makes it impossible to fix in the legislation the specifics of regulating the activities of ESS in the above-mentioned markets.

The classification of ESS both as an object of generation and as an object of consumption creates prerequisites for making excessive demands on them and for the impossibility of applying special regulatory measures for them that would take into account the peculiarities of their functioning and allow them to be operated with the greatest efficiency. Existing laws on the electric power industry prohibit the combination of electricity transmission activities and their purchase and sale (with the exception of purchases to compensate for losses or to meet their own production needs). This deprives power grid operators of the opportunity to include the corresponding costs in the calculation of the gross income required to purchase electricity stored in storage devices. This closes a whole set of opportunities for the effective use of ESS in the power grid complex, which could reduce consumers' energy costs and improve the quality of electricity supplied to them.

5. The operation of any technological equipment used for the production, conversion and transmission of electricity is certainly accompanied by serious technological risks at every stage of the product life cycle.

Since ESS are not separate products, but are technologically dependent on the sources of generation and the load of consumers, they are inherent in all the risks of malfunction characteristic of power systems as a whole.

The list of the main technological risks is presented in Table 4.

Table 4. Technological risks

Disadvantages of the project	Negative impact on the technological process at any further stage of the life cycle
Low quality of product manufacturing	Poor-quality materials during manufacture, poor-quality assembly, lack of acceptance tests can lead to failure in operation
Violation of installation technologies	Affects further operation and determines the probability of damage to the entire installation
Untimely maintenance and repair	Deterioration of the technical parameters of the product; rapid exhaustion of resources; premature aging and degradation
Lack of diagnostic methods	Increases the risk of equipment failure
Violation of the rules of operation	Development of defects; the inability of the equipment to function normally
Insufficient qualification of service personnel	The service personnel must have sufficient skills and the required qualifications, without which proper and high-quality operation of the product is not possible
Limited power output time	The supply from storage devices requires accurate calculations of the system for the balances of generated, stored and released energy. In case of their absence, the system will be ineffective or even useless

6. Environmental risks include risks arising from the manufacture, operation and disposal of batteries.

The process of disposal of spent standard service life of storage devices is accompanied by a large volume of waste released. The processing takes place by melting the batteries to a slag state and subsequent chemical separation, with the help of which it is possible to extract a certain amount of metal, for example, cobalt. Disposal requires a large amount of energy consumed and is accompanied by the release of toxic gases, and the extracted materials are of poor quality and are not suitable for further use.

To date, the only battery processor that does not disassemble the batteries, but immediately places them in a special reactor furnace, is the “Umicore” company.

As a result of utilization by this method, the extraction of nickel, copper and cobalt reaches 70% of their original content, and lithium goes into the slag. The described technology is currently the only one that allows you to slow down the growth of waste during the disposal of batteries.

5. CONCLUSION

On the threshold of 2022 a new global trend in energy development is clearly visible: any generation – wind, solar or hydro generation – must be continuously connected with the parallel accumulation of the generated energy. In Russia, this direction is in the initial stage of development, while energy storage systems are already being actively implemented and operated in foreign countries. For the successful development of the storage market in our country, it is necessary to make adjustments and make additions to the existing regulatory framework governing the production, storage, transmission and distribution of electricity, to consolidate the concept of ESS and approve the norms and features of their use. The implementation of these measures will be an incentive for the widespread use of ESS in the industrial and household sectors, while a radical change in the model of the electricity and capacity market is expected, improving the quality and availability of electricity supply services to consumers, developing the production of components and raw materials, as well as strengthening Russia's position in the global energy storage market.

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