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Modern Mechanical Energy Storage Systems and Technologies

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***Abstract* - The power system is always designed to fulfill the energy demand of the country. Rate of electrical energy production should not be changed randomly according to the temporary rise in the energy consumption. Most effective way to meet the momentary rise in energy demand is to develop advanced storage systems and technologies. Integration of renewable sources in electrical networks has increased dramatically in recent years. However, the power supplied by renewable energy sources is not secure and easy to adjust to any sudden change in demand. So advanced methods of energy storage systems must be implemented to increase the efficiency of the plant using these intermittent energy renewable energy sources .The modern energy storage systems and technologies can be broadly classified as mechanical, electrochemical /electrical, electromagnetic and thermal storages among which mechanical energy storage systems are described with their advantages and limitations is discussed in this paper. Not only that this paper also gives idea about different parameters of energy storage systems.**

Keywords:* *flywheel, CAES, PHES ,parameters.

I. INTRODUCTION:

Electrical energy storage is now becoming the integral part of the power generation infrastructure. Energy storage is highly required to balance supply and demand. However when both demand and supply are fluctuating rapidly continuously with time, the grid, which is the interface of power distribution, faces several problem in managing the power generation and distribution according to the demand. The grid balance can also be achieved through the use of different energy storage technologies. More over Higher levels of energy storage are required for grid flexibility and grid stability and to cope with the increasing use of intermittent renewable energy sources. Within the context of distributed generation, new energy sources rely mainly on renewable resources. Consequently, an energy reserve is required and energy storage devices can be very useful for an efficient energy management. Energy storage technologies basically perform two functions:

• Storing the excess energy generated in the system, and

• Providing the stored energy for use whenever demanded by the system .Different Energy storage technologies—such as compressed air energy storage, various types of batteries, flywheels, superconducting capacitors, etc., provide for multiple applications: energy management, backup power, load leveling, frequency regulation, voltage support, and grid stabilization.

II. NEED OF ENERGY STORAGE SYSTEMS AND TECHNOLOGIES:

The major need of energy storage system is due to importance given to utilize more renewable sources of energy and diminishing the use of fossil fuel and for the development of the future smart grid. Not only that there are other factors which encourages the need for the advanced storage systems such as-

1. High generation cost during peak hours. There is a huge scope to reduction of total generation costs through storage of electrical energy generated by low-cost power plants during the night and being reintroduced into the power grid during peak demand periods.
2. Sometimes the distance between generating stations and consumers are very large. As a result there is a great probability of power interruption for several causes like natural disasters or due to some other reasons like over load or operational accidents which may result in disruption of the supply and potentially affect large areas. Thus energy storage systems and technologies comes into act to supply power continuously for a certain period of time.
3. Some time difficulty in meeting up power demand as well as output power fluctuations also occurs which can be minimized by these energy storage systems and there by stabilizing the transmission and distribution grid.

III. DIFFERENT PARAMETERS:

There are different parameters which determine the quality of the storage devices .Some of them are given below :

1. Storage capacity : It is defined as the amount of energy that the device can hold after completing the charging cycle.
2. Energy density : It can be defined as the amount of energy that can be supplied from a particular storage device or technology per unit weight. The energy density determines the quantity of the energy that the device can deliver or can store energy.
3. Discharge time: it can be defined as the period of time for which the energy storage device or technologies completely discharge the stored energy.
4. Efficiency: it can be defined as the ratio of the total energy released is to total energy stored.
5. Durability: It is given by the number of times the storage device can be discharged. It can be expressed as the number of cycles ,each cycle consisting of one charging and discharging process.
6. Autonomy : it is the defined as the maximum time that the system continuously releases energy.
7. Energy rating: Energy rating determines how long the device can supply energy. It is expressed in MWh or KWh .
8. Power rating : Power rating determines how much energy is released in a particular period of time.

   Costs of energy storage devices are usually given in terms of cost/kWh or costs/kW.

IV. TYPES OF ENERGY STORAGE SYSTEMS :

There are different types of the energy storage technologies that vary in cost, performances and technological maturities. It can be classified according to the field of application and power rating :

category	application	Power rating
Small scale	Mobile devices, electric vehicles, satellites	≤ 1MW
Medium scale	Office building, remote communities	10-100 MW
Large scale	Power plants	≥300 MW

Again Electrical energy storage system can be classified according to the energy forms as given below

1. Mechanical system- flywheel, compressed air energy storage system, pumped hydro storage system, etc.
2. Electro chemical system- secondary batteries, flow batteries.
3. Chemical systems- hydrogen (electrolysis of water).
4. Electrical systems-super conducting magnetic coils(SMES) .
5. Thermal storage system- sensible heat storage, A-CAES system.

Detailed overview on the above mentioned electrical energy storage system is given below:

III. MECHANICAL SYSTEMS.

a. *Flywheel* **:** Flywheel is the mechanical form of energy storage system in which mechanical inertia is the basis and kinetic energy is stored in the rotor which is actually a huge rotating cylinder. The main parts of the flywheel energy storage system are

   i. Rotating body
   ii. Bearing
   iii. Electrical machine(generator/motor mounted on the shaft.)
   iv. Power converter.
   v. Containment chamber.

The rotating body is mainly composed of more energy dense composite and alloy materials. Ceramic superconducting materials can also be used in flywheel energy storage system. The rotor is kept at constant speed maintaining the energy in the flywheel. An increase in speed of the flywheel results in the increase in storage of the energy. The rotational speed of the flywheel can be increased by use of electrical motor and when the speed gets reduced then electricity is produced by the same electrical machine which now acts like a generator. The operation of flywheel energy storage system mainly faces the loss due to friction. So to increase the efficiency of the system by reducing frictional loss two methods are opted. Firstly the flywheel is rotated in vacuum to reduce air friction loss and the spinning rotor is kept on the stator by magnetically levitated bearing which not only reduces frictional loss but also increases the lifespan than that of conventional bearings. The electrical machines that are used in the flywheels are mainly permanent magnet , Induction and reluctance machines but permanent magnet machines are preferred to eliminate the copper losses and there by mitigating heat losses in the vacuum environment of flywheel energy storage system. Recently high saturation exchange coupled "spring" magnets, which increases the flux densities and the output of permanent magnet machines are used. Bi-directional power converters convert flywheel storage system output into grid level voltages and generate variable speed control signals for energy storage. GTO thyristors and IGBT are used in power.

*Advantage***:**

There are several advantages of flywheel energy storage system. Some of them are given below.

1. Longer life span and requires very less maintenance.
2. The system is very eco-friendly and does not cause any pollution.
3. Rapid response due to less complex arrangements.
4. It can provide high quality, highly reliable uninterrupted power supply when required for several field of applications like communication networks, commercial facilities, industrial manufacturing, etc.
5. It can produce high peak power without any overheating issues.
6. It has a very high efficiency depending upon the speed of flywheel which may vary up to 6000 rpm for low speed fly wheel and 10000-110000 rpm.

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Limitations:

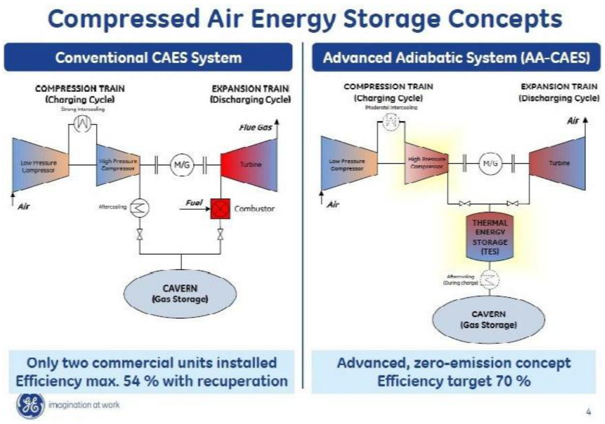
The major demerit of fly wheel storage system is it's high discharge rate of energy. The other important factors are its high acquisition cost as well as its low storage capacity.

application :

Flywheel energy storage systems can be used in load leveling in railway power systems, primary frequency regulations, peak shaving and off peak storage and for improving power quality in the renewable energy systems.

b. *Compressed air storage system* (CAES):

This technology is mainly based up on the compression of air and storage in the underground cavern. It is actually a considered as the hybrid generation/storage system as it requires the combustion in gas turbine. When the air is compressed then the heat is produced and if this heat is not stored then the compressed air in which with natural gas and fuel is mixed must be reheated and ignited before the expansion in turbine which is connected to a generator. Some additional energy (via a recuperator) is put into pre-heating stored air to prevent chilling and brittling of turbine blades to improve efficiency of combustion and thereby increasing efficiency of the CAES plant .This process is called the diabetic CAES .Again it should be remembered that the heat produced if not stored then the heat dissipated will be treated as loss. So another technology named as advanced adiabatic compressed energy storage system is used in which the heat produced during the compression transferred by heat exchangers to other heat storage sites. During discharge of the compressed air the heat storage sites provide the necessary heat to avoid the combustion of the compressed air which is required to prevent the freezing of the turbine blades and vastly Carbon dioxide neutral.



Generally in "normal" case, the gas turbine has to drive an air compressor that eats up a large part of the energy generated by the gas turbine (above 20%). Also the start-up of the turbine is slower as the combustion air needs to be compressed first. This problem is solved in this system to a large extent.

The suitable sites for underground storage may be classified as

1. Rock cavern which is created by excavating relatively hard and impervious rock
2. Salt caverns created by solution or by dry mining of the salt formations.
3. porous media reservoirs made by water bearing aquifers or depleted gas or oil fields e.g., sandstone, fissured limestone.

Advantages :

1. CAES increases the efficiency and the start-up time of gas turbine plant.
2. This technology can store relatively huge amount of energy.
3. It has fast response times.

Limitations:

The main limitations of this storage systems is its dependency on favorable geological structures. It is the main challenge which is in focus of the recent research of development of the system.

c. *Pumped hydro storage system (PHS):*

Pumped hydro storage system is one of the dominant energy storage system in the world which is really feasible technology capable of storing huge amount of energy for relatively longer period of time. This storage technologies work in a reverse way than that of the traditional hydropower generation plant. There are two types of pumped hydro storage system according to their installation sites – underground and over ground (conventional). Conventional pure PHS system makes use of two reservoirs at different elevations-an upper storage reservoir providing head to the hydro power turbine and another to collect water back into the upper reservoir using surplus electricity during off period hours. When electrical energy required during peak hours the water is allowed to flow from higher reservoir to the lower reservoir powering a turbine with the generator and thus produces electricity while in pump back PHS system ,only one reservoir is used and as a result later is more economic and also provides uses related to the base load generations specially during the time of excess flow. In case of underground PHS system unused salt or coal mines can be used as the lower reservoir while depending up on the circumstances upper reservoir can be built in caverns. However the underground PHS system is much more expensive than conventional PHS system and also faces many difficulties like fracturing of soil due to pumping of huge amount of water up and down in high pressures. In this storage technology, the ratio of energy supplied to the network and the energy consumed while pumping must be considered to evaluate the overall efficiency of the energy storage system.

Advantages:

1. This technology can provide reliable power within a very short notice period.
2. The efficiency of this storage technology is high around 70-85%.
3. PHS is highly reliable, flexible and can be used for regulation of power as well as frequency stabilization.
4. It is capable of storing huge amount of energy and practically unlimited cycle of installation.
5. This system has long life ,very slow discharge rates (from few hours to few days),low operation and maintenance cost.

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Limitations :
The some drawback of this storage system can be summarized as

1. Dependance on topographical conditions and large land use.
2. This storage technologies requires a huge water resource which may not be available at all places.
3. High capital cost, long development time, long pay-back periods and uncertain profitability are also problems regarding this technology.

Application:
Main application are the energy management via time shift like spinning reserve and supply reserve.

V. CONCLUSION:

Storage of large amount of energy will be a challenge in upcoming years to meet up the demand during peak hours. Pumped hydro storage plant is currently the most economical solution for this purpose. Another alternative for pumped hydro storage plant is adiabatic CAES plant which also have a very high efficiency rate. This paper presents the most relevant properties of mechanical energy storage technologies currently being developed in the design of power systems. It describes the most important parameters that characterize the behavior of different mechanical energy storing technologies.

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