International Journal of Engineering Applied Sciences and Technology, **2016**
Vol. 1, Issue 3, ISSN No. 2455-2143, Pages 1-5
Published Online December – January. 2016 in IJEAST (http://www.ijeast.com)

ENERGY STORAGE SYSTEM, THEIR TYPES AND NEED FOR INTEGRATION OF RENEWABLE ENERGY TO SMART GRID

Toshi Mandloi
Department of Electrical Engineering
SVITS, M.P. , India

Anil K Jain
Department of Electrical Engineering
SVITS, M.P. , India

Abstract- **The increased penetration of Renewable Energy Resources like Solar PV, wind, biogas and many others in existing installations is fundamentally altering the power sector across the world. The shift towards more and more distributed power in grid integration of renewable. The seasonal fluctuations in solar power generation and the inherent unpredictability of energy from these sources have led to increased adaption of energy storage systems, like batteries, flywheel, electrical vehicles etc. due to the intermittent behavior of the RES and uphold the endurance of the power network. Such increases the efficient and maximum utilization of renewable energy sources when available. Being at the prolific stage of development in India we often face issues like; complexity and non-flexibility, design considerations, high capital investment, and lack of technical conscience about ESS. The paper discusses Various Electricity Energy storage system, their need in integration of renewable energy to smart grid.**

Keywords- ***Electricity Storage System (ESS), Renewable Energy Resources (RER), Pumped Storage Hydro, Flywheel, Compressed Air Energy System (CAES), Smart Grid***

I. INTRODUCTION

Electrical energy is stored during times when production exceeds consumption, and the stores are used at times when consumption exceeds production. Till about a few years ago, we thought that electricity cannot be stored and needs to be consumed as and when it is generated. Times are changing, today electricity can be stored in megawatt scale thanks to developments made in storage technologies and solutions. These electricity energy storage (EES) applications are increasingly becoming viable around the world.

The smart grids are expected to be the biggest achievement of the 21st century. And energy storage technologies are going to be an important part of it. Electricity production need not be drastically scaled up and down to meet momentary consumption. Instead, production is maintained at a more constant level. Advantage that fuel-based power plants (i.e. coal, oil, gas) can be more efficiently and easily operated at constant production levels. In the present scenario, large amounts of wind, solar, and other renewable energy sources are added to existing electrical grids, Efficient and manageable energy storage becomes a crucial component to allowing a range of eco-friendly resources to play a significant role in our energy system. In order to increase the use of renewable energy production within the existing electrical power grid, Large Energy Storage Systems can provide a number of ways that energy can be stored and converted back to electricity.

II. TYPES OF ELECTRICAL ENERGY STORAGE SYSTEM

The storage techniques can be divided into four categories, according to their applications:

- Low-power application in isolated areas, essentially to feed transducers and emergency terminals.
- Medium-power application in isolated areas (individual electrical systems, town supply).
- Network connection application with peak leveling.
- Power-quality control applications.

  The Electrical energy Storage systems are broadly classified into mechanical, electrochemical, chemical, electrical and thermal energy storage systems.

A. Mechanical
- Pumped Hydro
- Compressed Air
- Flywheel

B. Electrochemical
- Secondary Batteries (Lead Acid / NiCd / Li / NaS)
- Flow Batteries

C. Chemical

D. Electrical
- Double Layer Capacitor
- Super conducting Magnetic coils

E. Thermal (sensible heat storage molten salt / A- CAES)

Globally there is about 202 GW of grid connected storage systems of which 135 GW is pumped hydro and 65 GW is UPS systems, rest about 267 7MW being new storage technologies:

International Journal of Engineering Applied Sciences and Technology, **2016**
Vol. 1, Issue 3, ISSN No. 2455-2143, Pages 1-5
Published Online December – January. 2016 in IJEAST (http://www.ijeast.com)

Table I

Technology	**MW**
Thermal	1000
Solar thermal	601
Batteries	594
Compressed air	440
Flywheels	42

A. **Pumped storage hydro**

In many places, pumped storage hydroelectricity is used to even out the daily generating load, by pumping water to a high storage reservoir during off-peak hours and weekends, using the excess base-load capacity from coal or nuclear sources. During peak hours, this water can be used for hydroelectric generation, often as a high value rapid-response reserve to cover transient peaks in demand. Pumped storage recovers about 75% of the energy consumed, and is currently the most cost effective form of mass power storage. The chief problem with pumped storage is that it usually requires two nearby reservoirs at considerably different heights, and often requires considerable capital expenditure. Pumped water systems have high dispatch ability, meaning they can come on line very quickly. A new concept in pumped-storage is utilizing wind energy or solar power to pump water. Wind turbines or solar cells that direct drive water pumps for an energy storing wind or solar dam can make this a more efficient process but are limited. Such systems can only increase kinetic water volume during windy and daylight periods. Hydroelectric dams with large reservoirs can also be operated to provide peak generation at times of peak demand. Water is stored in the reservoir during periods of low demand and released through the plant when demand is higher. The net effect is the same as pumped storage, but without the pumping loss. Depending on the reservoir capacity the plant can provide daily, weekly, or seasonal load flow. A hydroelectric dam originally built to provide base load power will have its generators sized according to the average flow of water into the reservoir. The most successful energy storage systems due to their fast response and storage capacity, pumped storage hydro have been proven to be excellent reserves. The world installed capacity is about 135GW. Their long lifetimes and stability are what makes them ideal storage systems. However technical and commercial issues have prevented their large scale adoption.

B. **Compressed air energy storage (CAES)**

Another grid energy storage method is to use off-peak or renewably generated electricity to compress air, which is usually stored in an old mine or some other kind of geological feature. When electricity demand is high, the compressed air is heated with a small amount of natural gas and then goes through turbo-expanders to generate electricity. 440MW of installations exist around the world. This technology is based on the conventional gas turbines and stores energy by compressing air in an underground storage cavern. Electricity is used to compress air and when needed the compressed air is mixed with natural gas, burned and expanded in a modified gas turbine. The turbine produces the same amount of output power as conventional gas turbines but uses only 40% of the gas. Round trip efficiencies of up to 70% are reached. Undersea insulated airbags based systems are the latest under trials. The advantage of CAES is its large capacity; disadvantages are low round-trip efficiency and geographic limitation of locations.

C. **Flywheels**

Mechanical inertia is the basis of this storage method. A heavy rotating disc is accelerated by an electric motor, which acts as a generator on reversal, slowing down the disc and producing electricity. Electricity is stored as the kinetic energy of the disc. Friction must be kept to a minimum to prolong the storage time. This is often achieved by placing the flywheel in a vacuum and using magnetic bearings, tending to make the method expensive. The ranges of power and energy storage technically and economically achievable, however, tend to make flywheels unsuitable for general power system application, they are probably best suited to load-leveling applications on railway power systems and for improving power quality in renewable energy systems. Rotational energy is stored in a large rotational cylinder where the energy is maintained by keeping its speed constant. A transmission device is used to accelerate or decelerate the flywheel by supplying and extracting electricity. When the speed is increased higher amounts of energy are stored. A vacuum chamber is used to reduce friction, and the rotors are made of carbon fiber composites suspended by magnetic bearings. Flywheels are extensively used for space applications. Latest generation flywheels are reported to be suitable for grid applications. The long life of this technology with relatively less maintenance requirements and excellent cycle stability make it an ideal storage solution, however the high levels of self-discharge due to air resistance and bearing losses make it less efficient.

D. **Batteries**

Battery storage was used in the early days of direct-current electric power networks, and is appearing again. Battery systems connected to large solid-state converters have been used to stabilize power distribution networks. Nickel-cadmium battery bank can be to stabilize voltage at the end of a long transmission line. Many "off-the-grid" domestic systems rely on battery storage, but storing large amounts of electricity in batteries or by other electrical means has not yet been put to general use. Batteries are generally expensive, have high maintenance, and have limited life spans. When plug-in hybrid and/or electric cars are mass-produced these mobile energy sinks could be used for their energy storage capabilities. However, a large disadvantage of using vehicle to grid energy storage is the fact that each storage cycle stresses the battery with one complete charge-discharge cycle.

- NaS - by far sodium sulphur batteries are considered the most matured technology.
- LiB - rechargeable Lithium Bromide has changed our daily life. This technology has products for all the four industry segments- electronics, EVs, home applications and grid connected applications. Li is a comparatively light metal and is very active.
- Lead Acid - Lead acid batteries are the world's most widely used battery type and have been commercially deployed since about 1890. Their usability decreases when

International Journal of Engineering Applied Sciences and Technology, 2016
Vol. 1, Issue 3, ISSN No. 2455-2143, Pages 1-5
Published Online December – January. 2016 in IJEAST (http://www.ijeast.com)

high power is discharged and this makes them unviable as MW scale solutions.

- Vanadium redox - this technology is a flow type battery that is emerging as a dark horse. Flow batteries use PEM fuel cell technology.

E. **Chemical Storage**

Chemical storage is achieved through accumulators and batteries. These systems have the double function of storage and release of electricity by alternating between the charge–discharge phases. They can transform the chemical energy generated by electrochemical reactions into electrical energy and vice versa, without harmful emissions or noise, and require little maintenance. Their main assets are their energy densities (up to 150 and 2000Wh/kg for lithium) and technological maturity. Their main inconvenience however is their relatively low durability for large-amplitude cycling (a few 100 to a few 1000 cycles).

F. **Electric Double layer capacitors**

Hydrogen is also being developed as an electrical energy storage medium. Hydrogen is produced using electrical energy and then compressed or liquefied, stored, and then converted back to electrical energy. Hydrogen can be produced by the electrolysis of water into hydrogen and oxygen. Hydrogen is then be converted back to electricity in an internal combustion engine, or a fuel cell which convert chemical energy into electricity. Energy is required to produce a kilogram of hydrogen by electrolysis, so the cost of the electricity clearly is crucial. Hydrogen can be used as a fuel for portable (vehicles) or stationary energy generation. Compared to pumped water storage and battery. 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 pumped storage systems or batteries.

G. **Super conducting 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. It 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%.

H. **Thermal storage**

Use of molten salt as a heat store to store heat collected by a solar power tower so that it can be used to generate electricity in bad weather or at night. Off-peak electricity can be used to make ice from water, and the ice can be stored until the next day, when it is used to cool either the air in a large building, thereby shifting that demand off-peak, or the intake air of a gas turbine generator, thus increasing the on-peak generation capacity. The second prototype of Isentropic Pumped Heat Electricity Storage System was a success proving the electricity-in to electricity-out (round trip efficiency) in the range of 72 to 85%. The isentropic PHES system utilizes a highly reversible heat engine/heat pump to pump heat between two storage vessels. Systems use cold water, hot water or ice storage to store the heat and use for later. The efficiencies vary with the material. They are important for integrating large scale renewable energy as concentrated solar thermal technology can be used as a reliable and despatchable source of energy to balance the supply and demand.

Table II
Comparison of Technical Parameters of Energy Storage Technologies

Storage Technology	Pumped Hydropower	Compressed Air Storage	Batteries	Flywheels	SMES	Capacitors
Energy Storage Capacity	<24,000 MWh	400–7200 MWh	< 200 MWh	< 100 kWh	0.6 kWh	0.3 kWh
Duration of Discharge at max. power level	~ 12 hours	4 – 24 hours	1 – 8 hours	Minutes to 1 hour	10 s	10 s
Power level	100–300	< 2000 MW	< 30 MW	< 100 kW	200 kW	100 kW
Cycle Efficiency	0.87	0.8	0.7 – 0.85	0.93	0.95	0.95
Lifetime	40 yrs	30 yrs	2 – 10	20 yrs	40 yrs	40 yrs

III. DEMAND / IMPORTANCE OF ENERGY STORAGE IN GRIDS

Growth of Renewable Energy Resources in the electric power system is undergoing significant changes as more Renewable Energy Resources (RER) such as wind and solar are added to the generation mix. These RER are being implemented primarily to satisfy the increasing load requirements of electricity through renewable-energy When distribution and transmission lines in India are not able to supply electricity to remote rural villages, then there is a hope of innovation. Over one third (33%) of India's rural population lacked electricity, as did 6% of the urban population. Of those who did have access to electricity in India, the supply was intermittent and unreliable. The solution to the current scenario of Smart-grid is integration of energy storage with the grid. This hybrid Smart-grid will solve most of the issues of Smart-grid like random generation of electricity. Energy storage can play two major roles in terms of energy management. Short-term: The battery regulates the system by absorbing or supplying power to maintain a balance between instantaneous power production and consumption. Long-term, Energy storage also helps the operator by storing electricity from off-peak period and delivering it at on-peak period. Thus it avoids wastage of energy at times when it is not required and supply energy when intermittent primary energy resources are unavailable. The fundamental drawback of any renewable energy is its intermittent nature. Integrating appropriate energy storage technologies with solar systems in India can make solar power despatchable, reduce stress on the grid and optimize overall system resources. Storage combined with solar can also improve the return on investment in solar by allowing the customer to utilize the solar energy most cost effectively. Energy storage systems can also provide the reactive power support required to ensure power quality. Electrical energy storage (apart from pumped storage hydropower) is still a peripheral part of the power generation infrastructure. However, the advancing use of renewable energy is changing the perception of storage and has lead to significant increase in interest towards energy storage. The developments over the last ten years have brought a range of new storage technologies to the brink of commercialization. Though only few of the new storage technologies have made it to the commercialization stage for the large-scale, grid-connected electricity sector, falling costs and increasing efficiencies among storage technologies could imply a much larger application of these technologies for the electricity generation sector.

Table III
Status of Electricity Storage Technology Development

Commercial	**Pre-commercial**	**Demonstration phase**	**Developmental**
• Pumped hydro • Flywheels (local power quality) • Compressed air energy storage (CAES) • Lead acid battery • Ni – Cd battery • Sodium sulphur battery	• Flywheel • Flywheel (grid device) • Zinc-bromine battery • Vanadium redox battery	• Electrochemical capacitor • Hydrogen loop	• Lithium ion (grid applications) • Super-magnetic energy (storage applications)

IV. RENEWABLE ENERGY AND ITS IMPACT ON ENERGY STORAGE

The fast growth of the Indian renewable energy sector is likely to spur significant growth in the use of energy storage systems as well. Most growth for energy storage is expected to emanate from the solar energy sector, within which, adoption will be highest for the off-grid power generation segment. Batteries will continue to remain the storage system of choice for off-grid renewable energy storage. There are a number of mechanisms by which the addition of Renewable Energy potentially increases the value of energy storage. For the purposes of this analysis, we consider two general categories of storage benefits: energy shifting and reserves provision. Energy shifting represents the ability of storage to levelize the net load on the system, charging during periods of lower demand using lower-cost base load resources (potentially including renewable energy sources) and discharging during periods of higher demand to avoid the operation of higher-cost units. It also includes the ability to avoid start-up and shutdown of thermal generators. The ability of energy storage to shift timing of generation and increase economic efficiency of the grid is a well-understood source of value. The value of energy storage in this application is largely dependent on the cost difference between units that generate during off-peak and on-peak periods. The potential impact of Renewable Energy resources is to decrease off-peak prices more than it decreases on-peak prices, increasing the price spread able to be arbitraged by energy storage.

A second potential impact of Renewable Energy on the value of storage is the change in operating reserves requirement. Operating reserves requires power plants to rapidly vary output in response to system contingencies or other short-term variation in net load. The addition of Renewable Energy increases the total reserves requirements, which could increase the cost of total reserves and the overall size of the market for reserves.

V. CONCLUSION

Virtually all devices that operate on electricity are adversely affected by the sudden removal of their power supply. Solutions such as UPS (uninterruptible power supplies) or backup generators are available, but these are expensive. Efficient methods of power storage would allow for devices to have a built-in backup for power cuts, and also reduce the impact of a failure in a generating station. Examples of this are currently available using fuel cells and flywheels. The importance of storage systems in electricity grids is finally receiving the attention of system planners as more storage options become available. As nations around the world continue to increase their portfolios of renewable energy, the participation of storage is increasing. The design of smart grids in the future will take advantage of storage in dealing with more dynamic loads and sources. It should be noted that not all energy storage technologies effectively provide all the services. For example, very fast-acting flywheel or super-capacitor technologies are not currently cost competitive with other storage technologies for energy arbitrage applications or providing multi-hour peaking capability. Interest in energy storage has exploded in the last few years, largely fuelled by the rapid development of variable renewable energy resources. Energy storage technologies span a range of approaches, capabilities, and development maturity. Relatively high capital costs of currently mature technologies compared with traditional generating resources has hampered their development. An emphasis on energy storage is merited as power systems continue to move toward higher levels of renewable-sourced generation, and reduced reliance on fossil fuels. Interest in energy storage is spurring improvement in many of the technologies that are at relatively early stages of maturity. After examining much of the literature available on energy storage, the following may be concluded:

- Complexities in calculating and realizing the value of energy storage results in a failure to recognize that the full system benefits of storage, at least partly because of the complexity involved.
- Energy storage includes both mature technologies and technologies that appear to have much development potential.
- Energy storage deserves to be evaluated on par with other resources in utility resource plans.
- Today, generation rises and falls to meet demand by tapping existing energy storage available in hydro reservoirs, natural gas production and storage fields.
- As reliance on variable generation grows, so will the need for balancing services and opportunities for storage during times of oversupply, Chemical and thermal technologies appear promising to meet that challenge.

VI. REFERENCES

[1] Y. Riffoneau, S. Bacha, F. Barruel, and S. Ploix, “Optimal power flow management for grid connected PV systems with batteries,” *IEEE Trans. Sustain. Energy*, vol. 2, no. 3, pp. 309–320, Jul. 2011.
[2] A Nourai and D. Kearns, BSmart grid goals realized with intelligent energy storage, IEEE Power Energy, vol. 8, no. 2.
[3] J. Eyer and G. Corey, Energy Storage for the electricity grid: Benefits and market potential assessment guide,’’Sandia Rep. SAND2010-0815, Feb. 2010.
[4] EPRI-DOE Handbook of Energy Storage for Transmission and Distribution Applications, 2003. [Online]. Available:www.epri.com
[5] KEMA, Benefits of Fast-Response Storage Devices for System Regulation in ISO Markets, June 2008 AES Corporation Rep., 2008.
[6] G. Bjelovuk and A. Nourai, B Community Energy Storage (CES) and the Smart Grid,[presented at the ESA Presentation, May 2009. [Online]. Available: www.aeptechcentral.com/ces
[7] S. Hamilton. (2008, Dec.). Batteries are key to wind integration. T&D World, pp. 34–37. [Online]. Available: www.tdworld.com
[8] EPRI-DOE Handbook Supplement of Energy Storage for Grid Connected Wind Generation Applications, 2004. [Online]. Available: www.epri.com
[9] B. Lee and D. Gushee. (2008, Jun.). Massive Electricity Storage. AICHe White Paper. [Online]. Available: www.aiche.org
[10] IEEE Power & Energy (2005) Magazine, Energy Storage Issue, Mar./Apr. 2005.
[11] Renewable Energy Interconnection and Storage - Technical Aspects, Ben Kroposki, PE
[12] National Renewable Energy Laboratory
[13] http://www.iec.ch/whitepaper/pdf/iecWP-energystorage-LR-en.pdf
[14] http://www.youtube.com/watch?v=xQW0CWzQ8oo
[15] http://www.eai.in/ref/ct/ees/ees.html
[16] EPRI. (July 1976). Assessment of Energy Storage Systems Suitable for Use by Electric Utilities. EPRI-EM264. Palo Alto, CA:EPRI.
[17] European Commission, A Roadmap for moving to a competitive low carbon economy in 2050, EU, March 2011.
[18] Fuchs, G., Lunz, B.; Leuthold, M.; Sauer, D. U.; Technology Overview on Electricity Storage; Smart Energy for Europe Platform GmbH (SEFEP), June 2012.
[19] Eyer, J.; Corey, G. (Feburary 2010). Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide. Sandia National Laboratories.
[20] Figueiredo, F.C.; Flynn, P.C.; Cabral, E.A. (2006). “The Economics of Energy Storage in 14 Deregulated Power Markets.” Energy Studies Review (14); pp. 131–152.