A comprehensive study on battery energy storage systems for renewable energy

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Abstract - *With increasing industrialization and explicitly developing economies, the demand for energy has considerably increased. Though the world is slowly moving towards carbon-free living, the majority percentage of the electrical energy utilized over the globe is still generated using fossil fuels. The larger economies including the United States, India, China, and the European Union countries accounting for the majority stake in energy requirements are dependent upon non-renewable sources for their energy requirement fulfillment. Moreover, the conventional energy sources are limited in nature and account for the emission of harmful pollutants resulting in the global warming crisis. To provide a sustainable and prudent solution to this alarming emergency, the usage of renewable sources can play a vital role in the generation of emission-free and clean electricity production. However, storage of this high voltage electricity for a lasting duration is a rising challenge. For such applications, battery storage systems are developed to store green electrical energy while laptops, mobile phones, and other battery-operated types of equipment are the best day-to-day simple examples of these systems. The present study focuses on the existing techniques of battery energy storage, the latest progress, and the future scope of development in this area. In addition, the economic aspects of the system have also been discussed in the present study.*

***Key Words*: Energy storage, Renewable energy, Electric Vehicles, Energy sustainability, Electric battery storage systems**

1. INTRODUCTION

The demand for energy been drastically increased over the last decades. This is more particularly due to the major developments in industrialization and human territory expansion. According to the data released in 2015, the net generation of electricity has accounted for the value of around 25000 TWh, which is produced by the head of non-renewable resources including coal being one of the major energy-producing fuels. With the increase in the need for electrical energy, resources providing the energy getting strinked over the years. Moreover, the energy generated by the use of fossil fuels is harmful to the environment and produces toxic gases as well as releases chemically harmful liquid to the water resources. To tackle this alarming situation, several attentions made by the major economies over the globe. Countries including the United States, China, India, the United Kingdom, and the European Union are stepping in to generate electricity by using green technology. This initiative will not only reduce the dependency of countries on fossil fuels including crude oil and coal but also account for the production of pollution-free electrical energy. The major contributor to the generation of green electrical energy includes solar power plants, windmills, and hydroelectric power plants. However, the initial capital required to set up the green power plants is multiple times more than the conventional energy sourcing power plants, which is a major problem for middle-income and low-income economies. While climate change is the common and concentrated point of discussion in annual meetings of G7 and G20 countries, several initiatives are being taken in the direction to reduce the dependency on fossil fuels. The major countries have set up a challenging target for themselves as net carbon-free emission countries, the time duration for which is varied according to the energy demand and the economic prospect of that specific country. According to the statements given by the country representatives at COP26 held in the year 2021 at Glasgow, the Republic of India is targeting towards becoming a net carbon emission country by the year around 2070, while the United States promised to do so by the year 2050. China being one of the huge economies and accounting for the majority of the percentage of energy demand has aimed to produce net emissions by the year 2060.

The journey of becoming an emission-free country can be achieved if directed steps are taken by the country and the concerned government. The major steps include setting up renewable power plants and replacing conventional engine-based vehicles with electric vehicles. Moreover, the solar power plants can be installed over a large area of land as well as floating solar power plants can be developed on the seawater. The country has large water sources that should empower water into electrical energy by constructing hydropower plants at the originating places or over the dams. The electrical energy generated with the ad of renewable resources including solar, wind, and water are dynamic in nature and it depends upon the variable factors. Such energy needs to be stabilized before transporting to industrial or household applications. Renewable energy sources are irregular in nature, in order to have system stability and reliability, energy generation and load maintenance are important, also energy consumption levels are changing with increased consumers so there is a requirement for an energy storage system for renewable sources. Electricity can be stored in large-scale batteries. In order to fulfill demand, the new storage system is required for renewable sources. Installation and operating costs for large-scale storage of electricity using batteries are different and its performance can vary. Prudent research has been carried out over the past few years to tackle this problem and it has been observed that Electrical Energy Storage is the perfect system that full fields all the energy stabilizing requirements. With the aid of electrical energy sources, the energy is transformed into the required form where it can be stored and preserved in multiple mediums. The medium of storage can be categorized into purely Mechanical, Electrical, Electrochemical, Chemical, and Thermal. The stored stable electric energy is then wire-transported to the end-user application [1, 2].

2. CLASSIFICATION OF ELECTRIC ENERGY STORING SYSTEMS

The electronic energy storage systems play several duties in green energy development including the attainment of maximum load requirements during peak demand, redeveloping the quality of the grid power being collected from renewable resources, and, optimum usage of energy-storing equipment.

Figure 1 shows the broad classification of electrical energy storing systems used to store and supply electrical energy for domestic and industrial usage. As can be seen in the classification the storage is categorized into direct and indirect storage. In the direct type of electrical energy storage, the green energy generator from renewable sources is stored in the superconducting magnet i.e., in case of electromagnetic storage or in the super capacitors. While in the indirect type of storage the energy is stored in the mechanical, thermal, and electrochemical forms.

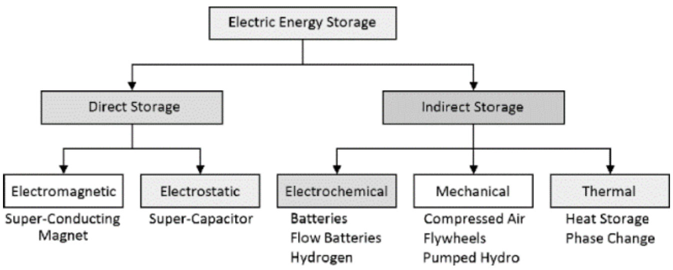

Fig -1: **Classification of Electric Energy Storing Systems** [1-4]

A few energy storing systems includes in NAS battery, Superconducting magnet energy storage, Lithium-sulphur battery and lithium-ion battery, VRB flow batteries, supercapacitors, or double-layer supercapacitors, and Hybrid energy storage systems. The range, efficiency, and durability of each system are varied from each other while superconducting magnetic energy storage provides maximum efficiency of 99% in contrast to other methods where the Grid-Tie BESS method provides 92.8% efficiency. The selection of the proper electric storage system method is valid in accordance with the end application. It has been seen that the NAS battery energy storing method is majorly utilized in electric vehicles, whereas a hybrid energy storage system is usually used for wind energy resources and grid operation. For car batteries, lithium-sulphur batteries and lithium-air batteries are widely used for electrical energy storage, while superconducting magnetic energy storage is preferably used for high-end applications including pumping hydro stations [5,6].

3. BATTERY ENERGY STORAGE SYSTEM

A battery is an electrochemical cell in which electrical energy is generated during chemical reaction. Battery has two types namely primary and secondary battery. Primary batteries are used for single use. Primary batteries are used in small portable gadgets, watches, and torches They cannot be rechargeable whereas secondary batteries can be rechargeable. In the secondary batteries, chemical energy is converted into electrical energy and vice-versa. They are used for energy storage in mobile, laptops electrical vehicles.

The secondary batteries can be recharged and reused; however, these batteries are costlier than the primary batteries. Secondary batteries are used for energy storage devices. Electrical energy storage i.e., EES. to reduce pollution due to conventional fuel in vehicles electrical vehicles can be used and it is needed for the future in order to save the environment. Another easily available source is renewable energy sources i.e., wind and solar power. Electrical energy can be produced from these RE sources [7-10].

Types of modern secondary batteries can be summarised as:

- Lead—Acid Batteries
- Nickel—Cadmium Batteries
- Nickel—Metal Hydride Batteries
- Lithium-Ion Batteries- Cobalt-based Li-ion batteries;
- Phosphate-based Li-ion Batteries.
- Sodium Sulphur Batteries

In the battery energy stream, the electrochemical batteries are connected in a circuit wherein the battery cells are joined in parallel or in series depending upon the requirement of the energy. There are multiple types of battery cells including Lead Acid battery, Lithium-Ion battery, Sodium-Sulphur battery, Nickel-Cadmium battery and Vanadium Rodex Flow battery. The depth of charge of each battery is very in accordance to the discharge rate for a cycle. The application of each battery varies in accordance to the environment, voltage requirement and cycle time. The batteries and its battery energy storing capacity can be discussed as further. Lead-acid batteries are widely utilized in applications where the battery cannot be interchanged and requires its recharging after certain duration. These batteries are rechargeable and can be utilized fully for a complete cycle. In this type of battery, the electrolyte solution is sulphuric acid, Lead acts as an anode whereas Lead-oxide acts as a cathode. The efficiency these batteries depend upon the environmental temperature, as in winter, it provides poor performance while in summers it works with its maximum efficiency. The performance of this kind of batteries is operated and manipulated by the proper implementation of thermal management systems. [8-11]

Another kind of widely used battery is a lithium-ion battery. In this kind, the electrolyte is used as non-aqueous solution, graphite carbon access anode and lithium metal oxide act as a cathode. These batteries provide maximum efficiency of up to 98 percent while the cycle time is dependent upon the depth of discharge and can be significantly affected by it. In recent days, these kinds of batteries are widely used in electric vehicles as primary electrical energy storage equipment. Another type of battery which includes beta alumina, molten Pharma sodium and sulphur as energy storing medium is sodium sulphur battery. In this kind the sodium and sulphur as electrodes and alumina acts as solid electrolyte. The greater advantage of operating sulphur sodium battery is its maximum ability of recycling, the result of which, these are usually incorporated for high energy storage applications.

Other form of battery i.e., Nickel-Cadmium battery uses two electrolytes of nickel hydroxide and cadmium in its metallic form. The major drawback of using these batteries is its toxicity in nature and low efficiency in high temperatures. Therefore, these kinds of batteries are usually used in low temperature applications.

Apart from the discussed batteries, the flow batteries are widely used in enhancing power qualities and power security devices. These are usually given as Vanadium Redox Flow Battery. The battery includes to separate electoral tanks and the energy is stored using vanadium redox acting as electrodes. This battery is provided high performance and quick response to maximum power requirement. While being operated for load leveling and electrical security, the operating cost of these batteries is a bit expensive.

Some factors are taken into consideration while choosing EES technology such as.

1. Small discharge time: Discharge time is between seconds to minutes. e.g., flywheels.
2. Medium discharge time: Discharge time is between minutes to hours. e.g., large capacity electrochemical batteries.
3. Large discharge time: Discharge time is between days to month e.g., Synthetic natural gas (SNG)

Capital cost is an important factor when installing an EES system in industrial and commercial use. It is expressed in kWhr, Rs/kWhr and Rs/kWhr/cycle.

The current profile of the load- Understanding the current profile of the load is essential when dimensioning the battery capacity, and is very often overlooked. This is acceptable when the load does not change during operation, but it is unacceptable when such changes occur.

4. ECONOMIC ASPECTS OF ENERGY STORAGE SYSTEMS

The power grid size and the energy requirement is an important aspect of the selection of proper electric storage systems for a particular application. If the energy requirement and its density are on the higher side, then the requirement of the size consider small. Figure 2 and figure 3 give an overview of the Power capacity and density of the electrical energy for electronic energy storage systems, while 4 shows the maximum power rating of EES [9-12]

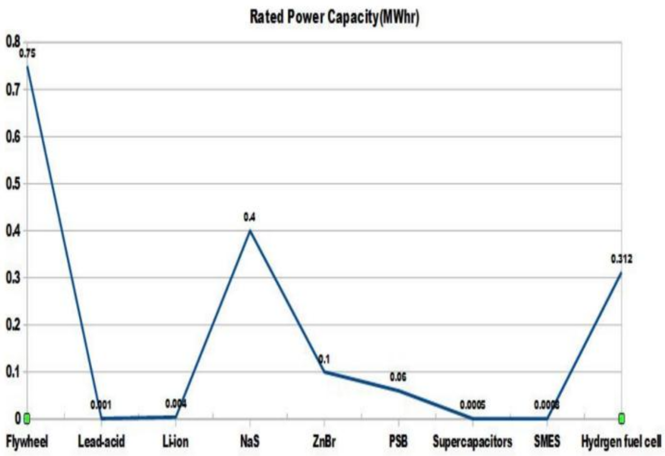

Fig -2: Rated power capacity of EES

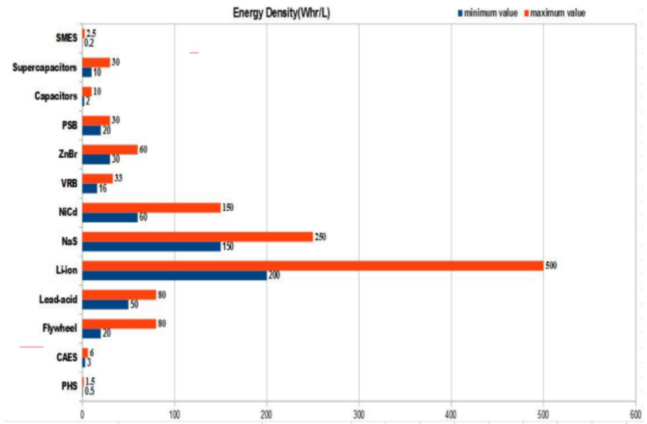

Fig -3: Energy density of EES

Further, the rating of energy differs from type of energy storage system used, the comparison analysis of which is shown in Figure.

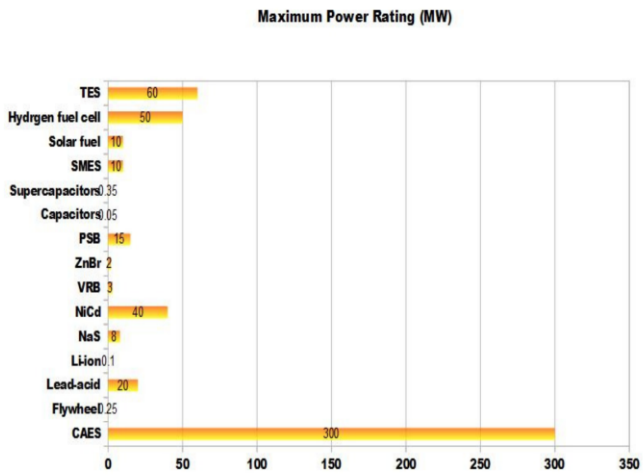

Fig -4: Maximum power rating of EES

An analysis is carried out considering the economic aspects and found that the optimized usage of electric energy systems can significantly reduce the cost required for energy production, storage, and transformation. This can be financially beneficial if the conventional sources of energy production are replaced by the energy storage systems which provide renewable green energy. Further, a few other economic perspectives include:

Most of the higher economies are reducing their dependency on fossil fuels and shifting to renewable resources, as a result of which the cost of energy is becoming economical. The energy storage systems are playing vital and beneficial role in this revolutionary change by cutting down the excessive cost of generating energy through fuels.

The reasonable grid can be provided as an additional service by implanting the battery energy storage equipment which significantly reduces the cost, thereby reducing the cost of energy. The power expenses for industrial as well as household applications can be significantly reduced by implanting BESS.

Further, the undeveloped areas where electricity is not available and transportation of energy cannot be implemented, the battery energy storage systems can be installed at search remote areas thereby reducing the cost of transportation wirelines and energy loss due to its heavy energy transfer [12-16].

CONCLUSION

The demand for energy has increased over the few decades as the major economies are you moving towards heavy industrialization and human expansion. The energy generated by fossil fuels is not only hazardous but also limited in nature. Providing a prudent solution to this alarming situation, the world is fastly adapting renewable sources to fulfill its energy requirements. However, the storage of high voltage energy and its transportation has been a major point of concern. The latest developments in this regard found that energy storage systems can effectively store green energy, the type of which varies in accordance to the environment, voltage requirement, and cycle time. In the present study, different energy storage methods and their usage have been discussed. Furthermore, the battery energy storage system was the prime focus of discussion were the types of batteries, their significance, and economic perspectives have also been showcased. The main focus is on secondary storage batteries which it is used in large application such as electrical vehicles. Here the main function of electrical energy storage is matching the demand and supply of electricity i.e., time-shifting for small and large industrial and commercial applications. If we want sustainable development in the coming decades, the globe needs to shift from conventional and depleting natural resources we have to shift to Energy storage devices considering all three pillars of sustainable development i.e. society, economy, and environment. The biggest factor is environmental issues like global warming and ozone depletion etc. which are forcing us to shift our systems from CO2 emissions to eco-friendly devices and energy storage is playing a vital role in this development.

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