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Energy Storage Technologies: A Review

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Abstract- ***Electrical energy storage is considered to be foundation of the smart grid. This paper reviews a variety of storage technologies such as chemical energy storage, super conducting magnetic energy storage and mechanical energy storage technologies. The unique capability of energy storage technologies helps to cope up with some critical characteristics of electricity. From the studies, three technologies seem to be the most significant i.e. electrochemical batteries, pumped hydroelectricity and SMES.***

I. INTRODUCTION

Energy storage technologies are gaining more and more attention due to the increase in the development level of new energy and smart grid technologies. Advanced countries like United States, Japan, South Korea have set aside special funds for pursuing the research in the arena of energy storage technologies [1]. Regarding the industrial applications, countries are still in the initial stage of energy storage devices.

Electrical Energy storage has played three critical roles. First, EES reduces the cost of electricity by storing it when the price is lower and using it at peak times when the prices are very high. Secondly, EES improves the reliability of supply by acting as a backup at the time of power failure. Thirdly, it plays an important role in maintaining the voltage level and frequency of supply [2].

According to the needs of the emerging market, for on-grid applications, EES helps solve issues such as-excessive power fluctuations and unreliable power supply. Whereas for off grid applications, electric vehicles with batteries is the most favourable technology to replace fossil fuels. Power congestion can occur in the transmission grids while balancing the supply and demand. Thus, the proper EES allocation can alleviate congestion, by storing it while the transmission lines maintain enough capacity.

EES systems are classified on the basis of the form of energy used. From the utility point of view, EES provides frequency control functions by adjusting the output of power generators.[3] On installing the EES at the end of a heavily loaded line, voltage drops are improved by discharging electricity and thereby, reducing voltage rise by charging electricity.

The suitability of the EES is dependent primarily on its power and energy rating and the rate at of storing and delivering these . Other features to be taken into consideration are: round trip efficiency i.e. amount of energy lost during the charge and discharge, cycle life i.e. the number of times the energy storage system can charge and discharge at a particular depth of discharge and the ramp rate i.e. the fastness of response of the technology.

Specific energy and specific power are the other parameters that are considered while choosing the storage technology. These refer to the amount of energy that can be stored depending upon the size of the energy storage system. The discharge time is the time taken to extract energy from energy storage system from full state of charge to lowest allowable state of charge. For example, Flywheels, SMES can discharge within an hour whereas batteries such as Li-ion, Pb acid, compressed air energy discharge in 10 hours or less.

Thus, the above parameters would play an important role in deciding the EES to be used for a particular site. The various types of chemical, mechanical and electrical energy storage technologies are discussed in detail.

II. VARIOUS ENERGY STORAGE TECHNOLOGIES

Energy storage devices can solve the problem of supply and demand mismatch thereby, improving the utilization efficiency of energy. It is thus, divided into mechanical or physical energy storage, chemical energy storage and electrical energy storage [4].

A. Mechanical Storage

It is an efficient utilization technique of natural resources that is environmentally green with advantages of low running cost and limitations of geographical constraints and requirements. There are three most common mechanical energy storage technologies i.e. pumped hydro, compressed air and flywheel storage. Mechanical energy is basically the energy produced due to the motion or position.

(i) Pumped Hydro Storage

With nearly 99% of world-wide installed storage capacity, pumped hydro storage is the most commonly used technology. This technology works by building two reservoirs at different elevations and pumping of water from lower to upper reservoir during off peak period i.e. charging. When needed, the water flows back from upper to lower reservoir, powering a turbine with a generator to produce electricity i.e. discharging. The reversible pump-turbine motor-generator acts as a turbine and generator when working in 'generating' mode whereas as a motor and pump during 'pump' mode. The storage capacity of PHES is measured by the reservoir volume whereas the capacity to produce power is dependent on the vertical distance between the penstock diameter and the two reservoirs. It is the most mature technology, economically effective with long service life of upto 25 years and power production on the gigawatt scale.

(ii) Compressed Air Storage

It is a storage technology known widely and used since 19th century, where air due to its availability is used as a storage medium. During 'off-peak' period, air is compressed by the use of electricity and stored in a structure built underground. Then during the 'peak' hours, the compressed air on mixing with natural gas, is burnt and expanded in a modified gas turbine. While running the turbine, the fossil fuel is still needed as the driving force but it saves normally half the fuel for energy production. While designing the compressed air power plant, necessary conditions are the rigorous seismic monitoring, nearby storage space and proper system designing.

(iii) Flywheels

One of the old energy storage technologies, rotational energy of flywheel is stored in an accelerated rotor. The main components are the rotating cylinder, bearings and the transmission device. The speed of rotating body maintains the energy production while the transmission device is used to extract or supply electricity to or from the system. Advanced FES systems have a discharge time of 15 to 30 minutes with rotors made of high strength carbon filaments. The major drawback of this technique is the cost.

B. Chemical Storage

The chemical energy storage is one of the most known technologies among developing countries. It works on the principle of chemical reaction conversion to electrical energy. The storage devices comprise of batteries which consist of multiple series or parallel electrochemical cells [5]. This paper discusses few of the batteries which are lead-acid batteries, sodium sulphur batteries, vanadium redox batteries and Nickel Cadmium batteries.

(i) Lead acid batteries

Lead acid batteries are one of the oldest forms of rechargeable battery technologies which are very often used in mobile and stationary applications such as cars, wheelchairs, standalone systems with PV, emergency power systems and starter batteries in vehicles. Each cell of battery is composed of a spongy pure lead cathode, lead oxide anode and 20 - 40% solution of sulphuric acid. These have advantages of service life of around 6 – 15 years with cycle efficiency levels of around 80 – 90% with disadvantages that during the discharge of high power, its usable capacity decreases and is environmentally unfriendly due to toxicity of lead.

(ii) Sodium Sulphur batteries

Developed in 2002, sodium sulphur batteries comprise of molten sulphur and molten sodium at positive and negative electrode respectively with the electrolyte of beta alumina. In order to keep the electrodes molten, the battery temperature is maintained within the range of 300^0 C – 350^0 C. NaS batteries are known for their long life spans, recyclable, high rated capacity and discharge time of 6 – 7.2 hours. The main drawback is that in order to maintain operating temperatures a heat source is required, which uses the battery's own stored energy, thereby reducing the performance of the battery. Due to quick response of batteries of around milliseconds, these are widely used in grid stabilization.

(iii) Vanadium Redox batteries

These batteries consist of two electrolyte tanks, each containing either of the two redox pairs (V^{2+}/V^{3+}) or (V^{5+}/V^{4+}). VRBs have a high efficiency of approximately 85%, quick response time in milliseconds and ability to combine with other battery technologies. These are widely used for systems that rely on intermittent renewable energy generation. VRBs improve the power quality by improving the load levelling and power security.

(iv) Nickel Cadmium batteries

From a technical point of view, NiCd batteries are a very successful product due to their capability to perform well even at low temperatures ranging from -20^0C to - 40^0C. These comprise of two electrodes of metallic cadmium and nickel hydroxide. These batteries are a threat to environment due to its composition of heavy metals of cadmium.

C. Superconducting magnetic energy storage

SMES works on the electrodynamic principle of storing the energy in the magnetic field that is created due to the flow of direct current in a superconducting coil, by keeping it below its superconducting critical temperature. It comprises of a coil made of superconducting material, power conditioning equipment, control unit and cryogenically cooled refrigeration system. The power conditioning unit transforms alternating current coming from grid to DC for charging. The amount of energy stored in SMES device depends on the geometry of coil and the permeability of magnetic material. The advantages of SMES are negligible loss of energy due to zero coil resistance in superconducting state, no harm to environment, round trip efficiency of 85 – 90% and fast response. Some of the applications of SMES are stability of transmission and distribution systems, controlling the quality of power in manufacturing plants, etc. Particle detectors and nuclear fusion use large SMES of more than 10 MW capacity.

III. TRENDS IN ENERGY STORAGE TECHNOLOGY

Various storage technologies described in the article such as flywheel and SMES are still under study whereas green flywheels and highly efficient SMES have a great future. Development of energy storage faces a bottleneck around three points which are efficiency, economical and environmental safety. The combinations of these three will bring a better future for batteries and storage devices to markets. Coordinated development is necessary for different energy storage technologies as every storage device has its own advantages and disadvantages which on combining with their applications help to achieve their weaknesses and work accordingly [6].

IV. CONCLUSION

Various energy storage technologies with their working principle, limitations, applications, technical status are reviewed in this paper. Moving towards higher conversion efficiency, high energy density, low cost application and environment friendly direction can help efficient utilization of energy, optimizing energy structure and secure supply of energy.

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