New Trends in Technology

Understanding Energy Storage Systems

Introduction

Electricity in its original form cannot be stored on any scale, but with the use of an Energy Storage System (ESS) it can be converted to other forms of energy which can be stored. These forms of energy can later be reconverted to electricity when needed.

An ESS provides a wide array of technological approaches to managing our power supply in an effort to create a more resilient energy infrastructure and bring cost savings to both utilities and consumers. Current electricity storage system technologies include batteries, flywheels, compressed air, pumped hydro storage, and others. Today all of these systems are still limited in the total amount of energy they can store, but research continues to improve these technologies at a rapid pace.

The US electric power grid is based on a delicate balance between the electricity supply generated and consumer demands. An effective way to help balance fluctuations in electricity supply and demand is to store electricity during periods of high production and low demand, then release it back to the electric power grid during periods of lower production or higher demand.

In this issue we will talk about how electricity storage will provide reliability, economic, and environmental benefits to us all. Depending on the extent to which it is deployed, electricity storage could help the US power grid operate more efficiently, reduce the likelihood of brownouts during peak demand, and allow for more renewable resources to be used.

Growing need for electricity storage

Since electricity was discovered, many researchers and scientists have sought effective methods to store energy for use on demand. Over the last 100 years, the energy storage industry has continued to evolve and innovate in response to changing electricity requirements and advances in technology.

Today, consumers in the US are using electricity 24 hours a day. Whether we're awake or asleep our need for electricity is continuous. US consumers tend to take for granted how easy it is to obtain the energy required to power devices, appliances, tools, machines, vehicles, and all the things we use throughout the day and night.

Now the rapid acceptance of electric vehicles is putting even more pressure on the power grid to handle a larger demand for electricity. In addition, the technological advancement and growth of the renewable energy markets — like solar, wind and others — has been a massive driving factor in the need for energy storage given the substantial impact on the grid.

Energy storage technologies

A major trait of the electric power sector is that the level of electricity that can be generated is somewhat fixed over short periods of time. Conversely, demand for electricity fluctuates throughout the day. Developing technologies to store electrical energy so it can be available to meet demand whenever needed represents a major change in the way electricity is distributed.

Energy storage systems

Energy storage systems (ESS) are designed to manage the level of power required to supply customers at peak times when the need is greatest — and, ultimately, will help make the use of renewable energy smoother and easier to inject into the distribution system.

ESS will also help balance microgrids to achieve a stable balance between generation and load. Energy storage systems can provide frequency regulation — maintaining the frequency at 60 Hz throughout the system which is critically important. This sustains the balance between the network's load and the power generated. Additionally, the deployment of an ESS can also achieve a more reliable power supply for high tech industrial facilities. Energy storage and power electronics hold encouraging promise for transforming the electric power industry.

High voltage power electronics

High voltage power electronics like switches, controllers and inverters, allow electric power to be controlled rapidly and precisely to support long distance transmission. These high voltage devices will allow the system to operate more efficiently and respond effectively to disturbances quicker. Another major challenge being addressed is to reduce the cost of energy storage technology and power electronics as an effort to achieve faster market acceptance.

DOE Energy Storage Program

An Energy Storage (ESP) Program developed by the US Department of Energy, Office of Electricity (OE) performs research and development on a wide variety of energy storage technologies. This broad technology base includes batteries (both conventional and advanced), electrochemical capacitors, flywheels, power electronics, control systems, and software tools for storage optimization and sizing. The ESP works closely with industry partners — and many of its projects are highly cost-shared.

The ESP offers the opportunity for utilities and State energy departments to collaborate on the design, procurement, installation and commission of major pioneering storage installations that are up to several megawatts in size. It also supports analytical studies on the technical and economic performance of storage technologies, as well as technical evaluations of both energy storage systems components and operating systems.

Enhanced energy storage can provide multiple benefits to the power industry and its residential customers, as well as to industrial manufacturing companies and commercial businesses. These benefits will include improved power quality and the reliable delivery of electricity to customers — and it will provide improved stability and reliability of transmission and distribution systems.

The ESP encourages utilities to retrofit existing equipment to defer or eliminate costly upgrades—improving availability and increasing market value of distributed generation sources. The ESP offers utilities and providers improved value of renewable energy generation and cost reductions through higher capacity, plus transmission payment deferral.

The ESP also strives to improve energy storage density by conducting research into advanced electrolytes for flow batteries, development of low temperature Na batteries, as well as nano-structured electrodes with improved electrochemical properties.

In power electronics, research into new high voltage, high-power, high-frequency, wide-band-gap materials such as silicon-carbide and gallium-nitride is advancing. In addition, research into advanced power conversion systems that use advanced magnetics, high voltage capacitors, packaging and advanced controls to significantly increase power density and performance is ongoing.

Energy Earthshots Initiative

Energy Earthshots Initiative, another program developed by the US Department of Energy, aims to accelerate breakthroughs of more abundant, affordable and reliable clean energy solutions within the decade. Fulfilling the Energy Earthshots Initiative will help America tackle the toughest remaining barriers to addressing the climate crisis, growing the clean energy economy and more quickly reach the goal of net-zero carbon emissions by 2050.

DOE – Long Duration Storage Energy Earthshots

The Long Duration Storage Energy Earthshots (LDSEE) establishes a target to reduce the cost of grid-scale energy storage by 90% for systems that deliver 10+ hours of duration within the decade. Energy storage has the potential to accelerate full decarbonization of the electric grid.

Shorter duration storage is currently being installed to support today's level of renewable energy generation. Longer duration storage technologies are needed as more renewables are deployed on the grid. Cheaper and more efficient storage will make it more feasible to capture and store renewable clean energy for use when energy generation is unavailable or lower than demand.

As an example, renewable sources generated during the daytime like solar-generated power can be used at night or nuclear energy generated during times of low demand can be used when demand increases. LDSS will consider all types of technologies — electrochemical, mechanical, thermal, chemical carriers or any combination that has the potential to meet the necessary duration and cost targets for grid flexibility.

Stakeholder engagement

The DOE has implemented plans to hold a series of events to engage communities, industries and other stakeholders, including a LDSS Summit that was held on World Energy Storage Day 2021. Check for upcoming events on the Energy Storage Grand Challenge website at energy.gov/energy-storage-grand-challenge.

Funding

Several DOE offices conduct energy storage activities and the President's Fiscal Year 2022 Budget Request included a total of $1.16 billion for these activities, tracked through the Energy Storage Grand Challenge crosscut. Pending appropriations, the DOE anticipates funding opportunities and other activities to help advance progress toward meeting LDSS goals, which align with DOE's Energy Storage Grand Challenge Roadmap.

Reaching the goal of net-zero carbon emissions

The Long Duration Storage Shot (LDSS) target is a key to reaching the goal of net-zero carbon emissions from the electricity grid by 2035 — and economy-wide by 2050. Energy storage can increase local control of the power system and build resilience for communities who experience frequent power disruptions or may not have access to the grid. Developing the technology and manufacturing to reach the LDSS cost targets will also establish a new US-based manufacturing industry for storage products.

Due to the rapidly falling costs of solar and wind power technologies, the increasing shares of variable renewable energy will become the standard in the future. And the efforts to decarbonize the transport sector are being accelerated by the use of electric vehicles.

The need to accommodate variable energy supply while providing undisrupted output in the electricity sector is an achievable goal. Efforts to integrate renewables — like solar, wind and other renewable resources — into the end-use sectors, has shown the significant potential, as well as crucial importance of electricity storage to making deep decarbonization a reality.

Electricity storage that is based on rapidly improving batteries and other technologies will permit greater system flexibility, a key asset as the share of variable renewables continues to increase. Electricity storage can make possible a transport sector dominated by electric vehicles, enable effective 24-hour off-grid solar home systems, and support 100% renewable mini-grids.

International predictions

The International Renewable Energy Agency (IRENA) has analyzed the current costs and performance of a range of electricity storage technologies in stationary applications, as well as the cost reduction and performance improvement potential to 2030 in the report "Electricity Storage and Renewables: Costs and Markets to 2030."

The report concluded that total electricity storage capacity could triple in energy terms by 2030. In tandem with rapid adoption of renewable energy, that should be sufficient enough to double the share of renewables in the global energy mix in less than a decade and a half. Battery electricity storage could grow by 17-fold and the costs of battery storage technologies could fall by up to 66%.

This study shows that battery electricity storage systems offer enormous deployment and cost reduction potential. By 2030, total installation costs could fall between 50% and 60% and battery cell costs by even more. This is all driven by optimization of manufacturing facilities, combined with better combinations and reduced use of materials.

Energy storage systems technology

Energy storage systems (ESS) provide a wide array of technological approaches to managing our power supply in order to create a more resilient energy infrastructure and bring cost savings to utilities and consumers. The following discusses the diverse approaches currently being deployed around the world.

Battery storage

Since Alessandro Volta invented the first battery in 1800, scientists and researchers have created our understanding of how electricity works. On its most basic level, a battery is a device consisting of one or more electrochemical cells. Within those cells, chemical reactions take place, creating a flow of electrons in a circuit. This flow activity of electrons provides the electric current required. This includes advanced chemistry batteries, flow batteries, and capacitors that convert stored chemical energy into electrical energy.

Types of batteries

Every type of battery has a positive side (cathode), a negative side (anode), and a type of electrolyte that chemically reacts with them. This process is common to all batteries, but different types of batteries store energy differently. The most common types of rechargeable batteries available for our use today are lithium-ion and lead-acid batteries.

Lead-acid batteries

Lead-acid batteries have been around for over 170 years — the oldest rechargeable batteries in existence. Every 12-volt lead-acid battery contains six cells — each with a positive terminal, a negative terminal, and a mixture of sulfuric acid and water. The chemical reaction causes the sulfuric acid to break down into the water stored inside each cell for the purpose of diluting the acid. During the use of power, the acid depletes in the battery. When the battery is generating power, it is discharging as it does so.

To charge up the battery, the process reverses and the battery's recharging restores the acid molecules. In short, that process is the storing of energy. Then, the energy stored in the acid is converted to electricity for use. While there are many different types of lead-acid batteries, they all use the same chemical energy storage process.

Lithium-ion batteries

As mentioned, all batteries have a cathode and an anode. In the case of lithium-ion batteries, the cathodes and anodes are capable of storing lithium ions. Energy is stored and released when lithium ions move from the cathode to the anode through the electrolyte. Unlike all lead-acid batteries that use the same chemical reaction, lithium-ion batteries come in many different chemistries.

A few of the most common types of lithium batteries are:

- **Lithium Cobalt Oxide (LiCoO2):** Known as LCO and commonly used in phones and computers.
- **Lithium Manganese Oxide (LiMn2O4):** Known as LMO and commonly used in power tools.
- **Lithium Nickel Manganese Cobalt Oxide (LiNiMnCoO2):** Known as NMC and used in Tesla electric cars.
- **Lithium Nickel Cobalt Aluminum Oxide (LiNiCoAlO2):** Known as NCA and used in Tesla electric cars.
- **Lithium Titanate (Li2TiO3):** Known as LTO and used in power tools and specialty applications.
- **Lithium Iron Phosphate (LiFePO4):** Known as LFP or "Life Po" batteries.

Sodium-sulfur (NaS) batteries

Sodium-sulfur (NaS) batteries have been used for 25 years and are well established, though expensive. The sodium-sulfur NaS battery, along with the related lithium-sulfur battery, employs cheap and abundant electrode materials. It was the first alkali-metal commercial battery and used liquid sulfur for the positive electrode and a ceramic tube of beta-alumina solid electrolyte (BASE).

Super capacitors

Capacitors store electrical energy on two metal plates separated by a semiconductor and they restore it at the moment of discharge. Super capacitors are very large and are used for energy storage undergoing frequent charge and discharge cycles at high current and short duration. They have evolved and have crossed into battery technology by using special electrodes and electrolyte. Super capacitors can charge and discharge very rapidly, which is advantageous when charging an electric vehicle.

Redox flow cell batteries

Redox flow cell (RFB) batteries, developed in the 1970s, have two liquid electrolytes separated by a membrane to give positive and negative half-cells, each with an electrode, usually carbon. They are charged and discharged by a reversible reduction oxidation reaction across the membrane. During the charging process, ions are oxidized at the positive electrode (electron release) and reduced at the negative electrode (electron uptake). This means that the electrons move from the active material (electrolyte) of the positive electrode to the active material of the negative electrode. When discharging, the process reverses, and energy is released.

Thermal storage

Thermal storage systems use heating and cooling methods to store and release energy. For example, molten salt stores solar-generated heat for use when there is no sunlight. Ice storage in buildings reduces the need to run compressors while providing air conditioning over several hours. Other systems use chilled water and dispatchable hot water heaters. In all cases, excess energy charges the storage system (heat the molten salts, freeze the water, etc.) and is later released as needed.

Mechanical storage

Mechanical storage systems are arguably the simplest, drawing on the kinetic forces of rotation or gravitation to store energy. The main options are energy storage with flywheels and compressed air systems.

Electricity accelerates a flywheel through which the energy is conserved as kinetic rotational energy. When the energy is needed, the spinning force of the flywheel is used to turn a generator. Some flywheels can attain rotational speeds up to 60,000 revolutions per minute. Electricity is used to compress air at up to 1,000 pounds per square inch and store it, often in underground caverns. When electricity demand is high, the pressurized air is released to generate electricity through an expansion turbine generator.

Pumped hydropower storage

Pumped hydropower storage is a type of hydroelectric energy storage. It is a configuration of two water reservoirs at different elevations that can generate power. As water moves down from one to the other, it passes through a turbine. Then the system requires power as it pumps water back into the upper reservoir or recharges. Pumped hydro systems, based on large water reservoirs, have been widely implemented to become the most common form of utility-scale storage.

Hydrogen storage

Electricity is converted into hydrogen by electrolysis. The hydrogen is then stored and eventually re-electrified, but the round-trip efficiency today is lower than other storage technologies. The interest in hydrogen energy storage is growing due to the much higher storage capacity when compared to batteries or pumped hydro and compressed air energy storage (CAES).

Gravitational energy potential

Gravitational energy is the potential energy a massive object has in relation to another massive object due to gravity. It is the potential energy associated with the gravitational field, which is released or converted into kinetic energy, when the objects fall towards each other. Potential energy increases when two objects are brought further apart.

What is next?

Even with the onslaught of new technologies, ESS still has many hurdles to clear to reach the level of stored energy that will be needed in the future. The continuing discovery of new approaches to managing our power supply is creating a more resilient and efficient energy infrastructure that will bring cost savings to utilities and consumers. The rapidly falling costs of solar power, wind power and other renewable resources will play a leading role in generating the electricity necessary for our ever-increasing needs.

Energy storage control products

As the grid changes and improves, energy storage systems will experience a greater need for electrical control at all levels — residential, commercial/industrial and inverter/battery. Low voltage electrical controls, both alternating current (AC) and direct current (DC), are critical for effective energy storage systems. These products include, but are not limited to the following:

- **Miniature Circuit Breakers (MCBs)** protect against overloads or short circuits.
- **Residual Current Circuit Breakers** protect against severe weather conditions.
- **Molded Case Circuit Breakers** protect against extremely excessive currents.
- **Disconnect Switches** offer a disconnecting method required to meet installation standards.
- **Surge Protective Devices** protect sensitive components from surges caused by lightning and over voltages.
- **Contactors** offer a way to switch a system on or off.
- **Energy Meters** offer a measurement of energy consumed and stored for informed decision making.
- **Terminal Blocks**, **Wire Duct** and **DIN Rail** offer ease of wiring during assembly.
- **Pilot Devices** offer human machine interface for communication and interaction.
- **Fuse Holders** protect and integrate fuses safely into an electrical system.

Many of these products required for energy storage systems are available from c3controls and we are ready and able to assist manufacturers with world-class products and services needed for the production of all types of energy storage systems.

For further details on our world-class products, call us today at 724.775.7926 or [visit c3controls.com](https://c3controls.com).