# A REVIEW OF ENERGY STORAGE SYSTEMS FOR RENEWABLE ENERGY SOURCES

Shashank Rai[1] Nikita shrivas [2]

engineer.shashank.rai@gmail.com[1], Nikitashrivas1926@gmail.com[2]

[1]*Mtech scholar, Dept.of Electrical & Electronics Engineering, Technocrats Institute of Technology, Bhopal, (INDIA)*

[2,] *Mtech scholar, Dept.of Electrical & Electronics Engineering, Technocrats Institute of Technology, Bhopal, (INDIA)*

**Abstract:**

***Renewable energy sources (RES) like wind and sunlight are often subject to fluctuations, such as when wind and sunlight are inadequate. Storage Methods alleviates problems by storage of excess generated energy and making it available when needed. There are various EST studies, but the literature remains isolated and outdated. It is also easy to compare the characteristics of ESTs and their possible uses. This treatise fills this gap. Based on selected criteria, the most important ESTs are identified and an up-to-date overview of the literature on ESTs and their potential applications in the field of renewable energy is provided. The intensive study reflects the high applicability of lithium-ion batteries and is best suited to mitigate RES fluctuations in the utility grid integration sector. However, cost savings are needed to fully adopt lithium-ion batteries for RES grid integration***

**Keywords :** ***Renewable energy sources (RESs), Energy storage technologies (ESTs)***

## 1. Introduction

Today, Due to the rapid growth of renewable energy generation capacity around the world. Of the capacity generated from renewable energy sources (RES), solar and wind energy continued to dominate the renewable capacity [1]. However, the supply of energy from such sources is also decreased due to inadequate wind or sunlight fluctuations. Therefore, it is necessary to maintain power fluctuations in energy systems that are integrated with large amounts of renewable energies such as wind and solar. Energy storage is important to mitigate these increased fluctuations and power quality issues by providing voltage support, smoothing output fluctuations, balancing power flows in the grid, and matching supply and demand. It is a means. In addition, EST is a complementary network service such as frequency adjustment, energy time shift, power quality improvement, load shaving, peak shaving, facilitating RES grid integration, grid expansion, and overall cost savings and operational reserves. Provides [2-5]. In addition, with the increase in electricity or energy production from renewable energy sources, it is very important to consider Method or techniques of selecting the appropriate type of ESTs for RESs grid integration application.

Therefore, the relationship between EST and its application is interdependent. Knowing the technical characteristics of individual ESTs and the potential of their applications in RES is critical to the implementation of the technology. In addition, industry and engineering generate a variety of ESTs, but the breadth and depth of these technologies are consistently reviewed and integrated. Therefore, our main research question is what are the most important ESTs and how to assess their technical, economic and environmental suitability. This white paper addresses key issues and informs researchers, industry, and policy makers of the latest technical, economic, and environmental characteristics of EST for applications for integrating RES into utility grids provides an overview.

## 2. Energy Storage System

Storage of energy are an important part of a hybrid, self-contained renewable energy system that is essential to maintaining a high level of power quality, reliability and health. An ideal storage system will provide rapid access to power as needed, provide high-capacity power and energy, have a long life expectancy and a competitive price.

However, an ideal Storage of energy is currently not usable. As a result, it is necessary to choose the correct storage technologies for the use of hybrid energy-based renewable energy systems. The preliminary implementations of energy storage technologies for a stand-alone hybrid renewable energy system are as follows:

**2.1 Renewable balancing and smoothing of power:** Renewable sources of energyare intermittent in nature. As a consequence, power generation sometimes failsto fit the load profile or the demand cycle. Energy storage can be used to adaptthe production of renewable sources to any load profile.

**Load leveling application**: In the application of load leveling, bulk energy is stored during peak wind conditions and then discharged during low or no windconditions. As a consequence, careful management of energy storage will ensure continuous operation of the device.

**Power quality:** Utility control is often affected by disruptions, such as momentary voltage sags or even power outages. In addition to harmonic distortions and other imperfections, sensitive equipment requiring high-quality power can be affected. Energy storage systems can be used to provide stable, high-quality power for critical loads. On the basis of the demand, energy storage can be categorized as long-term and short-term. Capacity-oriented energy storage technologies, such as pumped hydroelectric systems, compressed air storage and hydrogen storage, typically do not have a quick response time and are used for long-term energy storage. On the other hand, fast-reaction storage devices such as batteries, flywheels, super-capacitors and superconductive magnetic energy storage devices (SMES) are used to respond to short-term disruptions such as fast-charging transients and problems related to power quality.Figure 1 demonstrates the average storage capacity versus discharge time of the various energy storage systems.

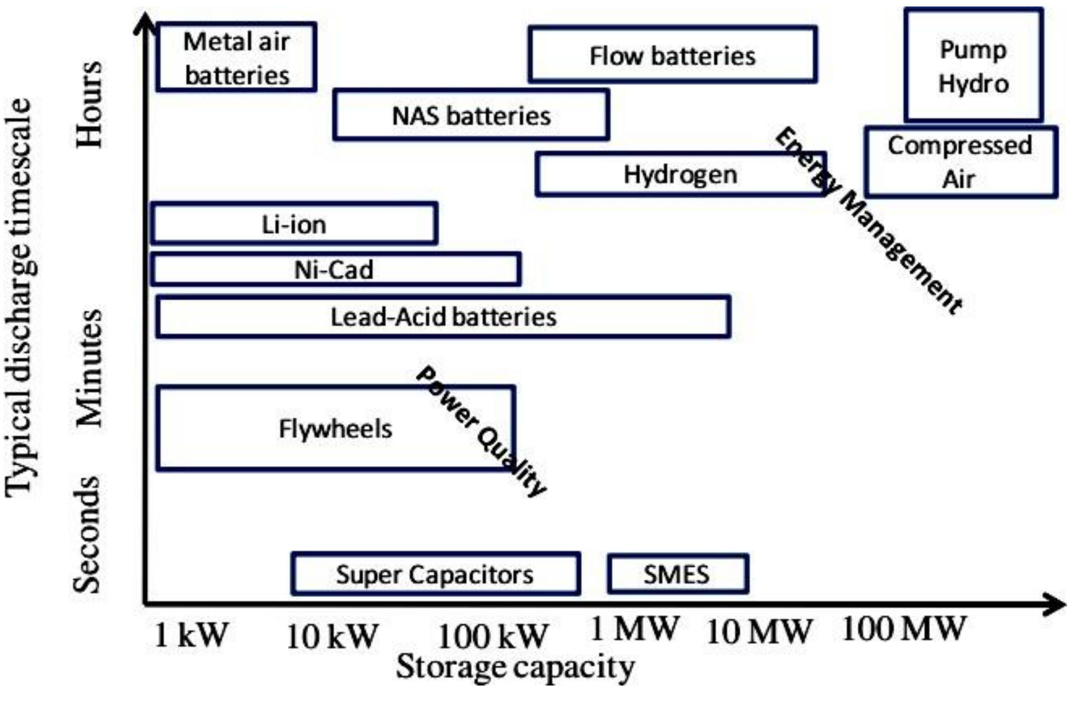


**Figure 1 Capacity versus time of discharge for various energy storage systems**

Energy storage can be electrochemical, electronic, electric, thermal or hydrogen-based.Electrochemical energy storage comprises lead-acid, lithium-ion, flow and sodium- sulfur batteries. Mechanical energy storage involves pumped hydroelectric electricity, compressed air energy and a flywheel. Electromagnetic storage systems, such assuperconducting magnetic energy storage (SMES) and thermal energy storage, may include solar thermal and thermal storage for heating, ventilation and air conditioning.Storage of hydrogen requires electrolyzers and fuel cells.Electrochemical Energy Storage

Batteries used for the storage and supply of energy from renewable energy systems must be efficient, robust and secure. Several innovative battery technologies exist for grid-connected or stand-alone renewable energy device applications, including lead- acid, lithium-ion, flow, sodium-sulfur batteries.

**2.1 Lead-Acid Batteries**: Lead-acid batteries are mature and tested technologies ina variety of applications, including frequency control, bulk energy storage forvariable energy renewable energy integration and distributed energy storagesystems. Such batteries are a viable choice due to relatively low cost, ease ofmanufacture, rapid electrochemical reaction kinetics and a strong life cycleunder controlled conditions [8]. Conventional lead acid batteries usually cross20-30 Wh / kg, with a power density of 4 kW / kg. Maintenance-free lead-acid(VRLA) batteries, also known as sealed lead-acid batteries, have increasinglyreplaced traditional high-maintenance, flooded cell batteries in a range of applications such as automotive, marine, telecommunications and uninterruptedpower supply. However, the flooded lead-acid technology is still considered thebest choice for large-scale storage system applications for grid support [9]. The life of the lead-acid batteries varies considerably depending on the application, the discharge rate and the number of deep discharge cycles. In thecase of a renewable energy-based power system, conventional lead-acidbatteries that have a limited life cycle and need substantial maintenance due touncontrollable charging and unloading of operating cycles.

**2.2 Nickel Based Batteries:** Nickel-based batteries can be developed in the form of nickel / cadmium

(NiCd) and nickel metal hydride (NiMH) systems. Portableelectronics is the primary application for Ni Cd batteries. Compared to the lead-acid battery, NiCad batteries have a longer lifetime, higher energy capacity and lower maintenance. NiMH batteries are a viable alternative to Ni Cd batteries due to improved efficiency and environmental benefits. Compared to lead-acidand NiCd batteries, NiMH does not contain harmful contaminants such as cadmium or mercury. The energy density of the NiCd cells is 25-30% higher than the Ni Cd cells, but well below the rechargeable Li-ion batteries [1].

**2.3 Lithium Ion Batteries:** Lithium is an desirable material for battery technology as it has a higher reduction capacity and a lighter weight [9]. Rechargeable Li- ion batteries are widely used in consumer electronic goods, accounting for much of the global production volume of 10 to 12 Giga-watt hours per year [9]. Such batteries are commonly used in plug-in hybrid electric vehicles (PHEVs) and electric vehicles (EVs).

Li-ion technology is fairly recent compared to the long history of lead-acid batteries. The demand for EV and energy storage is expected to benefit significantly from the advances in Li-ion battery technology. The high energy density and relatively low weight result in a viable option for electric vehicles and other applications where space and weight are significant. Thanks to their long life cycle and compactness, higher round trip energy of 85 – 90% [2], Li-ion battery manufacturers can be used for various utility grid support applications, including community-scale distributed energy storage systems, industrial end-user energy management, home back-up energy management systems, frequency control and wind and photovoltaic power smoothing applications.

**2.4 Flow Batteries:** A flow battery is a rechargeable battery where an electrolyte containing one or more dissolved electro-active species flows through anelectrochemical cell which converts chemical energy into electricity [9]. Vanadium red-ox battery technology is one of the most mature flow battery systems available with an estimated life of approximately 15 years [9]. However, the physical size of this battery is mainly due to the large amount of electrolyte needed when it is designed for utility projects.

Flow batteries are an appealing energy storage choice for the grid due to their ability to store a significant amount of energy with a potentially longer life cycle. However, this technology is still new, with an associated cost barrier. In addition, the presence of active species in electrolytes of anode and cathode canlead to loss of efficiency and contamination.

**2.5 Sodium Sulfur Batteries:** The sodium sulfide battery has a high energy and power density and electrical capacity. The long life results in an excellent alternative for electrical power system applications [9]. Sulfur is used as an active ingredient in a positive electrode and sodium is used in negative electrodes. Electrodes are isolated by sodium-ion-conductive ceramic rigid electrolytes. High temperature holds the electrode active materials in a liquid state while the electrode is solid. This reduces resistance and allows better battery output on average over a lifetime of discharge [9].

**2.6 Super-Capacitors:** Super-capacitors are devices that store electrical energy as a load separation in porous electrodes with wide surface areas. Some of the primary benefits of ultra capacitors include the highest capacitance density of any capacitor technology, low cost per travel, robust, long life, full cycle life, maintenance-free, environmentally friendly operation, a wide range of high power density operating temperatures and good energy density [8].For these characteristics, higher capacity and energy densities cross the gap between modern batteries and conventional high-speed, short-term energy storage capacitors. As a consequence, they are commonly used in utility applications for transmission line stability, spinning reserve, frequency control, voltage management, power quality anduninterrupted power supply applications [10].

## 3 Mechanical Energy Storage System

Pumped hydro, compressed air storage and flywheels can be categorized as mechanicalenergy storage.

**3.1 Pumped Hydro:** Pumped hydro electrical storage is the newest, most commonly used commercially available energy storage technology. These systems consist of two large reservoirs with a water pool at various levels. Off- peak energy is used to pump water up to the upper reservoir, which can then be discharged as needed, usually to the lower reservoir at the other end of the height differential. This water flow powers the turbines in the same way as the hydro-electric dams.

Technology can deliver reliable power in the short term, usually within one minute, with an efficiency range of 70-85% [2]. Today, technology is one of the most mature on the market and more technical advancements are consideredimpossible.Pumped hydro is the largest form of energy storage in the world and has been used since the 1890s. Approximately 90GW of pumped storage is in service worldwide, accounting for 3% of global generation capacity [3]. The large capital costs involved in building are a limiting factor (although costs are highlydependent on local topography and other factors).

**3.2 Flywheel:** Flywheels are a mechanical method of energy storage in which the kinetic energy of a fast-spinning cylinder absorbs stored energy. Recent technical advancements in flywheel have increased the performance of the conventional flywheel [9]. Modern flywheel systems usually consist of a large spinning disk, driven by magnetically levitated bearings on the stator, which reduces wear and prolongs machine life. In order to improve performance, the flywheel is worked in a low-pressure setting to reduce air friction. This energy storage device draws electricity from a primary source to spin a high density cylinder at speeds greater than 20,000 rpm. If the primary source loses its power, the engine functions as a generator. While the flywheel begins to spin, the generator provides electricity to the grid.

Flywheels have a high energy density of 50 – 100 Wh / kg and an capacity of about 90% depending on the speed range of the flywheel [3]. For any chemicaltreatment or recycling to be addressed, flywheels have some environmental benefits over battery systems.

**3.3 Compressed Air Energy Storage:** In the compressed air energy storage system (CAES), air is compressed into underground mines or caverns using off-peak electricity, which increases the performance of the gas turbine [9]. When needed, compressed air is used in conjunction with a gas turbine to generate electricity, resulting in a reduction of 60% in gas consumption compared to the same amount of electricity produced directly from gas [9]. To order to store extra energy during high wind periods, compressed air energy storage can be combined with the wind farm. The energy efficiency of

CAES is about 80%. The development or generation of large underground storage areas that have potential environmental effects, and the lack of suitable locations for underground air storage is a limitation on this technology.

## 4 Superconducting Magnetic Energy Storage

Superconducting magnetic energy storage (SMES) can store electrical energy in a magnetic field in a cooled superconducting coil. The coil is cooled above its superconducting temperature (-269$^0$ C) where the resistance of the material is very small. Such small electrical resistance allows SMES to achieve a high efficiency of upto 97%. Since small and medium-sized businesses can release immediate energy, it is useful when customers need an extremely high quality power output. As SMES is currently undergoing research and development, very little cost information is available.

Extremely low temperatures are needed for the superconducting device, which is a safety problem. Smaller scale SMES systems may need substantial safety to deal with magnetic radiation in the immediate vicinity.

## 5 Hydrogen Energy Storage

Hydrogen-based energy storage systems are currently attracting significant attention due to the long time over which hydrogen can be stored and the potential hydrogen ability to substitute petroleum fuels as an energy carrier for the transport sector. Once combined with renewable energy or low-carbon energy technologies, the production of hydrogen energy has the ability to reduce greenhouse gas emissions.

The essential elements of the hydrogen storage system consist of an electrolyzing unit,which converts electrical inputs to hydrogen during off-peak times, a storage component and an energy conversion component which converts stored chemical energy into electrical energy when the demand is high or when used in transport systems.

The electrolyzer and fuel cell components can be either dedicated or "reversible": capable of generating hydrogen electrochemically or working in fuel cell mode and converting the hydrogen back to electricity. Proton Exchange

Membrane (PEM) fuel cell technology has been most widely studied for reversible electrolyzer operation, butsolid oxide fuel cell (SOFC) and alkaline fuel cell (AFC) technologies can also be usedreversibly. One of the key issues about hydrogen systems is the reliability of the wholeprocess. Energy loss is inherent in the system as electricity is converted to hydrogen, stored, transported and then converted to electricity in a fuel cell. Estimates of this energy loss vary from 60 to 75% [1]. More advanced fuel cell technologies are underdevelopment and include: Direct Methanol Fuel Cells (DMFCs); Molten Carbonate Fuel Cells (MCFCs) and Solid Oxide Fuel Cells (SOFCs). MCFCs and SOFCs run at exceptionally high temperatures of approximately $620^0$ C and $1000^0$ C respectively.

MCFCs are approaching 60% efficiency in converting fuel to electricity, and SOFCs are expected to reach similar levels of efficiency [9]. When waste heat is collected andused, the output of both technologies will hit 85% [9].

## 6 Energy Management & Control

In order to achieve continuous, efficient and cost-effective operation, proper control and energy management of stand-alone hybrid power systems with multiple renewableenergy sources and energy storage are critical. The overall control and energy management system of the conventional hybrid power system is responsible for the proper management of energy storage, enabling the renewable energy-based hybrid system to provide the required power to the connected load at any given time of sufficient quality.

Usually, in a stand-alone power system, the control system must evaluate and delegate the active and reactive output power of each energy source while maintaining its outputvoltage and frequency at the appropriate level. In addition, the control system must ensure the reliability of the energy supply of the renewable energy-based hybrid powersystem in the event of unfavorable conditions such as no wind or solar power to prevent system blackouts.

## 7 Conclusion

Based on the assessment, the following conclusions were drawn. Although there are many TERs available in the market, a single storage system does not meet the requirements of all RES constraints. A single energy storage system may be suitable for specific applications in the renewable energy sector depending on the characteristics of the RES as well as the TER. From the above assessment, it is clear that the electrochemical energy storage system (battery) is the mainstream EST used when the energy and power density is high, the power range is high, the discharge time is longer, the duration is high. Fast response times and high cycle efficiency are paramount. These types of ESTs have potential applications in the renewable energy sector as well as in the power system in general, for example for transitional power and energy management applications. In electrochemical energy storage systems, Li-ion batteries are considered a more competitive due to fast response time and low environmental impact. However, for Li-ion batteries to be fully applied in the field of renewable energy, the cost of storage devices must be reduced. The cost of Li-ion batteries will be reduced by improving mobile technologies such as increasing the life of the device

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