“ENERGY STORAGE”

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**ABSTRACT**

Storage of energy is one of the main problems of contemporary technology. Currently used manners of the energy store are listed below- the magnetic accumulator – the energy is kept in the magnetic field of superconductive inductor, the accumulator with super capacitors. The low voltage (1, 6-2.5V) is the fault of this one, the accumulator with lead-acid or alkaline accumulator. The fault of this solution is very low charging and discharging efficiency, the electromechanical accumulator. Flywheels store energy mechanically in the form of kinetic energy. In this article the flywheel energy storage will be described precisely and compared with other energy storage technologies.

The main objective of utility companies is to provide enough energy to meet the energy demanded. In doing this, they must concur with a set of environmental, economic, and regulatory requirements. The energy should be provided at minimum cost with minimum effect on the environment. System operation should meet all local, state, and federal requirements, along with any contractual agreements. An effort should be made to maximize safety for employees and customers and also to maximize power quality.

**INTRODUCTION**

Energy storage as a natural process is as old as the universe itself - the energy present at the initial creation of the Universe has been stored in stars such as the Sun, and is now being used by humans directly (e.g. through solar heating), or indirectly (e.g. by growing crops or conversion into electricity in solar cells). Storing energy allows humans to balance the supply and demand of energy. Energy storage systems in commercial use today can be broadly categorized as mechanical, electrical, chemical, biological, thermal and nuclear.

A more recent application is the control of waterways to drive water mills for processing grain or powering machinery. Complex systems of reservoirs and dams were constructed to store and release water (and the potential energy it contained) when required.

Energy storage became a dominant factor in economic development with the widespread introduction of electricity and refined chemical fuels, such as gasoline, kerosene and natural gas in the late 1800s. Unlike other common energy storage used in prior use, such as wood or coal, electricity has been used as it has been generated. It has not been stored on a major scale but that may soon change. In the U.S, the 2009 Stimulus plan is researching energy storage and how it may be used with the new plans for a Smart Grid. Electricity is transmitted in a closed circuit, and for essentially any practical purpose cannot be stored as electrical energy. This means that changes in demand could not be accommodated without either cutting supplies (as by brownouts or blackouts) or by
storing the electric energy in another medium. Even renewable energy must be stored in order to make it reliable. Wind blows intermittently and so some form of storage is required to compensate for calm periods, and solar energy is not effective on cloudy days so stored energy must be available to compensate for the loss of sun energy.

An early solution to the problem of storing energy for electrical purposes was the development of the battery, an electrochemical storage device. It has been of limited use in electric power systems due to small capacity and high cost. A similar possible solution with the same type of problems is the capacitor. In the 1980s, a small number of manufacturers carefully researched thermal energy storage (TES) to meet the growing demand for air-conditioning during peak hours. Today a few companies continue to manufacture TES. The most popular form of thermal energy storage for cooling is ice storage, since it can store more energy in less space than water storage and it is also cheaper than fuel cells & flywheels. Thermal storage has shifted gigawatts of power away from daytime peaks, cost-effectively, and is used in over 3,300 buildings in over 35 countries. It works by storing ice at night when electricity is cheap, and then using the ice to cool the air in the building the next day.

Chemical fuels have become the dominant form of energy storage, both in electrical generation and energy transportation. Chemical fuels in common use are processed coal, gasoline, diesel fuel, natural gas, liquefied petroleum gas (LPG), propane, butane, ethanol, biodiesel and hydrogen. All of these materials are readily converted to mechanical energy and then to electrical energy using heat engines (turbines or other internal combustion engines, or boilers or other external combustion engines) used for electrical power generation. Heat-engine-powered generators are nearly universal, ranging from small engines producing only a few kilowatts to utility-scale generators with ratings up to 800 megawatts.

Electrochemical devices called fuel cells were invented about the same time as the battery. However, for many reasons, fuel cells were not well-developed until the advent of manned spaceflight (the Gemini Program) when lightweight, non-thermal (and therefore efficient) sources of electricity were required in spacecraft. Fuel cell development has increased in recent years due to an attempt to increase conversion efficiency of chemical energy stored in hydrocarbon or hydrogen fuels into electricity.

At this time, liquid hydrocarbon fuels are the dominant forms of energy storage for use in transportation. However, these produce greenhouse gases when used to power cars, trucks, trains, ships and aircraft. Carbon-free energy carriers, such as hydrogen, or carbon-neutral energy carriers, such as some forms of ethanol or biodiesel, are being sought in response to concerns about the possible consequences of greenhouse gas emissions.

Some areas of the world (Washington and Oregon in the USA and Wales in the United Kingdom are examples) have used geographic features to store large quantities of water in elevated reservoirs, using excess electricity at times of low demand to pump water up
to the reservoirs, then letting the water fall through turbine generators to retrieve the energy when demand peaks.

Several other technologies have also been investigated, such as flywheels or compressed air storage in underground caverns.

There are many measures of quality in the operation of power systems. For Example, system reliability is an integral part of operating philosophies and procedures. Environmental impact, area control error, and cost minimization are also important Parameters. One of the major concerns of both producers and consumers of power, and perhaps the most important measure of quality, is the maintenance of the proper system frequency. System frequency is a major indicator of the robustness of the system. The above measures of quality are used in developing the control strategies for system operation. Perhaps the most important of these controls is the automatic generation control.

**GRID ENERGY STORAGE**

Grid energy storage lets energy producers send excess electricity over the electricity transmission grid to temporary electricity storage sites that become energy producers when electricity demand is greater. Grid energy storage is particularly important in matching supply and demand over a 24 hour period of time.

**STORAGE METHODS**

**Chemical**
1. Hydrogen
2. Biofuels
3. Liquid nitrogen
4. Oxyhydrogen
5. Hydrogen peroxide

**Biological**
1. Starch
2. Glycogen

**Electrochemical**
1. Batteries
2. Flow batteries
3. Fuel cells
Electrical
1. Capacitor
2. Super capacitor
3. Superconducting magnetic energy storage (SMES)

Mechanical
1. Compressed air energy storage (CAES)
2. Flywheel energy storage
3. Hydraulic accumulator
4. Hydroelectric energy storage
5. Spring

RENEWABLE ENERGY STORAGE

Many renewable energy systems produce intermittent power. In this case, energy storage becomes absolutely necessary to provide firm energy supplies using intermittent sources such as wind or solar power. Further development of renewable power will require some combination of grid energy storage, demand response, and spot pricing. Intermittent energy sources is limited to at most 20-30% of the electricity produced for the grid without such measures. If electricity distribution loss and costs are managed, then intermittent power production from many different sources could increase the overall reliability of the grid.

Non-intermittent renewable energy sources include hydroelectric power, geothermal power, solar thermal, tidal power, Energy tower, ocean thermal energy conversion, high altitude airborne wind turbines, biofuel, and solar power satellites. Solar photovoltaics, although technically intermittent, produce some electricity during peak periods (i.e., daylight), and hence do reduce the need for peak power generation. In general, peak demand periods for power in some locations do not correspond with peak availability of solar energy, which motivates producers to develop new and more effective methods of energy storage and recovery.

On the demand side, demand response programs which send market pricing signals to consumers (or their equipment), can be a very effective way of managing variations in electricity production. For example, intelligent energy storage devices can be set to store energy when electricity is being produced beyond current demand (and prices are lowest), and conversely, and set to distribute energy when demand is high (and prices are highest.) This practice is called energy arbitrage.

THERMAL STORAGE

Thermal storage is the temporary storage or removal of heat for later use. An example of thermal storage is the storage of solar heat energy during the day to be used at a later time for heating at night. In the HVAC/R field, this type of application using thermal storage for heating is less common than using thermal storage for cooling. An example of the storage of "cold" heat removal for later use is ice made during the cooler night time hours for use during the hot daylight hours. This ice storage is produced when electrical utility rates are lower. This is often referred to as "off-peak" cooling.

The advantages of thermal storage are: Commercial electrical rates are lower at night. It takes less energy to make ice when it is cool at night. Source energy (energy from the
power plant) is saved. A smaller, more efficient system can do the job of a much larger unit by running for more hours.

**ENERGY STORAGE TECHNOLOGIES**

1. Batteries  
2. Fuel Cells  
3. Capacitors  
4. Supercapacitors  
5. Comparison Chart

Batteries, fuel cells, capacitors, and supercapacitors are all energy storage devices. Batteries and fuel cells rely on the conversion of chemical energy into electrical energy. Capacitors rely on the physical separation of electrical charge across a dielectric medium such as a polymer film or an oxide layer. Each type of device provides a different combination of power density and energy density.

Supercapacitors rely on the separation of chemically charged species at an electrified interface between a solid electrode and an electrolyte. Only super capacitors can provide a combination of high power density and relatively high energy density.

**Batteries**

A battery is a device that transforms chemical energy into electric energy. All batteries have three basic components in each cell — an anode, a cathode, and an anode and their properties relate directly to their individual chemistries. Batteries are broadly classified into primary and secondary.

Primary batteries are the most common and are designed as single use batteries, to be discarded or recycled after they run out. They have very high impedance which translates into long life energy storage for low current loads. The most frequently used batteries are carbon-zinc, alkaline, silver oxide, zinc air, and some lithium metal batteries (like lithium-thionyl-chloride).

Secondary batteries are designed to be recharged and can be recharged up to 1,000 times depending on the usage and battery type. Very deep discharges result in a shorter cycle life, whereas shorter discharges result in long cycle life for most of these batteries. The charge time varies from 1 to 12 hours, depending upon battery condition, Depth of Discharge (DoD), and other factors. Commonly available secondary batteries are Nickel-Cadmium, lead-acid, Nickel-Metal Hydride, some lithium metal, and Li-ion batteries.

Some of the limitations posed by secondary batteries are limited life, limited power capability, low energy-efficiency, and disposal concerns.
Fuel Cells

Like a battery, a fuel cell uses stored chemical energy to generate power. Unlike batteries, its energy storage system is separate from the power generator. It produces electricity from an external fuel supply as opposed to the limited internal energy storage capacity of a battery.

A typical fuel cell requires a large amount of extraneous control equipment like fuel pumps, cooling systems, fuel tanks, and re-circulators that make them impractical for portable applications. New developments like the small direct methanol fuel cell (DMFC) can do away with a large amount of the extraneous systems. Fuel cells range in size from hand-held systems to megawatt power stations. Most large fuel cells operate at high temperatures (200 °C to 1000 °C); the proton-exchange membrane fuel cell (PEMFC) may be able to operate at room temperature.

Fuel cells operate most efficiently over a narrow range of performance parameters and at elevated temperature, rapidly becoming inefficient under high power demands. Fuel cells will be used in tandem with either batteries or supercapacitors to provide a high-energy, high-power combination. Use of catalyst metals, such as platinum, makes fuel cells an expensive proposition.

Capacitors

Capacitors use physical charge separation between two electrodes to store charge. They store energy on the surfaces of metallized plastic film or metal electrodes; thus, the capacitance is a function of the dielectric medium and the overlapping surface areas. The surface area is a critical feature as the opposing charges are in close proximity separated by a dielectric medium. Most configurations contain a layered arrangement with a separation distance on the micrometer scale which is volumetrically inefficient.

Electrolytic capacitors rely on a layer of oxide material deposited on a metal surface. Here again, the thickness is on the micrometer scale and is very inefficient. Most capacitors can handle large voltages because they contain healing mechanisms that overcome the dielectric breakdown of the charge separation medium.

When compared to batteries and supercapacitors, the energy density of capacitors is very low—less than 1% of a supercapacitor's, but the power density is very high, often higher than that of a supercapacitor. This means that capacitors are able to deliver or accept high currents, but only for extremely short periods, due to their relatively low capacitance.

Supercapacitors

Supercapacitors are very high surface area activated carbon capacitors that use a molecule-thin layer of electrolyte, rather than a manufactured sheet of material, as the dielectric to separate charge. The supercapacitor resembles a regular capacitor except that it offers very high capacitance in a small package. Energy storage is by means of static
charge rather than of an electro-chemical process inherent to the battery. Supercapacitors rely on the separation of charge at an electrified interface that is measured in fractions of a nanometer, compared with micrometers for most polymer film capacitors.

In supercapacitors, the solution between the electrodes contains ions from a salt that is added to an appropriate solvent. The operating voltage is controlled by the breakdown voltages of the solvents with aqueous electrolytes (1.1 V) and organic electrolytes (2.5 to 3 V).

There are three types of electrode materials suitable for the supercapacitor. They are: high surface area activated carbons, metal oxide, and conducting polymers. The high surface electrode material, also called Double Layer Capacitor (DLC), is least costly to manufacture and is the most common. It stores the energy in the double layer formed near the carbon electrode surface.

The lifetime of supercapacitors is virtually indefinite and their energy efficiency rarely falls below 90% when they are kept within their design limits. Their power density is higher than that of batteries while their energy density is generally lower. However, unlike batteries, almost all of this energy is available in a reversible process.

**Comparison Chart**

The following table gives a brief summary of some critical properties of each technology. Because there are so many types with widely different properties, battery values are shown as a range.

<table>
<thead>
<tr>
<th>Property</th>
<th>CAP-XX Supercapacitors</th>
<th>Capacitors</th>
<th>Micro-Fuel Cells</th>
<th>Batteries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charge/Discharge Time</td>
<td>Milliseconds to Seconds</td>
<td>Picoseconds (10^{-12}) to Milliseconds</td>
<td>Typically 10 to 300 hrs. Instant charge (refuel).</td>
<td>1 to 10 hrs</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>-40 to +85 °C</td>
<td>-20 to +100 °C</td>
<td>+25 to +90 °C</td>
<td>-20 to +65 °C</td>
</tr>
<tr>
<td>Operating Voltage</td>
<td>2.3V - 2.75V/cell</td>
<td>6 to 800 V</td>
<td>0.6 V / cell</td>
<td>1.25 to 4.2 V / cell</td>
</tr>
<tr>
<td>Capacitance</td>
<td>100 mF to &gt; 2F</td>
<td>10 pF to 2.2 mF</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Life</td>
<td>30,000+ hrs average</td>
<td>&gt;100,000 cycles</td>
<td>1500 to 10,000 hrs</td>
<td>150 to 1500 cycles</td>
</tr>
<tr>
<td>Weight</td>
<td>1 g to 2 g</td>
<td>1 g to 10 kg</td>
<td>20 g to over 5 kg</td>
<td>1 g to over 10 kg</td>
</tr>
<tr>
<td>Power Density</td>
<td>10 to 100 kW/kg</td>
<td>0.25 to 10,000 kW/kg</td>
<td>0.001 to 0.1 kW/kg</td>
<td>0.005 to 0.4 kW/kg</td>
</tr>
<tr>
<td>Energy Density</td>
<td>1 to 5 Wh/kg</td>
<td>0.01 to 0.05 Wh/kg</td>
<td>300 to 3000 Wh/kg</td>
<td>8 to 600 Wh/kg</td>
</tr>
<tr>
<td>Pulse Load</td>
<td>Up to 100 A</td>
<td>Up to 1000 A</td>
<td>Up to 150 mA / cm²</td>
<td>Up to 5 A</td>
</tr>
</tbody>
</table>
SUPERCONDUCTING MAGNETIC ENERGY STORAGE

Superconducting Magnetic Energy Storage (SMES) systems store energy in the magnetic field created by the flow of direct current in a superconducting coil which has been cryogenically cooled to a temperature below its superconducting critical temperature.

A typical SMES system includes three parts: superconducting coil, power conditioning system and cryogenically cooled refrigerator. Once the superconducting coil is charged, the current will not decay and the magnetic energy can be stored indefinitely.

The stored energy can be released back to the network by discharging the coil. The power conditioning system uses an inverter/rectifier to transform alternating current (AC) power to direct current or convert DC back to AC power. The inverter/rectifier accounts for about 2-3% energy loss in each direction. SMES loses the least amount of electricity in the energy storage process compared to other methods of storing energy. SMES systems are highly efficient; the round-trip efficiency is greater than 95%.

Due to the energy requirements of refrigeration and the high cost of superconducting wire, SMES is currently used for short duration energy storage. Therefore, SMES is most commonly devoted to improving power quality. If SMES were to be used for utilities it would be a diurnal storage device, charged from base load power at night and meeting peak loads during the day.

ADVANTAGES OVER OTHER ENERGY STORAGE METHODS

There are several reasons for using superconducting magnetic energy storage instead of other energy storage methods. The most important advantages of SMES is that the time delay during charge and discharge is quite short. Power is available almost instantaneously and very high power output can be provided for a brief period of time. Other energy storage methods, such as pumped hydro or compressed air have a substantial time delay associated with the energy conversion of stored mechanical energy back into electricity. Thus if a customer's demand is immediate, SMES is a viable option. Another advantage is that the loss of power is less than other storage methods because electric currents encounter almost no resistance. Additionally the main parts in a SMES are motionless, which results in high reliability.

CURRENT USE

There are several small SMES units available for commercial use and several larger test bed projects. Several 1 MW 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. In northern Wisconsin, a string of distributed SMES units was deployed to enhance stability of a transmission loop. 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. Developers of such devices include American Superconductor.

The Engineering Test Model is a large SMES with a capacity of approximately 20 MWh, capable of providing 400 MW of power for 100 seconds or 10 MW of power for 2 hours.

**Calculation of Stored Energy**

The magnetic energy stored by a coil carrying a current is given by one half of the inductance of the coil times the square of the current.

\[
E = \frac{1}{2} \cdot L \cdot I^2
\]

Where

- \( E \) = energy measured in joules
- \( L \) = inductance measured in henries
- \( I \) = current measured in amperes

Now let’s consider a cylindrical coil with conductors of a rectangular cross section. The mean radius of coil is \( R \). \( a \) and \( b \) are width and depth of the conductor. \( f \) is called form function which is different for different shapes of coil. \( \zeta \) (xi) and \( \delta \) (delta) are two parameters to characterize the dimensions of the coil. We can therefore write the magnetic energy stored in such a cylindrical coil as shown below. This energy is a function of coil dimensions, number of turns and carrying current.

\[
E = \frac{1}{2} \cdot f(\zeta, \delta) \cdot R \cdot N^2 \cdot I^2
\]

Where

- \( E \) = energy measured in joules
- \( I \) = current measured in amperes
- \( f(\zeta, \delta) = \) form function, joules per ampere-meter
- \( N \) = number of turns of coil
**Solenoid versus Toroid**

Besides the properties of the wire, the configuration of the coil itself is an important issue from a mechanical engineering aspect. There are three factors which affect the design and the shape of the coil - they are: Inferior strain tolerance, thermal contraction upon cooling and Lorentz forces in a charged coil. Among them, the strain tolerance is crucial not because of any electrical effect, but because it determines how much structural material is needed to keep the SMES from breaking. For small SMES systems, the optimistic value of 0.3% strain tolerance is selected. Toroidal geometry can help to lessen the external magnetic forces and therefore reduces the size of mechanical support needed. Also, due to the low external magnetic field, toroidal SMES can be located near a utility or customer load.

For small SMES, solenoids are usually used because they are easy to coil and no pre-compression is needed. In toroidal SMES, the coil is always under compression by the outer hoops and two disks, one of which is on the top and the other is on the bottom to avoid breakage. Currently, there is little need for toroidal geometry for small SMES, but as the size increases, mechanical forces become more important and the toroidal coil is needed.

The older large SMES concepts usually featured a low aspect ratio solenoid approximately 100 m in diameter buried in earth. At the low extreme of size is the concept of micro-SMES solenoids, for energy storage range near 1 MJ.

**Low-Temperature versus High-Temperature Superconductors**

Under steady state conditions and in the superconducting state, the coil resistance is negligible. However, the refrigerator necessary to keep the superconductor cool requires electric power and this refrigeration energy must be considered when evaluating the efficiency of SMES as an energy storage device.

Although the high-temperature superconductor (HTSC) has higher critical temperature, flux lattice melting takes place in moderate magnetic fields around a temperature lower than this critical temperature. The heat loads that must be removed by the cooling system include conduction through the support system, radiation from warmer to colder surfaces, AC losses in the conductor( during charge and discharge), and losses from the cold-to-warm power leads that connect the cold coil to the power conditioning system. Conduction and radiation losses are minimized by proper design of thermal surfaces. Lead losses can be minimized by good design of the leads. AC losses depend on the design of the conductor, the duty cycle of the device and the power rating.

**Cost**

Whether HTSC or LTSC systems are more economical depends because there are other major components determining the cost of SMES: Conductor consisting of superconductor and copper stabilizer and cold support are major costs in themselves.
They must be judged with the overall efficiency and cost of the device. Other components, such as vacuum vessel insulation, have been shown to be a small part compared to the large coil cost. The combined costs of conductors, structure and refrigerator for toroidal coils are dominated by the cost of the superconductor. The same trend is true for solenoid coils. HTSC coils cost more than LTSC coils by a factor of 2 to 4. We expect to see a cheaper cost for HTSC due to lower refrigeration requirements but this is not the case. So, why is the HTSC system more expensive.

It is worth noting here that the refrigerator cost in all cases is so small that there is very little percentage savings associated with reduced refrigeration demands at high temperature. This means that if a HTSC, BSCCO for instance, works better at a low temperature, say 20K; it will certainly be operated there. For very small SMES, the reduced refrigerator cost will have a more significant positive impact.

Clearly, the volume of superconducting coils increases with the stored energy. Also, we can see that the LTSC torus maximum diameter is always smaller for a HTSC magnet than LTSC due to higher magnetic field operation. In the case of solenoid coils, the height or length is also smaller for HTSC coils, but still much higher than in a toroidal geometry (due to low external magnetic field).

**ENERGY STORAGE DEVICES**

The ability to store energy in large quantities would greatly affect the operating practices and philosophies of electric utilities. Power demand could be met instantaneously with stored energy and the system would rely less on strategies such as automatic generation control or load prediction. Large generating stations could be run at their optimum output 24 hours a day, meeting base load during the day and providing power, along with charging energy storage devices, at night. Pumped hydro plants have already proven their worthiness, with about 38 stations existing today. New technologies have arisen providing more options to electric utilities companies in their use of energy storage devices. Superconducting magnetic energy storage facilities and battery energy storage facilities with thyristor controlled converters are capable of providing instantaneous supply or demand of power. This can improve power quality and improve system operation in terms of frequency maintenance, reduction of area control error, and inadvertent tie-line flow.

The following subsections discuss the proven technology of pumped hydroelectric storage and the largely experimental, but highly promising, technologies of SMES and battery energy storage.

1. Pumped Hydroelectric Energy Storage

2. Superconducting Magnetic Energy Storage

TECHNICAL CHALLENGES

The energy content of current SMES systems is usually quite small. Methods to increase the energy stored in SMES often resort to large-scale storage units. As with other superconducting applications, cryogenics are a necessity. A robust mechanical structure is usually required to contain the very large Lorentz forces generated by and on the magnet coils. The dominant cost for SMES is the superconductor, followed by the cooling system and the rest of the mechanical structure.

1. Mechanical support
2. Size
3. Manufacturing
4. Infrastructure
5. Critical current
6. Critical magnetic field
7. Possible Adverse Health effects

APPLICATIONS

1. HTS Power Transmission Cables-Requires simple Liquid nitrogen cooling that is cheap and easy to produce HTS cables can increase capacity without increasing the environmental footprint
2. HTS Motors - Smaller than conventional motors which reduces friction, windage, and losses in the armature material.
3. Generators - Convert mechanical energy into electrical energy more efficiently. Greater weight and volume economy than other methods. Can generate power at transmission voltages, which eliminates the need for transformers at generating stations.

CURRENT LACK OF REPRESENTATION IN INDUSTRY

(1) As current is passed through a superconductor, the superconductivity was destroyed by the created magnetic field before appreciable values for a utility application could be reached.
(2) Expensive refrigeration units and high power cost to maintain operating temperatures.
(3) Existence and continued development of adequate technologies using normal conductors.

These still pose problems for superconducting applications but are improving over time. Advances have been made in the performance of superconducting materials. Furthermore, the reliability and efficiency of refrigeration systems have improved significantly to the point that some devices are now able to operate on electrical power systems.

CONCLUSION

The use of energy storage devices in the electric power system is not a new concept. Thomas Edison used lead-acid batteries in his early electric power business. They were used to store energy during the daytime for use at night when the generating stations were shut down. Ironically, the most common use of energy storage devices in utility companies today is just the opposite. Energy is stored at night when the cost is low for use during the day when the cost is high. The need for energy storage in the power industry arises mainly due to the variations in electric power demand. Electric power demand is constantly changing. Rapidly changing loads can bring about problems with maintaining the desired system frequency, large area control errors, and with inadvertent tie-line flow.

REFERENCES


