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Energy Storage – Crucial for Balance

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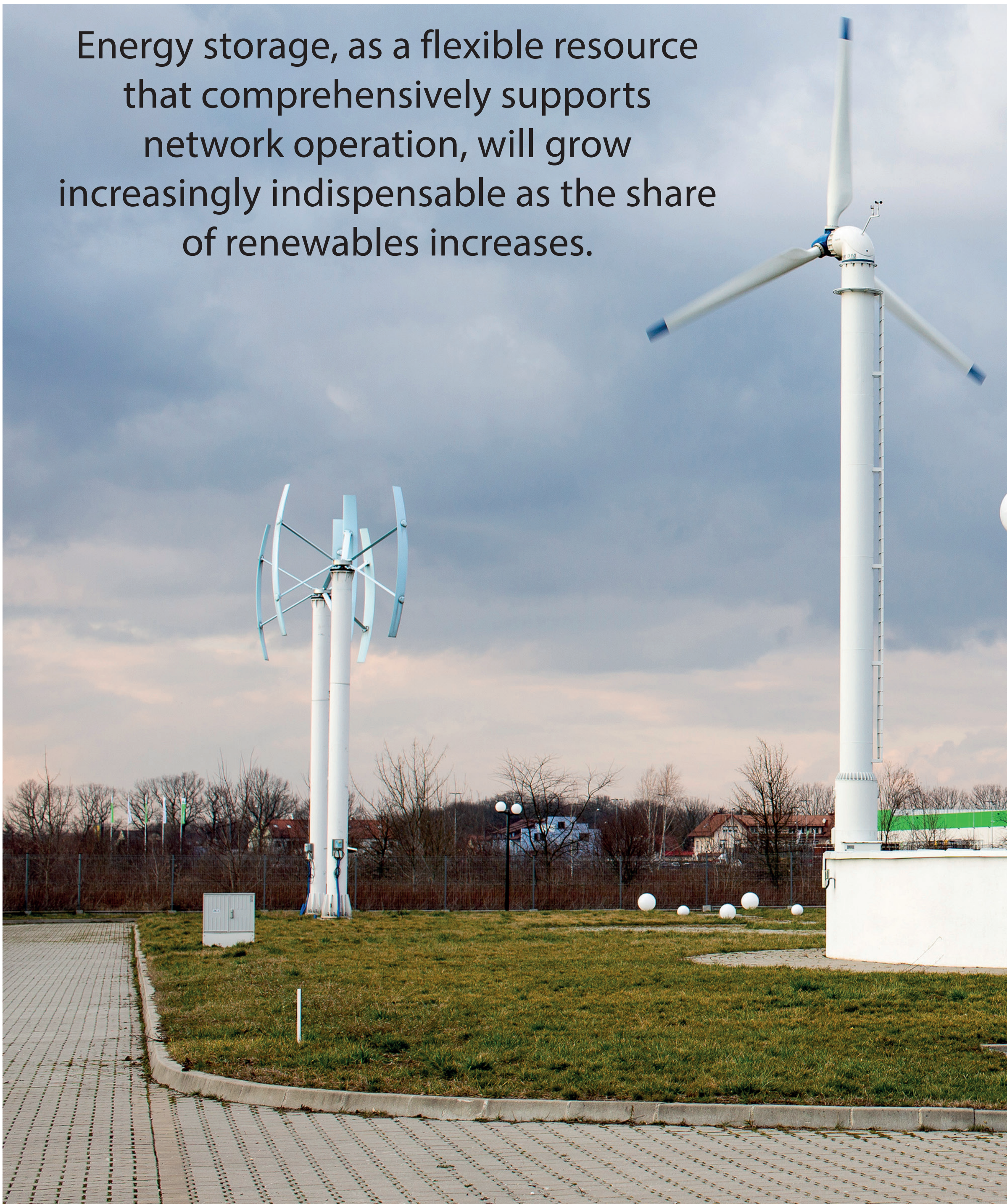
Energy storage, as a flexible resource that comprehensively supports network operation, will grow increasingly indispensable as the share of renewables increases.



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STAY-ON Energy Management in Puławy

Electric power is becoming the dominant energy carrier, by means of which we satisfy a growing share of our energy needs. This is largely due to its efficiency of long-distance transmission and its ease of conversion into other forms of energy. Thanks to the development of new technologies, such as heat pumps and electric cars, electricity is boldly entering new sectors of use that were once reserved for fossil fuels.

But behind the scenes, reliably supplying electricity to end users requires continuous operation of a whole complex power system, which is like a well-oiled machine in this regard. Maintaining the key parameters of voltage and frequency for the operation of the system is contingent upon preserving the energy balance, i.e. the balance between energy production vs. consumption. For many years, this balance has been regulated by means of regulating the power output of plants burning fossil fuels. This

The Energy Conversion and Renewable Sources Research Centre (KEZO) of the Polish Academy of Sciences in Jabłonna, outside of Warsaw

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An energy storage facility utilizing flow technology, with 260 kW power and 2.2 MWh capacity, in Jeonju, South Korea

has the disadvantage of not only under-utilizing the production potential of such plants, but also detracting from their efficiency.

The twenty-first century has brought new challenges connected with dynamic development of renewable energy sources. The ever-more ambitious climate targets being adopted at the European and global level are stimulating growth in the share of photovoltaic and wind sources in electricity production. However, these sources are relatively capricious, being dependent on the weather and season, so properly balancing them within the larger power system is growing increasingly difficult. Here, of course, is where energy storage systems come in. Their installation increases the flexibility of transmission systems and creates opportunities for stable operation despite having a large share of renewable sources. It has grown increasingly clear that it will be impossible to meet the ambitious climate goals without large-scale deployment of such energy storage systems.

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A view inside a vanadium redox flow battery installation, showing the cell stacks

It should be borne in mind, however, that energy balancing is just one of the many services that energy storage facilities can offer. There may be many more reasons to install them, as they allow for:

- the establishment of micro-scale power systems (microgrids), locally ensuring energy balancing or even complete self-sufficiency,
- ensuring the autonomous (island-mode) operation of such systems, ensuring continuity of power supply in the event of a power outage,
- increased transmission capacity of the current system, by relieving the heavy load on transmission lines, thus taking the place of costly investments in new lines or generation sources,
- improved power quality parameters, by minimizing voltage fluctuations or compensating for reactive power,
- restarting the power system after an extensive failure (called a "black start"),
- taking advantage of energy price differences for the purposes of arbitrage (i.e. charging up with cheap energy during off-peak hours, later discharging it during peak hours),
- minimizing peak power demand, which translates into lower bills or the ability to make better use of available capacity,
- the provision of system services such as frequency regulation and operating reserve.

How to store energy?

The challenge of energy storage has been a subject of study for many years. The first batteries came into use back in the early 1900s, and the first pumped-storage facility was commissioned in 1920. However, it was not until the late 20th century, with the emergence of significant demand for such solutions, that energy storage technologies started to see significant advancement.

There are many methods of energy storage, based on numerous physical or chemical phenomena. The best known and currently used techniques are as follows:

- pressure-based methods: hydraulic peak pumps, compressed air,
- mechanical methods: springs, kinetic solutions, flywheels,
- thermal methods: heat and cold storage tanks,
- electrochemical methods: lead-acid batteries, lithium-ion batteries, flow batteries, and more,
- electrical methods: capacitors, supercapacitors, superconducting coils,

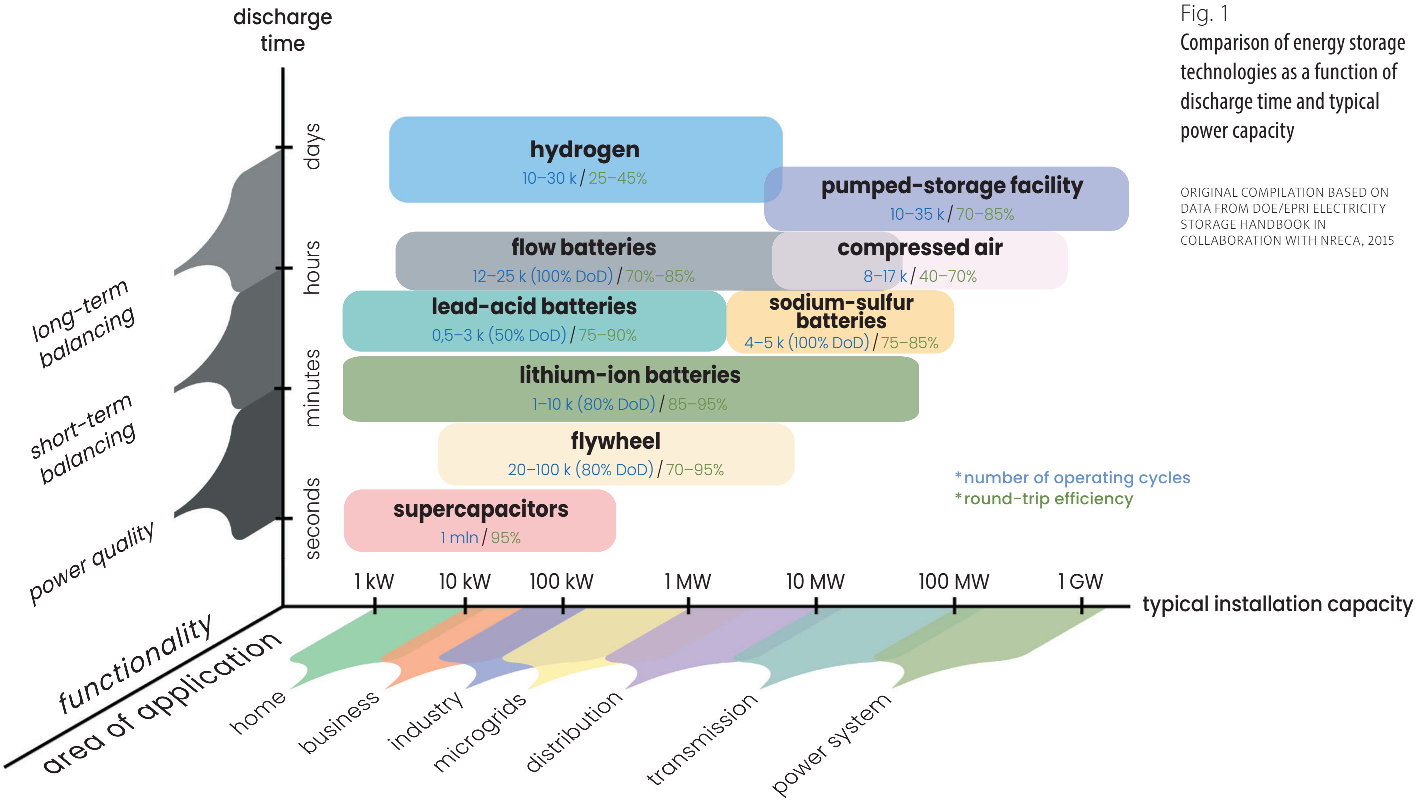


Fig. 1
Comparison of energy storage technologies as a function of discharge time and typical power capacity

ORIGINAL COMPILATION BASED ON DATA FROM DOE/EPRI ELECTRICITY STORAGE HANDBOOK IN COLLABORATION WITH NRECA, 2015

- chemical methods: hydrogen, synthetic fuels, biofuels, and more.

Each of the technologies listed differs significantly, with the most significant performance parameters being:

- available power and overload capacity,
- usable capacity (stored energy),
- round-trip efficiency of the system charge/discharge cycle,
- calendar lifespan and achievable number of operating cycles,
- initial cost (CAPEX) and maintenance cost (OPEX) of the system,
- energy and power density ratios, and the associated mass and building area,
- safety of operation, recyclability,
- environmental requirements, temperature, expansion possibilities.

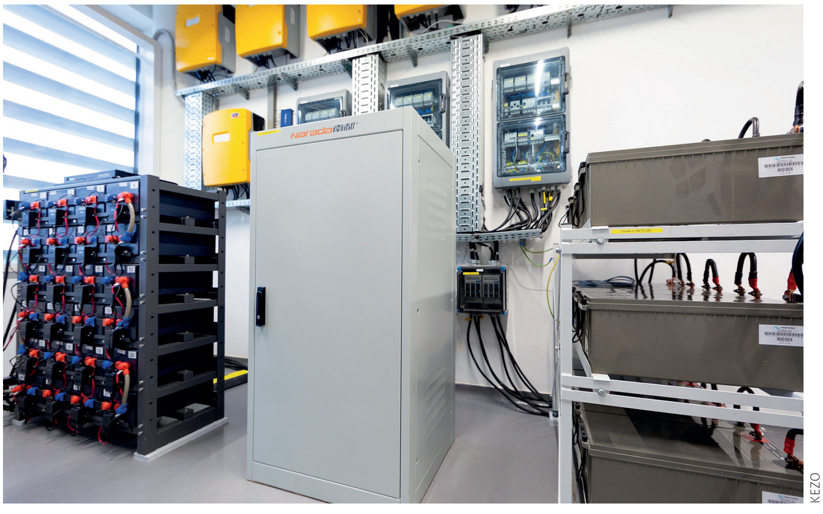
In general, energy storage methods can be classified into the following types:

- short-term: supercapacitors, superconducting coils, flywheels,
- daily: electrochemical batteries, pumped storage, compressed air, etc.,
- medium- and long-term: hydrogen, biofuels, etc.

Figure 1 compares technologies as a function of discharge time to power. Selecting the right energy storage technology ultimately depends on the user demand and operational parameters, as well as on the expected functionality. The factors to be considered at the technology selection stage include: the load profiles, the power sources and energy costs (the grid connection conditions, local energy sources), the expected availability of power and capacity, the available space and environmental conditions, the legal conditions, safety of use, financing, and many others.

In light of the above, electrochemical storage technologies – including flow storage – are gaining popularity due to their flexible configurability, i.e., independent power and energy scaling, easy energy access, and

Demonstration installation of hybrid energy storage at the Energy Conversion and Renewable Sources Research Centre (KEZO) of the Polish Academy of Sciences in Jabłonna



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relatively lower price per kWh. Therefore, the remainder of this article will mainly be devoted to this technology.

Ubiquitous batteries

Technological advancements and society's ever-greater demand for cheap and easy energy storage, especially for electric power, have led a very large number of battery technologies to be brought to market in recent years. Energy storage technology using electrochemical batteries is typically chosen because of advantages such as:

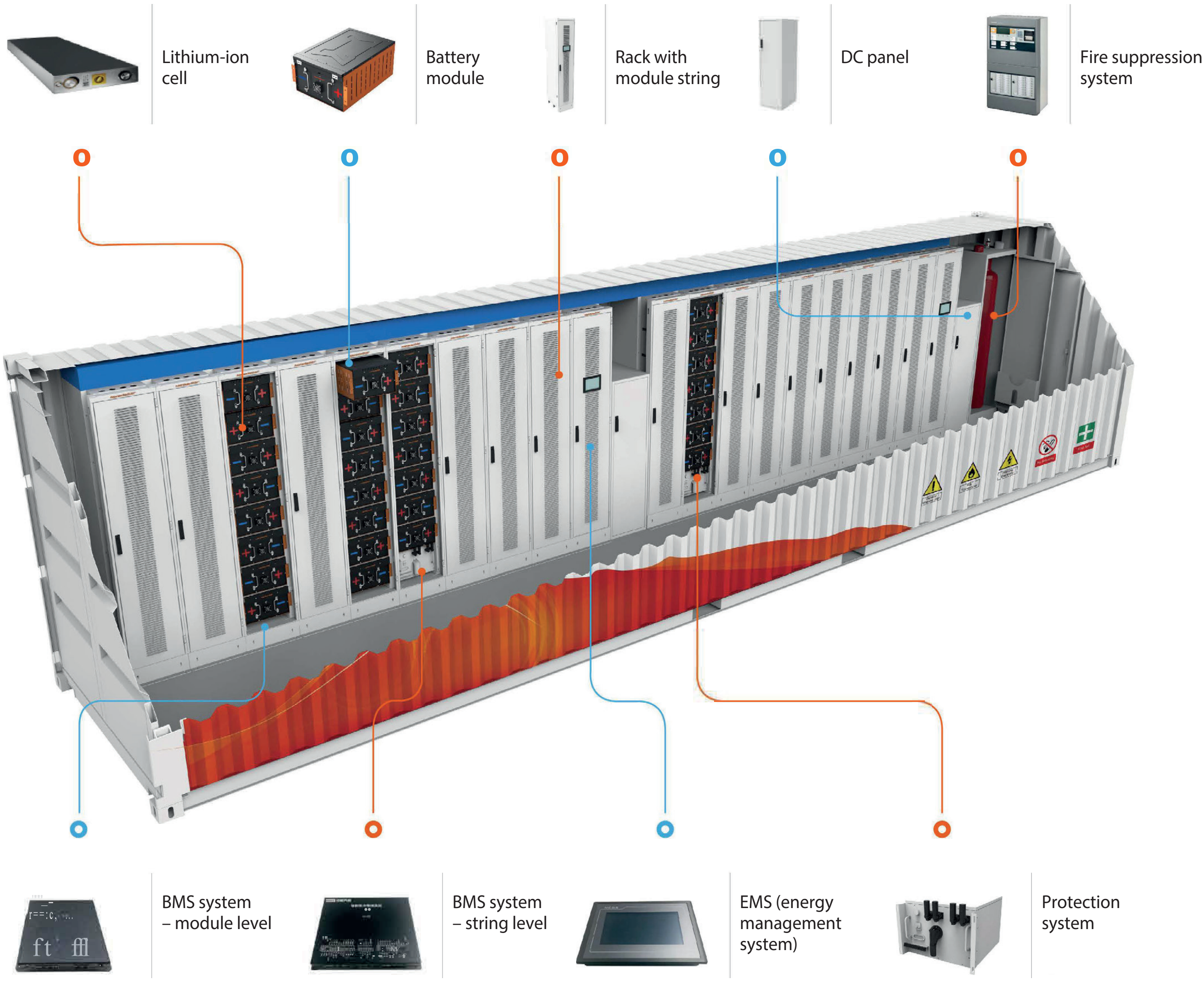
- energy conversion by means of the same technology (electrochemistry),
- universal, "convenient" voltage characteristics,
- market availability,
- acceptable dimensions and flexibility of installation (standard shipping-container solutions),
- declining costs,
- maturity of the technology (presence in the market).

Guided by the criterion of technology maturity, commercial availability, and existing large-scale installations, the following technologies are typically applied:

- lithium nickel manganese cobalt oxide (NMC),
- lithium iron phosphate (LFP),
- lithium titanate oxide (LTO),
- vanadium redox flow battery (VRFB),
- lead acid battery (LAB).

Each of these groups is distinguished from the others by certain specific characteristics that make it most suitable for installations of a particular type (and in addition to those listed, many other promising technologies are currently under development in laboratories around the world). Lithium technologies, for

Group	Type	Advantages	Disadvantages
Lithium-ion	NMC	• mature technology • multiple companies manufacturing cells and integrating complete energy storage systems • very high energy density	• technology considered dangerous (requires special attention in terms of explosion and fire safety) • relatively high price • availability restrictions due to a market priority (whereby electromobility comes first) • costly recycling • medium number of operating cycles
Lithium-iron -phosphate	LFP	• safe • relatively the cheapest option from the lithium group	• costly recycling • depth-of-discharge regime required to maintain warranty • high operating cost for high cycle applications (>1 cycle per day) due to cost of replacing used batteries • degradation • medium number of operating cycles
Lithium- -titanium	LTO	• long service life due to number of cycles • large discharge depth range • safe • high efficiency (not including auxiliary systems)	• relatively high price • limited functionality due to price • costly recycling
Acid lead	LAB	• very mature, widely available • relatively cheap, offering low CAPEX • mature recycling technology	• very high operating costs (OPEX) due to a very low number of cycles (frequent replacement of used batteries) • severely limited functionality due to rapid degradation at deep discharge
Flow	VRFB	• very low operating cost • safe: non-explosive, non-flammable • negligible degradation • unlimited number of cycles • longevity • scalability (power independent of capacity) • negligible self-discharge (i.e. a charged battery left for a longer period of time will not lose its charge) • 100% recyclable	• few references, given the novelty of the technology • requires more installation space due to relatively low energy density • low currents for charging and discharging (i.e. low ratio of power to storage capacity) limit the choice of functionality



COURTESY OF NARADA POWER SOURCE CO., LTD.

Cross-section of a lithium-ion energy storage facility

instance, are ideally suited for systems requiring high instantaneous output and fast response. A good example can be found in the plant in Cremzow, Germany, with power of 22 MW and a capacity of 35 MWh. It is mainly used for frequency regulation of the grid, providing services to the so-called primary regulation market.

Different roles in the system are played by long-duration technologies, such as flow batteries. One example is a 260 kW, 2.2 MWh installation in the South Korean city of Jeonju. Located at a paper mill, it is used for arbitrage: at night it is charged with cheap off-peak energy, then during the day it powers the paper machines. Additional incentive programs launched in South Korea reward such flattening out of the daily load curve, turning energy storage an additional source of revenue.

Hybrid, meaning what?

Clearly, energy storage systems can serve a variety of functions. It seems natural, therefore, that an investment in energy storage will be most profitable in cases where one installation has multiple functions, providing several sources of income or savings. But how to choose the right technology in such a case, so as to ensure the right versatility? The solution to this problem may involve the use of a hybrid storage method, combining two or more storage technologies in a single installation. In principle, these should be technologies with complementary properties, e.g. one with high instantaneous power plus another with long retention time.

One such installation was launched in 2020 at the Bystra wind farm in Poland (in the municipality of Pruszcz Gdański): a hybrid energy storage facility combining 1 MW lithium-ion batteries with 5 MW lead-acid batteries. The facility is used to stabilize wind energy production and to support the local transmission grid. In this case, the technologies used, including the control and conversion system, were supplied by the Japanese.

Independent work on developing hybrid energy storage methods is being carried out by a team at the PAS Institute of Fluid-Flow Machinery. At the Energy Conversion and Renewable Resources Research Centre (KEZO) in Jabłonna near Warsaw, a demonstration installation of a hybrid energy storage system has been in operation since 2018. The system has a total power of 60 kW and a capacity of 180 kWh. It employs four battery technologies:

- vanadium redox flow – 12 kW/100 kWh,
- lithium iron phosphate – 24 kW/24 kWh,
- lead carbon– 12 kW/24 kWh,
- lead acid – 12 kW/32 kWh.

This hybrid energy storage facility supports the research center's internal microgrid by balancing its photovoltaic and wind power generation and the power consumption by its offices, laboratories, electric vehicle charging and heat pump (among other things). Another topic of research is battery technologies operating under operational conditions. The research team's goal is to develop a methodology for selecting a hybrid storage configuration that will provide maximum investor benefits for a given mode of operation while ensuring a long service life of the component batteries.

> It will be impossible to meet the ambitious climate goals without large-scale deployment of such energy storage systems.

Energy management

The ongoing development of distributed, predominantly renewable energy sources and energy storage systems is changing the traditional energy flow in power systems. In many cases, energy storage is a key enabler for establishing an energy cluster, microgrid, or local balancing area. These terms are often used interchangeably for logically separate sections of a power system, ensuring maximal energy self-sufficiency. Their efficient operation depends not only on the existence of sources and storage, but also on the use of appropriate control methods.

In all energy microgrids, Energy Management Systems (EMS) are a key layer. An EMS primarily provides capabilities for monitoring and controlling energy resources. In addition to the obvious function of managing the charging and discharging of energy storage systems, it can also provide the ability to manage controllable loads, curtail the power generated by renewables if it becomes excessive, maintain optimal operating conditions for combustion-based sources, or use these techniques to ensure island-mode operation (functioning autonomously, without connection to the power system).

The issue of energy storage management becomes more complicated in case of hybrid energy storage, where the charging and discharging processes must be individually tailored to the distinctive characteristics of each battery in the system. A solution for this issue is being developed by the KEZO team under the framework of the HyStore project ("Hybrid Energy Storage Management System"). Its stated objective is to develop an EMS system specially tailored for hybrid energy storage.

Energy storage comes to Poland

Looking at the experience of other countries, we can conclude that the large-scale integration of energy storage capacities represents the second wave of the energy transition, right after the rise of renewable sources.

Among technologies available today, lithium-ion batteries are attracting the most public attention. At present there are also many other technologies ready for large-scale deployment, such as flow batteries. It seems that the only obstacle to their development is the lack of positive examples of large-scale installations (i.e. with a capacity above 100 MWh). The story is similar for hybrid installations – despite their undoubted advantages, properly selecting, integrating, and operating them is more complex, and that fact may discourage investors.

Of course, the cost of creating an energy storage facility is also an important factor. Currently, batteries are mainly installed in places where grid stability is threatened, and they can also successfully take the place of costly investments to expand the grid and generation infrastructure. In some European countries where the market for system services has been deregulated, battery storage facilities are successfully earning money from frequency regulation. Battery costs are coming down to what is considered a watershed boundary of $100 per kWh, which will open up many business models – involving, for instance, price arbitrage or the creation of hybrid sources harnessing renewables, featuring a high rate of energy availability.

In Poland, legislation dealing with energy storage remains underdeveloped and does not offer attractive business models for investors. However, the first pilot projects related to energy storage installation are being undertaken. These include a project by the operator Energa in the seaside town of Puck, demonstrating the potential of local energy balancing by means of storage facilities, and a storage facility by the grid operator PGE in Rzepedź (Podkarpacie region) designed to support the distribution system. In the coming years, energy storage may become a source of interesting innovations and many new jobs in Poland.

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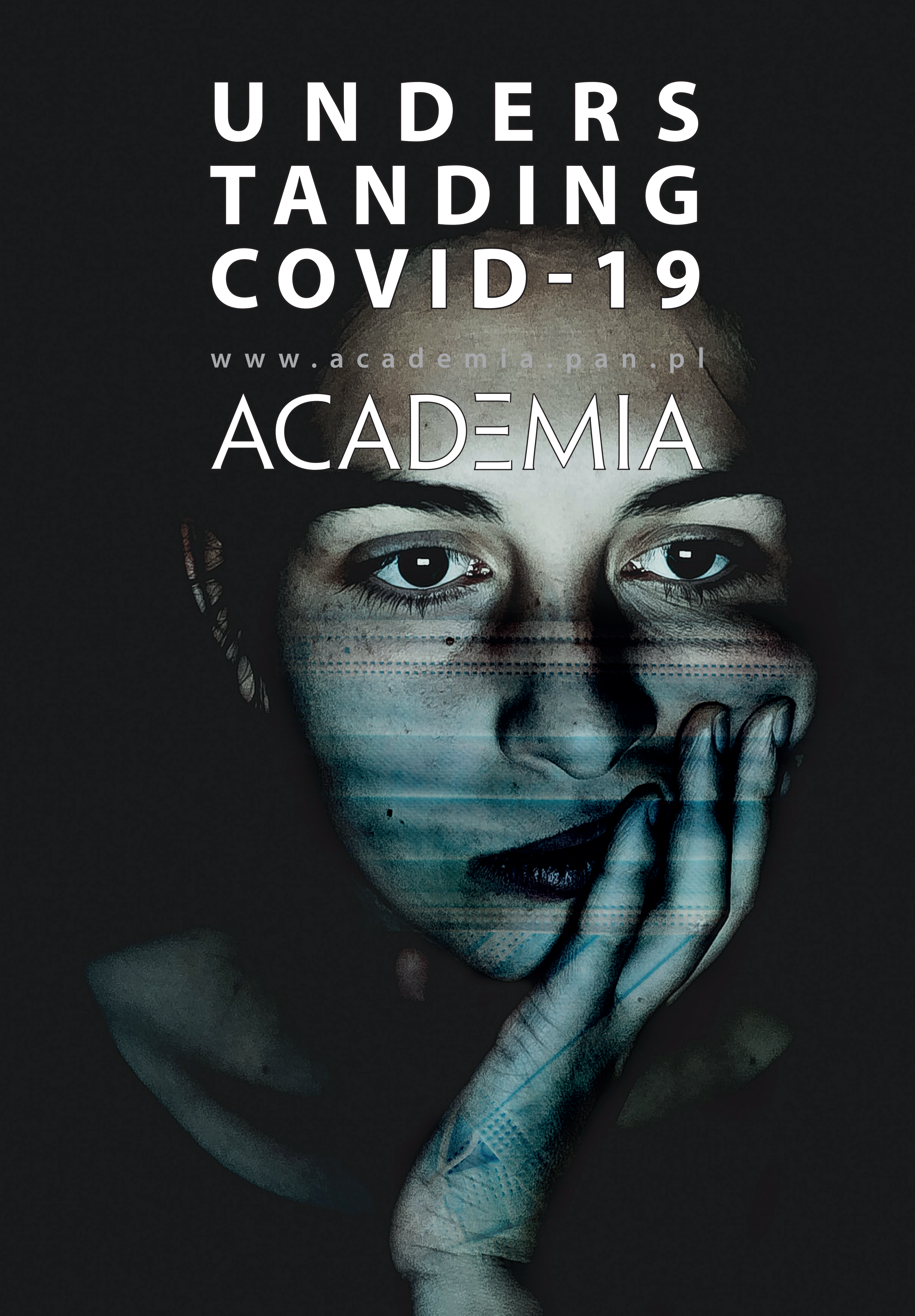
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