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Captive Energy Methods For Electrical Power System

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Abstract

In Electric Power systems, power quality and reliability has become one of the issues of prime importance. Some of the major disadvantages in electric power supply system are the deviations in power supply which make some of the electronic equipment's and domestic devices highly sensitive to it. To avoid such problems we need to find out devices that can provide a backup during the time of voltage sags and such deviations. Energy storage technologies help to avert such conditions.The energy storage devices does not represent energy sources, they provide valuable added benefits to improve stability, power quality, and reliability of supply. Over the past few decades many new and innovative ideas have been explored in the broad area of energy storage.Battery technologies have improved significantly in order to meet the challenges of practical electric utilities. Flywheel technologies are being used as an advanced nonpolluting uninterruptible power supply technique. Superconducting energy storage systems are still in their prototype stages but receiving attention for utility applications. Compressed Air Energy Storage and Thermal heat storage are a few recent methods developed for providing peak load supplies. Also there are hydrogen fuel and pump storage hydroelectricity technologies for storing energy. These technologies can also be incorporated into traditional power generating stations to increase the overall efficiency. These energy storage devices and technologies help to store and harness the renewable source of energy which is very essential. This paper focuses on these advancements made and provides a composite picture of costs and trends in storage technologies.

I. INTRODUCTION

The generation of electric power is the basic pillar for normal functioning of every modern society. India has experienced impressive gross domestic product (GDP) growth rates exceeding 7% over the past few years. Although recent trends appear to indicate an economic slowdown, long-term 7%+ GDP growth is expected to continue through at least 2020. To support India's expanding economy, large-scale power capacity additions in the range of 150 GW to 175 GW are projected over the next 10 years. However the rate of growth of the economy and the powetgeneration capacity of India has not been proportional. The power sector has not seen tremendous increase as it should have seen in terms of its capacity. Also for the past many years there has been a shortfall in the peak load demand and the demand that is met by the power sector utilities. This is shown by the figure below. All these have eventually lead to voltage fluctuations and deviations and other issues related to power quality.

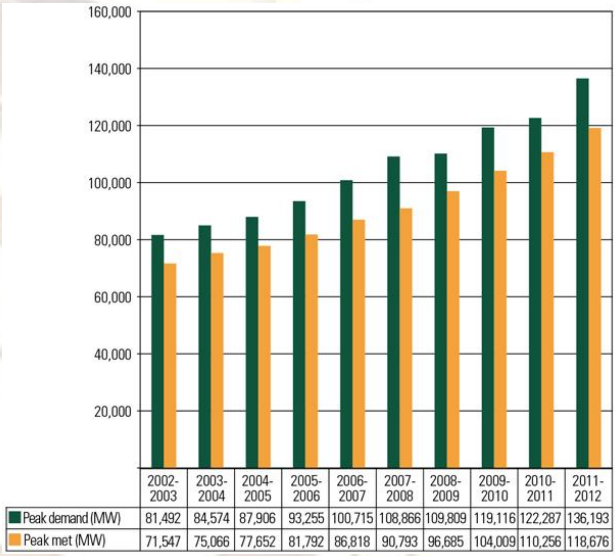

Figure 1. India's peak demand gap

Talking in terms of the future, according to the Five-year plans established by the government's Planning Commission has laid out specific targets for new generation capacity. For the 12th five-year plan (2012–2017), 83,000 MW of new capacity has been targeted [8]. In order to achieve this target we require better captive energy storage systems to increase the overall generation capacity and the power quality.

These storage elements will also help to meet the consumer's demand for electric power which varies cyclically during day and night, as well as within the week and the seasons. Moreover the quality of an electric power supply is determined by the available reserve capacity at the energy utility. In general an electrical power generating system should have 15-20% of reserve power available to meet any consumer demand. In case the demand is not met or there is insufficient reserve capacity to meet that demand, a decline in voltage at the consumer side will appear which would upset the normal operation at the user's end and would eventually lead to a failure. For this reason it is essential for the normal functioning and development of each nation to have reliable national and local electric power systems with capacities exceeding the actual energy demand by at least 15%. However, in most of the developing nations like India have capacities that can only just meet their energy demands, and in some cases are simply inadequate as shown in fig1. This shortfall of electrical energy often hinders the social and economic progress of a nation.

Now with this growth of different industries the mechanical and electronic loads have increased tremendously. Thus the issue of quality of power supply has become a critical issue and has gained importance. Power system engineers facing these challenges seek solutions to allow them to operate the system in a more flexible, controllable manner. Generally when power system disturbances occur, synchronous capacitors which are mostly used are not always able to respond rapidly enough to keep the system stable. This is where energy storage technology can play a very important role in maintaining system reliability and power quality. The ideal solution is to have means to rapidly damp oscillations, respond to sudden changes in load, supply load during transmission or distribution interruptions, correct load voltage profiles with rapid reactive power control, and still allow the generators to balance with the system load at their normal speed. Thus with this paper we provide an insight into the new methods of captive energy storing.

II. EXSISTING METHODS OF ENERGY STORAGE

Electrical energy in a system cannot be stored electrically. However, energy can be stored by converting the ac electricityand storing it electromagnetically, electrochemically, kinetically, or as potential energy. Each energy storage technology usuallyincludes a power conversion unit to convert the energy from one form to another.

The existing methods for energy storage include batteries and flywheel while, the latest technology in includes compressed air energy storage, super capacitor energy storage and superconducting magnetic energy storage.

A. BATTERY STORAGE SYSTEMS.

Batteries are one of the most cost-effective energy storagetechnologies available, with energy stored electrochemically.A battery system is made up of a set of low-voltage/powerbattery modules connected in parallel and series to achievea desired electrical characteristic. Batteries are "charged"when they undergo an internal chemical reaction under apotential applied to the terminals. They deliver the absorbedenergy, or "discharge," when they reverse the chemicalreaction. Key factors of batteries for storage applicationsinclude: high energy density, high energy capability, roundtrip efficiency, cycling capability, life span, and initial cost.There are a number of battery technologies under considerationfor large-scale energy storage. Lead-acid batteriesrepresent an established, mature technology. Lead-acidbatteries can be designed for bulk energy storage or for rapid charge or discharge.Lead-acid batteries still represent a low-cost option for most applications requiring large storage capabilities, with the low energy density and limited cycle life as the chief disadvantages. Mobile applications are favoring sealed lead-acid battery technologies for safety and ease of maintenance. Valve regulated lead-acid (VRLA) batteries have better cost and performance characteristics for stationary applications. Several other battery technologies also show promise for stationary energy storage applications. All have higher energy density capabilities than lead-acid batteries, but at present, they are not yet cost effective for higher power applications. Leading technologies include nickel–metal hydride batteries, nickel–cadmium batteries, and lithium-ion batteries. The last two technologies are both being pushed for electric vehicle applications where high energy density can offset higher cost to some degree.

Due to the chemical kinetics involved, batteries cannot operateat high power levels for long time periods. In addition,rapid, deep discharges may lead to early replacementof the battery, since heating resulting in this kind of operationreduces battery lifetime. There are also environmentalconcerns related to battery storage due to toxic gas generationduring battery charge/discharge. The disposal of hazardousmaterials presents some battery disposal problems. The disposal problem varies with battery technology.

B. FLYWHEEL ENERGY STORAGE SYSTEM(FESS)

A flywheel stores energy in a rotating mass. Depending on the inertia and speed of the rotating mass, a given amount of kinetic energy is stored as rotational energy. The flywheel is placed inside a vacuum containment to eliminate friction-loss from the air and suspended by bearings for a stabile operation. Kinetic energy is transferred in and out of the flywheel with an electrical machine that can function either as a motor or generator depending on the load angle (phase angle). When acting as motor, electric energy supplied to the stator winding is converted to torque and applied to the rotor, causing it to spin faster and gain kinetic energy. In generator mode kinetic energy stored in the rotor applies a torque, which is converted to electric energy. Thus flywheel is basically an electromechanical device that couples a motor generator with a rotating mass to store energy for shortdurations.The kinetic energy stored. The kinetic energy stored in a flywheel is proportional to the mass and to the square of its rotational speed.

$$T = \frac{1}{2} J\omega^2$$

Where J is polar moment of inertia about axis of rotation and ω is the angular velocity. The energy storage capability of flywheels can be improved either by increasing the moment of inertia of flywheel or by turning it at higher rotational velocities, or both.

Apart from the flywheel additional power electronics is required to control the power in- and output, speed, frequency etc. This forms the flywheel electrical interface and generally includes the motor drive inverter and bus voltage regulator. The figure below shows the flywheel energy storage system

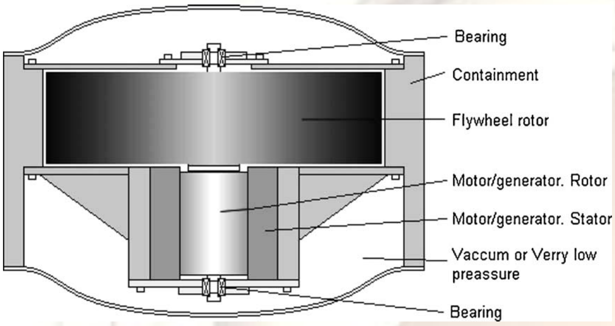

Figure 2. Basic layout of flywheel energy storage

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□ □ □ Flywheels can respond to many power quality issues such as frequency deviation, temporaryinterruptions, voltage sags, and voltage swells. The amount of energy stored in an FES device mainly depends on the angularvelocity of the rotor**.** Flywheel energy storage system constitutes short term storage systems, which are generally sufficient to improve the power qualitycompared to other ways of storing electricity, Flywheel energy storage systems have long lifetimes. Rapid charging of a system occurs in less than 15 minutes. FESS has an overall round trip efficiency includingthe electronics, bearings, and flywheel drag of 80-85% . With the life expectancy of about 20 years, the currentflywheel designs are modular and can range in size up to 10 plus MW systems. Advanced flywheels constructed from carbon fibermaterials and magnetic bearings can spin in vacuum at speeds up to 40,000 to 60,000 RPM.

C. FUEL CELLS

Fuel cells, electrochemical devices that directly convert hydrogen, or hydrogen-rich fuels into electricity without combustion,are another alternative to reciprocating engines. Although their structure is somewhat like thatof a battery, the charge duration is extended by the ability to use an external fuel source, mainly hydrogen, stored directly orreformed from other fossil fuels. The technology is developing with a few commercial uses today, but with a promise toemerge as a significant source of electricity in the near future. This process is much more efficient than traditional thermal power plants, theoretically converting up to 80% of the chemical energy in the fuel into electricity (compared to the 60% efficiency of combined cycle power plants).The overall efficiency of hydrogen storage depends greatly on the technique used and the scale of the operation, but is typically 50 to 60% which is lower than for compressed air systems or batteries. Hence this process is generally avoided for providing the excess energy demand.

III. EMERGING TECHNOLOGIES FOR ENERGY STORAGE

The above methods are not very efficient and also prove costly in terms of both feasibility and maintainability. Hence, there have been quite a few emerging techniques which have been developed over a period of years. These techniques help us to provide efficient solutions to all storage related problems. These methods also act as an storage element for renewable sources of energy like solar, wind and geothermal. The major upcoming techniques include compressed air energy storage, super magnetic energy storage.

A. COMPRESSED AIR ENERGY STORAGE(CAES)

The largest share of the energy generated by a gas turbine is consumed by itscompressor. This fact combined with the fluctuations in the demand for power and itsconsequent time of use pricing formed the motivation for the development of theCompressed Air Energy Storage (CAES) technology.

As the name implies, the compressed air energy storage (***CAES***) plant uses electricity to compress air which is stored in underground reservoirs.The CAES technology consists of converting excess base load energy into storedpneumatic energy by means of a compressor for a later release through a gas turbineas premium peaking powerDue to the storage option, a partial-load operation of the CAES plant is also very flexible. More often, during the period of high electrical energy demand, the compressed air is mixed with natural gas and they are burnt together, in the same fashion as in a conventional turbine plant. This method is actually more efficient as the compressed air will lose less energy. CAES consumes two third less fuels than other conventional sources [4]. The basic components required in a CAES plant are as shown in fig: 3[7]

• During off-peak periods a motor is operated to drive the compressor train using electricpower from the grid, which is usually supplied by coal or nuclear base load plants.

• The air compressor which may require two or more stages, intercoolers and after coolers to achieve economy ofcompression, and reduce the moisture content.
• The recuperator, turbine train, high and low pressure turbines.
• Equipment control centre for operating the combustion turbine, compressor.
• Auxiliaries to regulate and control changeover from generation mode to storage mode.

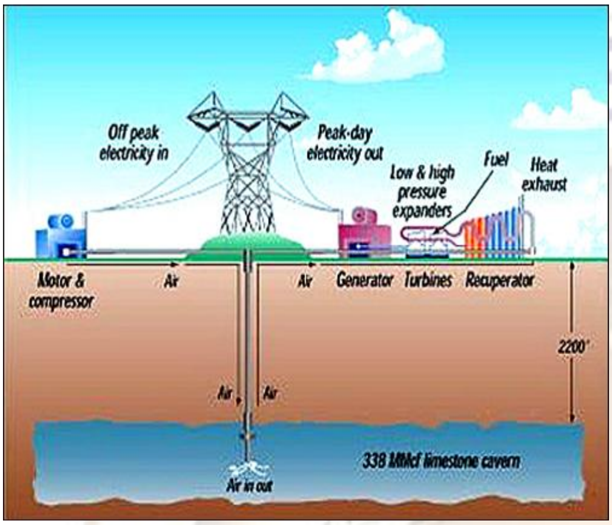

Figure 3. Compressed air energy storage system

A CAES operates by means of large electric motor driven compressor that store energy in the form of compressed air in cavern. The compression is done outside periods of peak demand. The air is then pressurized to about 75 bars. To supply electricity to the customers, air is extracted from the cavern. It is first preheated in the recuperator. The recuperator reuses the energy extracted by the compressor coolers. The heated air is then mixed with small quantities of oil or gas, which is burnt in the combustor. The hot gas from the combustor is expanded in the turbine to generate electricity. The key requirement to a CAES system is that the reservoir has to be air tight and very large.

The advantages of CAES plants are as it has high storage capacity is take less starting time which makes it efficient from other conventional storage systems. It does not involve huge and costly installation. Also the emission of greenhouse gases is substantially lower than in normal gas plants.

The only drawback this system has is that there is actually not a lot of underground cavern around, which substantially limits the usability of this storage method. However, for locations where it is suitable, it can provide a viable option for storing energy in large quantities and for long times

B. ULTRA CAPACITORS

An ultra-capacitor, also known as supercapacitors or electrochemical double layer capacitor, basically consists of two electrodes, a separator and an electrolyte. The electrode made up of a metallic collector, which is the high conducting part, and an active material, which is the high surface area part. The two electrodes are separated by a membrane, the separator, which allows a mobility of the charged ions but forbids an electronic conductance. The most interesting electrodes materials are: metal oxides, carbons and conducting polymers. The electrolyte may be of the solid state, organic or aqueous type depending on the applicationCapacitors store electric energy by accumulating positive and negative charges separated by an insulating dielectric. The capacitance represents the relationship between the stored charge, and the voltage between the plates. The energy stored on the capacitor depends on the capacitance and on the square of the voltage. It is given as follows

$$E = \frac{1}{2}C.v^2$$

The amount of energy a capacitor is capable of storing can be increased by either increasing the capacitance or the voltage stored on the capacitor. Capacitors are used in many ac and dc applications in power systems. DC storage capacitors can be used for energystorage for power applications. At present, ultra capacitors are most applicable for high peak-power, low-energy situations. Capable of floating at full charge for ten years, an ultra-capacitor can provide extended power availability during voltage sags and momentary interruptions [2]. Ultra capacitors can be completely discharged, installed easily, are compact in size, and can operate effectively in diverse (hot, cold, and moist) environments, no cooling required

Ultra-capacitors are now available commercially at lower power levels. A disadvantage is that a SC does not approach the energy density of batteries. Considering the technical maturity, the chemical inertness ,the environmental impact ,the manufacturing process, the expected performances and costs, carbon based supercapacitors are the most interesting and promising devices for industrial applications[3].

C. SUPER MAGNETIC ENERGY STORAGE(SMES)

Instead of storing kinetic or chemical energy, SMES devices store electrical energy in magnetic field. An SMES unit is a device that stores energy in the magnetic field generated by the dc current flowing through a superconducting coil. 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. It consists of a large superconducting coil at the cryogenic temperature. This cryogenic temperature is maintained by a cryostat that contains helium or nitrogen liquid vessels.

A power conversion/conditioning system (PCS) connects the SMES unit to an AC power system, and it is used to charge/discharge the coil. Two types of power conversion systems are commonly used. Current source converter (CSC) to both interface to the ac system and charge/discharge the coil and Voltage source converter (VSC) to interface to the ac system and a dc–dc chopper to charge/discharge the coil. The modes of charge/discharge/standby are obtained by controlling the voltage across the SMES coil. The SMES coil is charged or discharged by applying a positive or negative voltage across the superconducting coil. The SMES system enters a standby mode operation when the average VCOIL is zero, resulting in a constant average coil Current ICOIL shown in figure

The inductively stored energy (E in joules) and the rated power (P in watts) are commonly given specifications for SMES devices, and they can be expressed as follows:

$$E = \frac{1}{2}L.I^2 \text{ ,} P = \frac{dE}{dt} = \text{V.I}$$

where L is the inductance of the coil, I is the dc current flowing through the coil, and V is the voltage across the coil. Since energy is stored as circulating current, energy can be drawn from an SMES unit with almost instantaneous response with energy stored or delivered over periods ranging from a fraction of a second to several hours.

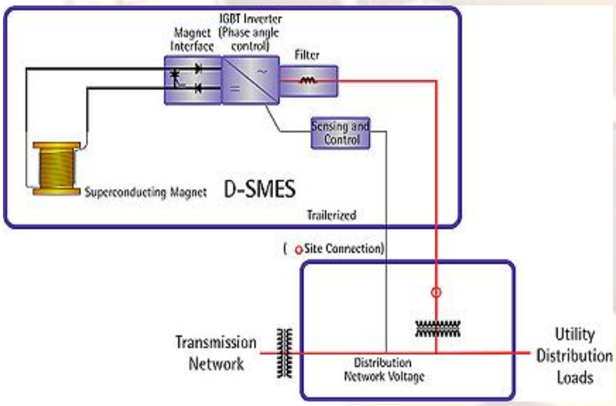

Figure 4. Components of typical SMES system

The dynamic performance of a SMES system is far superior to other storage technologies. Faster and more efficient access to the stored energy and a shorter response time are the leading advantages [1]. But there are a few concerns in it application at large scale. One of the major problems is its cost**.** When compared with other energy storage technologies, today's SMES systems are still costly. The integration of an SMES coil into existing flexible ac transmission systems (FACTS) devices eliminates the cost for the inverter unit, which is typically the largest portion of the cost for the entire SMES system. The use of high temperature superconductors should also makeSMES cost effective due to reductions in refrigeration needs. There are a number of ongoing SMES projects currently throughout the world.

IV. ECONOMICS OF ENERGY STORAGE ELEMENTS

Energy storage system costs for a transmission application are driven by the operational requirements. The costs of the system can be broken down into three main components: the energy storage system, the supporting systems (refrigeration for SMES is a big item), and the power conversion system. The cost of the energy storage system is primarily determined by the amount of energy to be stored. The configuration and the size of the power conversion system may become a dominant component for the high-power low energy storage applications. Energy storage is economical when the marginal cost of electricity varies more than the costs of storing and retrieving the energy plus the price of energy lost in the process. However, the marginal cost of electricity varies because of the varying operational and fuel costs of different classes of generators. At one hand, base load power plants such as coal-fired power plants and nuclear power plants are low marginal cost generators, as they have high capital and maintenance costs but low fuel costs. At the other hand, peak power plants such as gas turbine natural gas plants burn expensive fuel but are cheaper to build, operate and maintain. To minimize the total operational cost of generating power, base load generators are dispatched most of the time, while peak power generators are dispatched only when necessary, generally when energy demand peaks. However, operators are storing lower-cost energy produced at night, then releasing it to the grid during the peak periods of the day when it is more valuable. This is called economic dispatch.In order to establish a realistic cost estimate, thfollowingsteps are suggested:

- Identify the system issue(s) to be addressed;
- Select preliminary system characteristics;
- Define basic energy storage, power, voltage and current requirements
- Optimize system specification and determine system cost;
- Determine utility financial benefits from operation;
- compare system's cost and utility financial benefits to Determine adequacy of utility's return on investment;
- compare different energy storage systems performance and costs.

V. ANALYSIS OF ENERGY STORAGE DEVICES

On the basis of different parameters different energy storage devices have been analyzed as shown in the Table 1.

PARAMETERS	SMES	CA-ES	FESS	SCES	BESS
TYPICAL RANGE	1-100 MW	25 to 350 MW	Ranging in KW	1-250 KW	100-20 MW
POWER DENSITY (kW/m3)	>530		>700 - 1800	>17500	>(100-7000)
EMISSIONS	No	No	No	No	Very few
ELECTRICAL EFFICIENCY	~95%	~70 %	90-95%	<95%	88-92%
LIFE TIME	~30 Years	<50 Years	10-20 yr (HS) 20 yr (LS)	10-20 Years	3-6 yrs
RESPONSE TIME	Milliseconds	~1-2 Mins	~1-2 Mins	Milliseconds	Few seconds
BACKUP TIME	Seconds	Hours	Minutes	Seconds	Hours

TABLE I. ANALYSIS OF DIFFERENT ENERGY STORAGE ELEMNTS

VI. CONCLUSION

Among the potential performance benefits produced byadvanced energy storage applications are improved systemreliability, dynamic stability, enhanced power quality, transmissioncapacity enhancement, and area protection. An energystorage device can also have a positive cost and environmentalimpact by reducing fuel consumption and emissionsthrough reduced line losses and reduced generation availabilityfor frequency stabilization.

As deregulation takes place, generation and transmissionresources will be utilized at higher efficiency rates leadingto tighter and moment-by-moment control of the spare capacities.Energy storage devices can facilitate this process,allowing the utility maximum utilization of utility resources.The new power electronics controller devices will enableincreased utilization of transmission and distribution systems with increased reliability. This increased reliance will resultin increased investment in devices that make this asset moreproductive. Energy storage technology fits very well withinthe new environment by enhancing the potential application of custom power, and power quality devices.

This paper shows that energy storage devices can be integratedto power electronics and other mechanical devices to provide powersystem stability, enhanced transmission capability, and improvedpower quality. Adding energy storage to power electronicscompensators not only enhances the performance ofthe device, but can also provide the possibility of reducingthe MVA ratings requirements of the front-end power electronics conversion system. This is an important cost/benefitconsideration when considering adding energy storage systems. Also the method is useful in storing energy from non-renewable energy sources. Thus these techniques help us to increase the overall efficiency and increase the net plant output.

REFERENCES

[1] Buckles W., Hassenzahl W. V. May 2000. Super conducting magnetic energy storage, *IEEE Power Engineering Review*.
[2] Bullard G. L., Sierra-Alcazar H. B., Lee H. L., Moms J. L., January 1989. Operating principles of the Ultracapacitor, *IEEETransactions in Magnetics*, Vol.25.
[3] Hassenzahl W. V., 1997. Capacitors for electric utility energy storage: *Electric Power Res. Inst.*
[4] Smith S.C., Sen P.K., Benjamin K. 2008. Advancement of energy storage devices and applications in electrical power systems,*IEEE PES General*
[5] ELNA America Inc.,1988. Comparison of double layer capacitor, batteries and super magnetic storage device, *Technical Paper*
[6] http://www.wikipedia.org.
[7] http://phys.org/news188048601.html
[8] http://www.powermin.nic.in