Energy Storage Systems: What to Expect?

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Unlike conventional energy, some renewable energy sources like solar and wind are not continuously available. On windy days, a wind farm may generate an excess of electricity that cannot be added to the grid, while on quieter days there may be too little energy generated. In order to make renewable energy sustainable, there is a need to store energy generated during low-demand times so that it is available during high-peak times. Energy storage is also critical for energy management.

New energy storage systems (ESS) are being developed and deployed around the world as the usage of renewable energy increases globally. It is currently expected that by 2030, the total usage of ESS will have increased by 600% from what they are now.

Types of Energy Storage Systems

A number of different energy storage systems are currently deployed at this time. In addition to systems currently in use, there are also new technologies being tested. We can look forward to the development and usage of cryogenic energy storage, superconducting magnetic energy storage (SMES), supercapacitors, and hydrogen storage within the next few years, along with other early-stage technologies that are currently still in the earliest phases of development.

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The following energy storage systems are designed to be available to provide this additional energy:

Pumped Hydroelectric Storage (PHS)

PHS pumps water from a low ground to a higher reservoir. When electricity is needed, water is released through a hydroelectric turbine which generates electric energy from kinetic energy. PHS plants have a lifetime of about 50-60 years and operational efficiencies between 70-80%. In the USA, 96% of energy storage comes from PHS.

Compressed Air Energy Storage (CAES)

Compressed air is stored in an underground cavern. When electricity is needed, the pressurised air is heated and expanded in a natural gas combustion turbine, which drives the generator.

At this time, CAES plants are based on the diabatic method, where the compression of the combustion air is separate from the gas turbine. The diabatic method generates three times the output for every natural gas input, reducing CO_2 emissions by 40-60% and enabling the plant efficiencies of 42-55%.

Flywheel Energy Storage (FES)

Mainly used for power management rather than a solution for longer-term energy storage, FES systems store kinetic energy by spinning a rotor in a frictionless enclosure. Flywheels account for 0.058 GW of rated power in the USA, with efficiencies between 85-87%.

Figure 1: A TES at a CSP in North Africa – CEERISK 2019

Thermal Energy Storage Systems (TES)

Thermal energy can be stored in TES units to be used when more electricity is needed in the grid during peak times. One example is used in CSP (Concentrated Solar Power) plants, where the heat from the sun is harvested by molten salt and stored in large insulated tanks. At a later time, such as in the evening, this heat can be used to generate electricity even after there is no longer any direct sunlight.

New technology continues to develop, increasing the efficiency, capacity, performance and liability of different ESS.

Battery Energy Storage Systems

Batter Energy Storage Systems (BESS) are often located near or within substations. The battery connects to the system operation as well as to power electronics that monitors the quality of the energy and to detect any potential problems or malfunctions before they develop in catastrophic losses.

There are multiple types of batteries deployed to different substations depending on the environmental exposures and other considerations.

Some types of batteries include:

Lead acid batteries, the oldest type of rechargeable batteries. Lead acid batteries are rugged and forgiving. Compared to other batteries, they can take certain abuse and exposures and do not require additional internal safety measures. Lead acid batteries are used in car batteries and in uninterrupted power supplies (UPS).

A drawback of lead acid batteries is that they have very low specific energy, limiting the amount of energy that can be contained within them.

Nickel-based batteries are well-understood batteries commonly used in situations where long service life, high discharge currents, and extreme temperature tolerance is required, such as in medical devices, power tools and industrial applications.

Other types of nickel-based batteries include nickel cadmium (“NiCd”) which are the most enduring type of batteries, with a chemistry that allows for ultra-fast charging that results in minimal stress.

Flow batteries are accumulators that store electrical energy in two chemical liquid components. They are typically easy to scale up to a size required to store energy on a large scale, and due to this are typically used on a large scale.

These batteries can be made of zinc bromide and sodium sulphur. Due to their size and high possible capacity, flow batteries are well-suited for large scale energy storage.

Lithium-ion batteries have recently begun to be used in applications where lead acid and nickel-based batteries used to be used.

Lithium-ion batteries require special handling and protection circuits. They are more expensive than other types of batteries, but with a high cycle count[1] and less maintenance required, the cost per cycle is overall better compared to other batteries.

Safety of Lithium-Ion Batteries

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Although in recent years a number of cases of lithium-ion batteries exploding in mobile phones, lithium-ion batteries are considered to be generally safe. Considering the extent of the market for batteries of this kind, the number of fires and explosions is comparatively small.

Unfortunately, the possibility of fire and explosion always presents a potential loss of life or serious personal injury, in addition to collateral material damage or costs that could arise from a claim, especially when looking at lithium-ion batteries required for energy storage.

Past Losses

We have already seen losses that involve lithium-ion batteries stored in energy storage systems:

- **August 2012:** A fire broke out in the battery room at Kahuku Wind Energy Storage Farm in Hawaii, a 12-turbine, 30-megawatt wind farm.
- **August 2017:** A fire at a wind farm in Gochan County, Jeollabuk-do, South Korea resulted in the loss of the majority of the site, which subsequently made the investigation of the root cause more difficult.
- **April 2019:** Following reports of smoke at McMicken Energy Storage Project in Arizona, USA, the site experienced a catastrophic failure when the door to the battery room was opened. A single rack of modules was compromised by the initiating thermal event, although the fire did not spread to surrounding racks. The compromised modules emitted a mixture of explosive gases, which built up in the container.

Thermal Runaway Events

One of the most catastrophic failures in a lithium-ion battery system is a cascading thermal runaway event. Following the failure of a single individual cell, adjoining cells in the battery then fail due to exposure to excessive temperatures.

Figure 2: Thermal runaway destroys battery racks at a data centre used by a mobile phone operator in DRC - CEERISK 2017

The initial causes of thermal runaway can be either external (such as over-heating, over-charging, over-discharging, high current charging, structural damage, crush or external shorts) or internal events or exothermic reactions (electrode-electrolyte reactions, decompositions, electromechanical reactions).

If the heating rate exceeds the dissipation rate, the result will be a thermal runaway event where the failure of one battery cell leads to the failure of others. In such an event, toxic and flammable gasses will also be vented, and a significant energy in the form of heat is released. If ignited, these gases can

[1] How many times a battery can be charged and depleted.

cause enclosed areas to over-pressurise, which may result in an explosion and severe damage to the battery and surrounding equipment.

When an explosion occurs in a large battery pack, the subsequent explosion can be even more severe, as heat generated by one cell can result in the adjacent neighbouring cells heating up, leading to a thermal cascade throughout the battery.

Battery fires are difficult to control and intense, as in addition to the immediate fire and electricity risks, firefighters also might potentially be exposed to toxic fumes, hazardous materials and building decontamination issues. Different types of batteries react differently during a fire, so when trying to control a fire the firefighters must be aware of what they are dealing with in order to effectively control it.

Inherent Risks

Certain risks will always be present regardless of the monitoring, testing and control in place. Lithium-ion batteries are sensitive to "abuse factors," which can be qualified as one of three types:

- Electrical abuse, which includes overcharging, over-discharging and short-circuiting
- Thermal abuse, which includes overheating, external heating high temperature storage, and inadequate cooling
- Mechanical storage, which include the puncture of the cell, compressive stress and electrolyte expansion beyond the mechanical strength of the packaging
- Manufacturing defects, which are a risk present in all industrial situations.

These inherent risks can lead to certain failures, including separator tearing, electrolyte breakdown and electrode damage.

Lithium-ion batteries are particularly sensitive to mechanical damage and electrical damage compared to other, conventional batteries. Internal battery short circuits can lead to internal battery heating, battery explosions and fires in an individual battery, which can then cascade to nearby batteries. Depending on the size of the battery affected, the resulting fire will vary in size: what could be a dangerous inconvenience when the lithium-ion batteries in a phone will be far more catastrophic when it occurs on a large-scale battery farm.

Over the years, CEERISK engineers have been instructed to investigate a number of battery fires and explosions including a fire at a data centre for a mobile phone provider in the Democratic Republic of Congo and a TV satellite link site for a TV station in Florida, USA. In addition, CEERISK experts investigated other energy systems used at renewable energy power plants including a fire and explosion at a VAR compensator at a PV plant in Jordan, a leak at a salt tank at a CSP in Morocco and a fire and explosion of capacitor banks in a filter at a wind farm in Ireland.

For more information on the topic or to discuss investigation of a battery system failure, including catastrophic fire, please contact Mamoon Alyah at +44 7495 737 005 or by email at mamoon.alyah@ceerisk.com.

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