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Energy Storage: A Review

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Abstract*—*Efficient and economic energy storage, if implemented in the current power infrastructure on a large scale, could bring about some of the greatest changes in the power industry in decades. Additionally, energy storage would improve the reliability and dynamic stability of the power system by providing stable, abundant energy reserves that require little ramp time and are less susceptible to varying fuel prices or shortages. Energy storage can shift the higher peak load to off-peak hours in order to level the generation requirement, allowing generators to run more efficiently at a stable power level, potentially decreasing the average cost of electricity. Additionally, increased energy storage capacity can avoid generation capacity, decrease transmission congestion, and help enable distributed generation such as residential solar and wind systems. In this paper energy storage methods are discussed in such a way to provide a detailed overview of how each of the energy storage devices work so that the reader is able to get a better feel for the potential benefits and drawbacks of each device.

Index Terms*— *Energy Storage , Battery ,Renewable Energy Sources, CAES ,PHS, Fuel Cell, Flywheel.

I. INTRODUCTION

Energy storage is the most promising technology to reduce fuel consumption in the transport sector. Reliable and affordable electricity storage is a prerequisite for using renewable energy in remote locations, the integration into the electricity system and the development of a future decentralized energy supply system. Energy storage therefore has a vital role in the effort to combine a future, sustainable energy supply with the standard of technical services. A delayed response to a power requirement and inadequate or excessive power levels are unacceptable to industrial, commercial and private consumers and can lead to application failures. Energy storage systems match the requirements of applications to the energy supply. [1]Power stations, compressors, heating systems etc all have different performance characteristics concerning their response time to changing demand, their lead times for starting up or shutting down and their most efficient point of operation.

Without energy storage the timely availability of energy is compromised and operation of energy generation and conversion devices at low efficiency levels has to be accepted. The decision to use an energy storage system depends on the demands of the application and the cost of competing solutions in renewable energy systems, for instance, the use of fossil fuel based generation and grid connection are competing solutions.[2],[3]

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Energy storage systems can usually be replaced by conventional energy generation. However, this can lead to an inefficient use of fossil fuels and a need for investment in additional energy generators with high power output and fast response time. Where this is acceptable and cost efficient, energy storage systems will not be used. Conversely, low cost and efficient energy storage systems can lower fuel consumption and emissions and can reduce the overall capital investment for an energy system.[4] Hybrid transport systems are an example of this. Basic principles are electrochemistry for batteries and reversible fuel cells, electromagnetic fields for capacitors and Superconducting Magnetic Energy Storage Systems SMES, for the storage of heat and cold and mechanical engineering for flywheels, compressed gas and pumped hydro storage. The driving forces for the use of energy storage are both economical and technological in nature: reducing size cost of operation and investment, increasing efficiency to lower fuel consumption and emissions, and minimizing the impact on the energy infrastructure. [5]

II. DIFFERENT TECHNIQUES USED TO STORE ENERGY

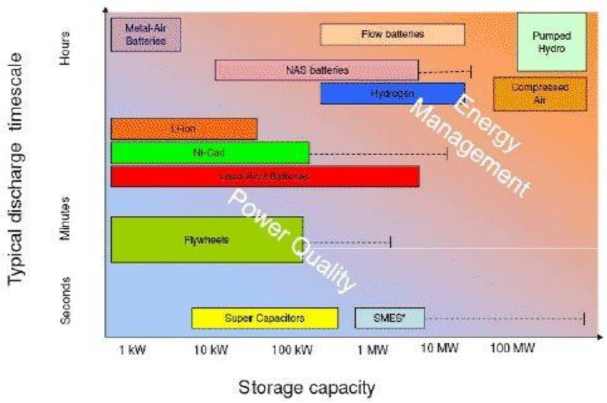

Figure 1. Energy Storage Device

A. Super Conducting Magnetic Energy Storage

This is the only energy storage technology that stores flowing electric current, this flowing current generates a magnetic field in which the energy is stored. These devices are extremely efficient, fast-responding, scalable to large sizes, and environmentally friendly, however, costly. They store electrical energy directly in a magnetic field with essentially no losses due to superconducting coils, aside from losses to keep the coil cool.

WORKING - Direct current that is carries through superconducting material experience no resistive loss. The electric Current that flows in the coil induces a magnetic field in which the energy is stored. The current continues to loop around the coil indefinitely until it is needed and is discharged. However, there is a price for the superconducting

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Property, and it is that the superconducting coil must be super-cooled to very low temperatures, some in the range of 50-77k , others such as alloys of niobium and titanium around 4.5k . These devices require a cryogenic cooling System using liquid nitrogen or helium, and this system presents, in itself, a parasitic energy loss. The amount of energy these devices store depends on both the size of the coil and its geometry (which determines the Inductance, *l*, of the coil). Since a coil is an inductor, it follows physical principles that it stores energy based on the Square of the current, *i*, so

$$E = \frac{1}{2} L * I^2$$

The amount of current flowing in the coil can be incredibly large. At a magnetic Flux density of 5 (tesla), practical superconductors can carry currents of 300,000A/cm^2. [8]

VARIATIONS - The major design variations are in the power and energy capacity of the unit and the geometry of the superconducting coil, none of which deviate by much from the functionality described above. Sometimes smaller capacity SMES Systems (less than 0.1 mwh) are referred to as micro-SMES.[17]

OPERATION & MAINTENANCE - The primary focus of operation and maintenance would be on ensuring that the cryogenic cooling system is functioning properly.

ENVIRONMENTAL IMPACT - The one concern with these systems is the potential effects of large magnetic fields, as there is some uncertainty as to the effects of non-ionizing radiation on human physiology. Aside from that, there are little to no negative environmental impacts of these devices, since the components are nontoxic, and there are no chemical reactions. Also the footprint of this device is rather small, so the ecological impact is negligible. [8]

APPLICATIONS - There are several small SMES units available for commercial use and several larger test bed projects. Several 1 MWH units are used for power quality control in installations around the world, especially to provide power quality at manufacturing plants requiring ultra-clean power, such as microchip fabrication facilities. These facilities have also been used to provide grid stability in distribution systems. SMES is also used in utility applications. The transmission line is subject to large, sudden load changes due to the operation of a paper mill, with the potential for uncontrolled fluctuations and voltage collapse. The engineering test model is a large SMES with a capacity of approximately 20 MWh, capable of providing 40 MW of power for 30 minutes or 10 MW of power for 2 hours.[8],[20]

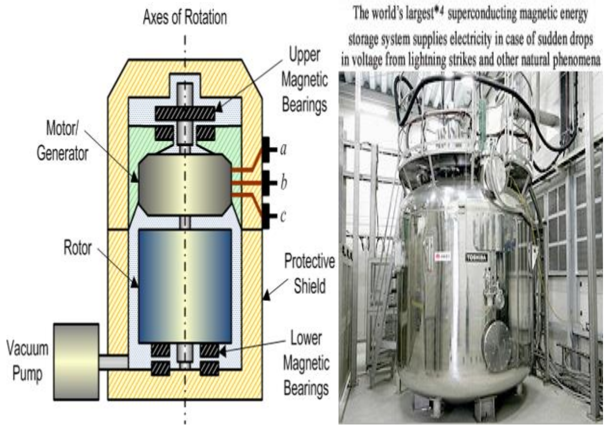

Figure 2. SMES Unit

B. SUPER CAPACITORS:

The most confusing part of this technology may be its name, because in different publications it has gone by many names, Including: supercapacitor, ultracapacitor, pseudo capacitor, electric double-layer capacitor (EDLC), and gold capacitor. These devices are the descendant of the conventional capacitor (electrostatic or electrolytic), but with the capability to hold orders of magnitude more energy (although still less than conventional batteries per volume). [18]

WORKING - Conventional electrostatic capacitors, this is the simplest form of capacitor, and works by storing energy in an electric field. Two plates (electrodes) are placed very close together, but not touching, with either air other non-conductive material (known as a dielectric) in between the plates. A power source is then connected across the plates which place a voltage across the plates, with one side being positively charged and the other negatively charged. This desire of the electron to equalize the charge is their potential to do work, or the stored energy (stored in the electric field). The amount of energy stored in a capacitor is

$$E = \frac{1}{2} C * V^2$$

Electrolytic capacitors, these devices operate essentially the same way as the electrostatic capacitor, except they use an electrolyte as one of the two plates, which means a larger capacitance per unit volume. Electrochemical capacitors the design of "supercapacitors" is essentially a hybrid between batteries and capacitors. They have two electrode plates and an electrolyte in between (like batteries) and when a power source is connected, ions make their way to the electrodes with opposite charges due to the electric field (since oppositely charged objects attract). The difference is that a chemical reaction does not occur; merely the ions migrate; so the storage mechanism is still the electric field. Therefore, unlike batteries that would wear out after being cycled due to numerous chemical reactions, the lifetime of these devices is not significantly impacted by cycling. Also, the electrodes are often made of carbon nanotubes, which, under a microscope, appear as masses of tangled string. This significantly increases the surface area of the electrodes, increasing the storage capacity of these devices significantly. In some devices, every square centimeter of electrode consists of one to two thousand square meters of surface area. [8]

VARIATIONS - There are symmetric and asymmetric designs, referring to the similarity of the two electrodes, and aqueous and organic electrodes. These lead to four potential configurations.

DESIGN CONSIDERATIONS - Due to lower single-cell voltages of about 6 Volts, hundreds of these cells have to be connected in series to achieve higher voltages. This can be a serious problem for larger system designs, since the typical failure mode for a cell is an open circuit. If a single device fails then the entire system may fail. This presents a reliability risk to be factored into the design of the system. Another consideration is due to potential damage due to placing a higher-than-rated voltage across a cell, since, unlike batteries, electrochemical capacitors cannot deal with gassing or the drying-up of electrolyte from electrolysis.

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To keep the voltages within safe operating limitations, resistors or Zener diodes may be connected in parallel and state-of-charge of each device can be monitored and charged or discharged individually.

OPERATION & MAINTENANCE - One of the biggest advantages of electrochemical capacitors over batteries is the ability to Charge and discharge more quickly (since there is no waiting for a chemical reaction to occur). And can practically be charged at any rate as long as the system stays within its designed temperature range, which is 55◦C to 85◦C. [18]

ENVIRONMENTAL IMPACT **-** There is little to no negative environmental impacts of these devices.

APPLICATION- The main applications of super capacitors are vehicles, heavy and public transport, automotive, motor racing, complementing batteries, low-power applications. [8]

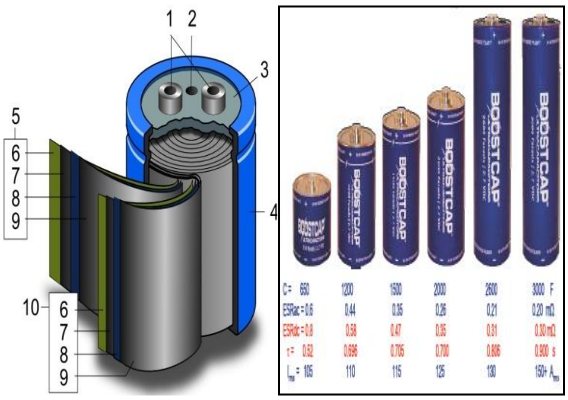

Figure 3. Super Capacitor

C. FLYWHEELS:

Flywheels have been in existence for centuries, however, over the past few decades they have been considered as forms of bulk energy storage. A simple form of kinetic energy storage, these systems are extremely rapid in their response time and, with recent developments in bearing design, have been able to achieve high efficiencies for short durations of storage. Their disadvantages are that they have a high rate of self discharge due to frictional losses, and their relatively high initial costs. **[14]**

WORKING **-** Flywheels store energy in rotating discs as kinetic energy in the form of angular momentum. To "charge" this device, energy is used to power a motor which spins the disc, and the disc remains spinning until the energy is needed. At that point the disc is allowed to turn a generator, which produces electricity. The speed of the flywheel increases during charge (adding energy) and decreases during discharge (losing energy). The kinetic energy of a spinning Mass:

$$E = \frac{1}{2} I * W^2$$

Where, *I* is the moment of inertia and for a solid rotating disc is defined as I= 1/2mr^2 (*m* is mass of The disc, and *r* is the radius of the disc), and ω is the rotational velocity. This implies that by increasing the maximum speed of the disc the energy capacity is more greatly increased than by increasing the mass of the disc .[21],[8]

VARIATIONS **-** These devices are categorized into low-speed and high speed designs.

-Low Speed, most low-speed designs are 10,000 rpm or less, and are typically made of extremely heavy steel discs. The shaft is either vertical or horizontal, and may have mechanical or magnetic bearings.

-High Speed High-speed designs operate above 10,000 rpm, some upwards of 100,000 rpm.

Many flywheels are designed to provide high power output for short periods, on the order Of 5 to 50 seconds.

OPERATION & MAINTENANCE **-** The component that requires the most maintenance would be the bearings. Typically magnetic Bearings are complex systems requiring some care to operate and maintain. Since these devices have hazardous failure modes inspecting these devices for signs of fatigue is critical for preventing catastrophic failure.

ENVIRONMENTAL IMPACT **-** There are little to no negative environmental impacts for flywheels since the materials are not dangerous to health and are rather compact.

APPLICATIONS- The main applications of flywheel energy storage are transportation, rail vehicles, rail electrification, uninterruptible power supplies, laboratories, amusement rides, pulse power, motor sports, grid energy storage, wind turbines, toys, toggle action presses.[8],[22]

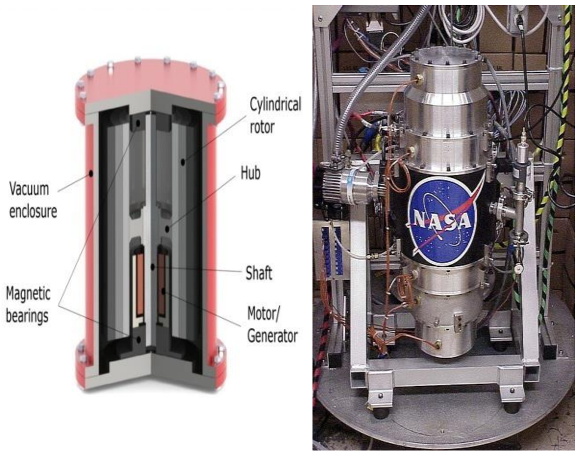

Figure 4. Flywheel

D. PUMPED HYDEOELECTRIC STORAGE (PHS):

PHS simplicity of design, relatively low cost, and similarity in operation to hydroelectric power has made it the industry standard for storage for a century. These systems can quickly ramp up to full load: 10 seconds if the turbine spinning, and 1 minute from standstill. However, they require very specific geographic features that limit unit siting. These systems have high capital cost but very low maintenance costs, and also face criticism due to their significant impact on local wildlife and ecosystems.

WORKING **-** PHS consists of two reservoirs with a height differential and a pipe (or Penstock) connecting them. To store energy, electricity turns a motor which pumps water from the lower reservoir, up the pipe, to the upper reservoir. To produce energy, water is allowed to flow from the upper Reservoir down the pipe through a turbine and into the lower reservoir. The turbine is connected to a generator and as the turbine turns so does the generator, producing electricity.

Today, the motor and generator are typically one in the same, since a motor can also act as a generator. There are two factors that control the power and energy rating of the system: the height difference between the reservoirs (known as the "head" and the volume of the reservoirs (the flow") . The larger the volume of water

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available and the greater the height, the more energy can be stored. The greater the flow rate through the pipes, the more power can be produced. This comes from the basic physical principle that potential energy due to gravity is proportional to mass times height, with the constant of proportionality being acceleration due to gravity.

VARIATIONS - A few design alternatives have been proposed:

- *Underground Pumped Hydroelectric Storage*, in this design the lower reservoir is constructed by excavating rock as far as 300 m underground. The generator/motor is placed in the excavated region underground, and water is pumped from the underground reservoir to the above-ground reservoir. This design allow for the water to flow vertically, minimizing losses due to friction. The environmental impact of this design on the surface is less because it only requires one reservoir that affects the surface. This design requires specific geographic and geologic structures to be in place for this to be viable at a given Site.
- *Pumped Seawater Hydroelectric Storage*, in this design the lower reservoir is the sea, the rest of the design remains unchanged. One benefit is that this can be implemented in many more locations than other designs since there is so many coastlines available. At the same time the use of seawater may lead to Corrosion of the equipment, and adding seawater to the upper reservoir may negatively affect the upper reservoir's ecology .

OPERATION & MAINTENANCE - The operation and maintenance required for this system would be minimal, as these designs are well understood and have been around for many years. Routine maintenance of the generator and turbine, and cleaning the penstock if required would be expected tasks.[8]

ENVIRONMENTAL IMPACT - These systems have significant impacts on the local wildlife, especially if one or both of the reservoirs need to be constructed. Also, the fluctuating water levels can significantly disrupt the inhabitants of the reservoirs.

APPLICATION - In 2009 world pumped storage generating capacity was 104 GW, while other sources claim 127 gw, which comprises the vast majority of all types of utility grade electric storage. The European Union (EU) had 38.3 gw net capacity (36.8% of world capacity) out of a total of 140 gw of hydropower and representing 5% of total net electrical capacity in the EU .

Figure 5. PHES

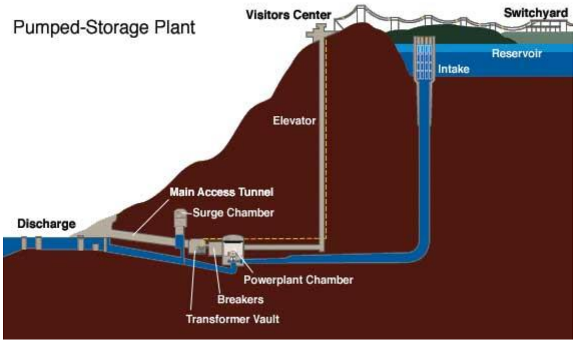

Figure 6. Working Of PHES

E. COMPRESSD AIR ENERGY STORAGE (CAES):

In compressed air energy storage systems, off-peak grid power is used to pump air underground until it reaches a high pressure. It remains underground in a geologic formation until energy is needed, then it is released and heated, and passing through and turning a turbine, which generates power. CAES systems are essentially high-efficiency combustion turbine plants. In CAES systems, the air is already compressed, and therefore uses significantly less fuel. Because of their similarity to standard combustion turbine systems, they are easily integrable into existing power networks. With a ramp rate similar and slightly faster than traditional gas plants, these systems are ideal for meeting peak load.

WORKING - The storage process begins as air is passed through a compressor. The motor for the compressor can be either a separate device or the generator operating as a motor. Cooling the air occurs between each stage (intercoolers) as well as after the compression (after cooler), which reduces the volume of the gas to be stored and removes the heat generated during the compression. Once the air is compressed and stored, it may be released when needed to produce power. [23]During discharge, the air is mixed with fuel (such as gas, oil, or hydrogen) and combusted, and is then passed through the turbine stages, at which point the air expands, releasing energy, causing the turbine to spin and thereby driving the generator to produce electricity.

VARIATIONS - There are two major designs that are considered for this system at present:

- Diabatic CAES cycle, this is the design described above, and the only variation that has been implemented commercially so far. In this case, the heat that is generated during compression is dissipated into the atmosphere, and upon expansion, the compressed air must be reheated, typically with natural gas. The dissipation of heat and use of fuel to reheat the air upon compression result in overall losses of efficiency, but this design is simpler to implement than adiabatic CAES.
- Adiabatic CAES cycle, in this design, the heat that is created during compression is stored and used to reheat the air during decompression, reducing, or theoretically eliminating, the need for fuel consumption. [8]

OPERATION - These systems startup within 5-12 minutes with a ramp rate of 30% of maximum load per minute.

MAINTENANCE - The maintenance requirements are similar to that of a standard combustion turbine natural gas plant of a similar size.

ENVIRONMENTAL IMPACT - Since this technology produces emissions from combustion, there is an

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environmental concern especially compared to emissions-free devices. However, the level of nitro produced is below 5ppm.

APPLICATION - A compressed air engine uses the expansion of compressed air to drive the pistons of an engine, turn the axle, or to drive a turbine. Other applications are cars wind power. [24]

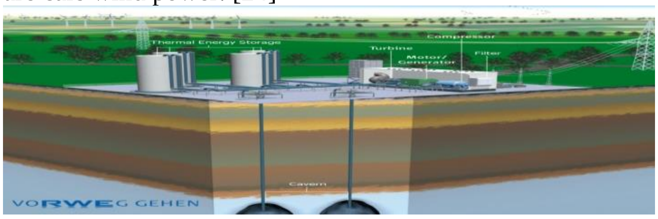

Figure 7. CAES

F. LEAD ACID BATTERIES (L/A):

Rechargeable/secondary battery stores electricity in the form of chemical energy. A battery is made up of one or more electrochemical cells and each cell consists of an electrolyte (liquid, paste or solid) with a positive electrode and a negative electrode. During discharge, electrochemical reactions occur at the two electrodes, generating a flow of electrons through an external circuit. The reactions are reversible, allowing battery to be recharged by applying an external voltage across the electrodes

WORKING **-** Each cell has a negative electrode assembly composed of a lead alloy grid and pure lead active material. The positive electrode is made of a lead alloy grid with lead oxide active material. The electrolyte is a solution of sulfuric acid in water at a concentration of around 37%.

VARIATIONS - There are a number of types of lead acid batteries available, each with different characteristics:

- Flooded Or Vented (VLA).
- Starting, Lighting, And Ignition (SLI)
- Stationary
- Sealed (SLA) and Valve-regulated (VRLA)
- Absorbed Glass Mat (AGM)

OPERATION -There are a number of important operational considerations for this battery type.

- Thermal Considerations: This battery type performs optimally around 77◦F (25◦C). Power capacity falls with decreased temperature since the resistance of the electrolyte is increased..
- Float Charging: When a battery is fully charged, but not in use, it slowly loses energy due to self-discharge.
- Cell-post Maintenance: The metals in cell posts can corrode due to battery fumes and humidity, so they should be regularly inspected and greased.
- Watering: Since overcharging (by even small amounts) leads to hydrolysis (water is lost as hydrogen gas is produced from it), most lead acid batteries (with the exceptions of VRLA) must be refilled with distilled water 3 to 4 times a year .

MAINTENANCE- Due to the chemistry of these devices there are a number of maintenance considerations.

- Gassing: These batteries produce both hydrogen and oxygen gasses during normal charging and especially when the battery is overcharged (significant amounts), and this mixture can be dangerously explosive.
- Sulfation: When cells are undercharged and during regular discharge lead sulphate (pbso4) precipitates on the electrode surfaces and by building up this can lead to decreases in capacity and may damage the cell.
- Hydration: This effect occurs when the battery remains in a low state-of-charge for extended periods the lead components can begin to dissolve into lead hydrates.
- Grid Corrosion: Especially for infrequently-cycled units, this is the most prevalent degradation and failure mode.

ENVIRONMENTAL IMPACT -Clearly, these devices contain large quantities of toxic lead and dangerous sulfuric acid. However, the Battery Council International cites that over 96% of the lead from lead acid batteries is recycled. The sulfuric acid can be neutralized then safely disposed off. [15] ,[11]

APPLICATION- stationary batteries designed for deep discharge are commonly used in large backup power supplies for telephone and computer centers, grid energy storage, and off-grid household electric power systems. Lead–acid batteries are used in emergency lighting and to power sump pumps in case of power failure. Traction (propulsion) batteries [8] are used for in golf carts and other battery electric vehicles. Large lead–acid batteries are also used to power the electric motors in diesel-electric (conventional) submarines and are used on nuclear submarines as well.

G. LITHIUM-ION BATTERIES (LI-ION):

Lithium-ion batteries have become popular in recent years due to their extremely high efficiency (compared with other batteries) as well as their high energy density, power density, and cell voltage, as compared to other battery systems. Their high capital cost, however, has prevented many large-scale systems from being developed.

*WORKING***-** The positive electrode in this design is made of a lithiated (treated with lithium) metal oxide, and the negative electrode is composed of layered graphitic carbon. The electrolyte is made of salts of lithium that have been dissolved in organic carbonates. The principle for electrochemical storage in this device is the redox reaction.

VARIATIONS **-** Other designs involving lithium typically use metallic lithium, which is extremely toxic, lithium-ion designs, therefore are less chemically reactive and therefore more stable and will last longer.

DESIGN CONSIDERATIONS **-** Similar to lead acid batteries, Lithium-ion batteries are typically available in predetermined sizes, and in larger energy storage systems they are typically connected in series/parallel combinations to get the desired power and energy capacity.

ENVIRONMENTAL IMPACT **-** Lithium is caustic and may cause fires when exposed to moisture. The electrolyte used in some lithium batteries is toxic, so care should be taken in recycling these units. Recycling programs are available for these battery designs.[5]

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Figure 8. Battery Energy Storage

H. FUEL CELL

HISTORY **-** In 1938, William Grove developed a new type of "battery" that became known as the "Grove cell." Using a platinum electrode immersed in nitric acid and a zinc electrode immersed in zinc sulphate, he was able to generate about 12 A at 1.8 V. In 1958, Francis Thomas Bacon demonstrated an alkali fuel cell using a stack of 10-in-diameter electrodes. The company, Pratt & Whitney, carried out development resulting in fuel cells on manned space flight vehicles. Fuel cells, using hydrogen as a fuel, became a possibility to replace lead-acid batteries in standby applications. [25]

A fuel cell is a device that converts the chemical energy from a fuel into electricity through a chemical reaction with oxygen or another oxidizing agent. Hydrogen is the most common fuel, but hydrocarbons such as natural gas and alcohols like methanol are sometimes used. Fuel cells are different from batteries in that they require a constant source of fuel and oxygen to run, but they can produce electricity continually for as long as these inputs are supplied. There are many types of fuel cells, but they all consist of an anode (negative side), a cathode (positive side) and an electrolyte that allows charges to move between the two sides of the fuel cell. Electrons are drawn from the anode to the cathode through an external circuit, producing direct current electricity. As the main difference among fuel cell types is the electrolyte, fuel cells are classified by the type of electrolyte they use.

TYPES OF FUEL CELLS **-** Major types of fuel cells considered for standby and alternative electric power use.

- Proton exchange membrane fuel cells (PEMFC) - The archetypical hydrogen–oxygen proton exchange membrane fuel cell (PEMFC) efficient frontier design, a proton-conducting polymer membrane, (the electrolyte), separates the anode and cathode sides. This was called a "solid polymer electrolyte fuel cell" (SPEFC) in the early 1970s, before the proton exchange mechanism was well-understood.
- Solid oxide fuel cells (SOFCs) - SOFCs use a solid material, most commonly a ceramic material called yttria-stabilized zirconia (YSZ), as the electrolyte. Because SOFCs are made entirely of solid materials, they are not limited to the flat plane configuration of other types of fuel cells and are often designed as rolled tubes. They require high operating temperatures (800 to 1000 °C) and can be run on a variety of fuels including natural gas.
- Molten carbonate fuel cells (MCFCs) - MCFC require a high operating temperature, 650 °C (1,200 °F), similar to SOFCs. MCFCs use lithium potassium carbonate salt as an electrolyte, and this salt liquefies at high temperatures, allowing for the movement of charge within the cell ,in this case, negative carbonate ions. [8]

APPLICATIONS **-** Fuel cells utilizing hydrogen as fuel can operate for relatively long periods of time (hours) or for short periods in standby service, much like engine-generator sets or batteries. The following are some specific applications:

- Fuel-cell systems are used in space on the Gemini, Apollo, and Space Shuttle missions.
- Fuel cells are used in UPS, which requires instant availability of power when utility service fails. The fuel cell by itself requires heating to start up. UTC fuel cells show a 5-kW UPS to supply 48 V dc for telecom applications, which uses "ultracapacitor" to supply the energy during the start-up of the fuel cell system.
- The telecom industry is considering fuel cells as an alternative to VRLA batteries for sites requiring 1–3 kW for up to 8 h.

The energy efficiency of a system or device that converts energy is measured by the ratio of the amount of useful energy put out by the system ("output energy") to the total amount of energy that is put in ("input energy") or by useful output energy as a percentage of the total input energy. In the case of fuel cells, useful output energy is measured in electrical energy produced by the system. Input energy is the energy stored in the fuel. [26],[27]According to the U.S. Department of Energy, fuel cells are generally between 40–60% energy efficient. This is higher than some other systems for energy generation. For example, the typical internal combustion engine of a car is about 25% energy efficient. In combined heat and power (CHP) systems, the heat produced by the fuel cell is captured and put to use, increasing the efficiency of the system to up to 85–90%.

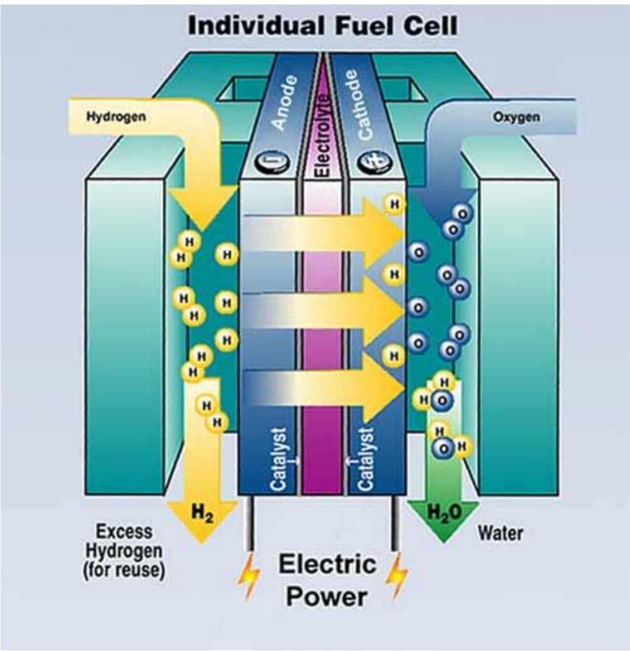

Figure 9 FUEL CELL WORKING

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Figure 10. FUEL CELL

III. CONCLUSION

Energy storage devices provide valuable benefits to improve stability, power quality, and reliability of supply in power systems. In this regard, this paper presents an overview on energy storage devices for power systems applications in the framework of a broader project that intends to project an energy storage system for facilities based on non dispatchable renewable energies. From the analysis performed, it is concluded that long-term energy storage devices like pumping-hydro and compressed air systems are the best suited for centered large-scale storage, on the other hand, batteries and hydrogen fuel cell systems space requirements and modularity place them as ideal solution for distributed energy storage. Moreover, short-term response energy storage devices like supercapacitor are found to be well suited for use in power systems during transient periods that result from a system disturbance such as a line switching. Flywheels, with higher energy storage capacity look like the most appropriate to maintain voltage level and frequency, especially in power systems with considerable penetration of renewable energy like wind.

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