Course on Integrating Renewable Energy Sources into Emerging Electric Power Systems

(16-20 May, 2011)

IIT Mandi

LARGE SCALE ENERGY STORAGE SYSTEMS

By:

Dr. R.P. Saini
Associate Professor
Alternate Hydro Energy Centre,
Indian Institute of Technology Roorkee

Roorkee - 247 667, INDIA
Large-scale energy storage is also called as Grid energy storage. The methods used to store electricity on a large scale within an electrical power grid.
LARGE ENERGY STORAGE SYSTEM

- Electrical energy is stored during times when production exceeds consumption.

- The stores are used at times when consumption exceeds production.
LARGE ENERGY STORAGE SYSTEM

• 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 past, to convert to renewable sources of energy, many issues were raised on the economics and the difficulties of sitting energy storage.

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.

The question is how to enhance renewable generation energy storage relative to economic and carbon impact.

The issues of reliability, sitting, economics, and efficiency are required to be discussed.

It should include the practicalities of energy storage, generation, and absorption of electrical power.

Under this presentation, various types of storage system are discussed.
TYPES OF ENERGY STORAGE SYSTEMS

- Flywheel.
- Battery Storage.
- Compressed air.
- Superconducting magnetic energy.
- Thermal
- Hydrogen.
- Pumped water.
FLYWHEEL ENERGY STORAGE

- 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.
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.

Vehicle-to-grid technology can be employed, turning each vehicle with its 20 to 50 kWh battery pack into a distributed load-balancing device or emergency power source.

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.
Companies are researching the possible use of Electric Vehicles for meeting peak demand.

A parked and plugged-in EV could sell the electricity from the battery during peak loads and charge either during night (at home) or during off-peak.
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.
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.
SUPERCONDUCTING MAGNETIC ENERGY STORAGE

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.
SUPERCONDUCTING MAGNETIC ENERGY STORAGE

- 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%. The high cost of superconductors is the primary limitation for commercial use of this energy storage method.

- For superconducting magnetic energy to become practical the technical challenges have to be solved.
SUPERCONDUCTING MAGNETIC ENERGY
THERMAL ENERGY 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 utilises a highly reversible heat engine/heat pump to pump heat between two storage vessels.
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

- 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.
PUMPED-STORAGE HYDROELECTRICITY

- 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.
Worldwide installed storage capacity for electrical energy

- Pumped Hydro: 127,000 MW

- Compressed Air Energy Storage: 440 MW
- Sodium-Sulfur Battery: 316 MW
- Lead-Acid Battery: ~35 MW
- Nickel-Cadmium Battery: 27 MW
- Flywheels: <25 MW
- Lithium-Ion Battery: ~20 MW
- Redox-Flow Battery: <3 MW

Over 99% of total storage capacity

Source: Fraunhofer Institute, EPRI
PUMPED WATER

Diagram showing the process of pumped water, including generation and storage, with components such as substations, motor/generator, pump-turbine, weight, return pipe, and deep storage shaft.
PUMPED WATER

Pumped Storage Hydroelectric Power Plants

- Flow of water
- Flow of electricity

Power Plants: Thermal Nuclear

Daytime peak (Generating)

Pumped Storage

Power Plants: Thermal Nuclear

Nighttime off-peak (Storing water)
Mountain Pumped-Storage Plant

- Visitors Center
- Switchyard
- Reservoir
- Intake
- Elevator
- Main Access Tunnel
- Surge Chamber
- Powerplant Chamber
- Breakers
- Transformer Vault
- Discharge
PUMPED-STORAGE HYDROELECTRICITY

- Pumped water systems have high dispatchability, meaning they can come online 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 dam up rating

- 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.
Hydroelectric dam up rating

- 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 following.

- Many existing hydroelectric dams are fairly old and their original design predated the newer intermittent power sources such as wind and solar by decades.

- 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.

- Up rating such a dam with additional generators increases its peak power output capacity, thereby increasing its capacity to operate as a virtual grid energy storage unit.
LARGE ENERGY STORAGE SYSTEM

- Economics
- Load leveling
- Energy demand management
- Portability
Generally speaking, 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 extreme, 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 extreme, peaking 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. This is called “economic dispatch”.
Demand for electricity from the world's various grids varies over the course of the day and from season to season.

For the most part, variation in electric demand is met by varying the amount of electrical energy supplied from primary sources.

Increasingly, 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.

In areas where hydroelectric dams exist, release can be delayed until demand is greater; this form of storage is common and can make use of existing reservoirs.

Renewable supplies with variable production, like wind and solar power, tend to increase the net variation in electric load, increasing the opportunity for grid energy storage.
LOAD LEVELING ECONOMICS

The demand for electricity from consumers and industry is constantly changing, broadly within the following categories:

- **Seasonal** (during dark winters more electric lighting and heating is required, while in other climates hot weather boosts the requirement for air conditioning)
- **Weekly** (most industry closes at the weekend, lowering demand)
- **Daily** (such as the peak as everyone arrives home and switches the television on)
- **Hourly** (one method for estimating television viewing figures in the United Kingdom is to measure the power spikes during advertisement breaks or after programmes when viewers go to switch the kettle on)
- **Transient** (fluctuations due to individual's actions, differences in power transmission efficiency and other small factors that need to be accounted for)

There are currently three main methods for dealing with changing demand.

- Electrical devices generally having a working voltage range that they require, commonly 220–240 V. Minor variations in load are automatically smoothed by slight variations in the voltage available across the system.
LOAD LEVELING ECONOMICS

- Power plants can be run below their normal output, with the facility to increase the amount they generate almost instantaneously. This is termed 'spinning reserve'.
- Additional power plants can be brought online to provide a larger generating capacity. Typically, these would be combustion gas turbines, which can be started in a matter of minutes.

- The problem with relying on these last two methods in particular is that they are expensive, because they leave expensive generating equipment unused much of the time, and because plants running below maximum output usually produce at less than their best efficiency.

- Grid energy storage is used to shift load from peak to off-peak hours. Power plants are able to run closer to their peak efficiency for much of the year.

- Optimal supply-demand leveling strategies depend on the supply-demand mismatch: daily (diurnal) storage must be high efficiency, while seasonal storage would need very low storage costs.
ENERGY DEMAND MANAGEMENT

➤ The only way to deal with varying electrical loads is to decrease the difference between generation and demand.

➤ If this is done by changing loads it is referred to as demand side management (DSM). For decades, utilities have sold off-peak power to large consumers at lower rates, to encourage these users to shift their loads to off-peak hours, in the same way that telephone companies do with individual customers.

➤ Usually, these time-dependent prices are negotiated ahead of time. In an attempt to save more money, some utilities are experimenting with selling electricity at minute-by-minute spot prices, which allow those users with monitoring equipment to detect demand peaks as they happen, and shift demand to save both the user and the utility money.

➤ Demand side management can be manual or automatic and is not limited to large industrial customers. In residential and small business applications, for example, appliance control modules can reduce energy usage of water heaters, air conditioning units, refrigerators, and other devices during these periods by turning them off for some portion of the peak demand time or by reducing the power that they draw.
ENERGY DEMAND MANAGEMENT

- Energy demand management includes more than reducing overall energy use or shifting loads to off-peak hours. A particularly effective method of energy demand management involves encouraging electric consumers to install more energy efficient equipment.

- For example, many utilities give rebates for the purchase of insulation, weather stripping, and appliances and light bulbs that are energy efficient.

- Some utilities subsidize the purchase of geothermal heat pumps by their customers, to reduce electricity demand during the summer months by making air conditioning up to 70% more efficient, as well as to reduce the winter electricity demand compared to conventional air-sourced heat pumps or resistive heating.

- Companies with factories and large buildings can also install such products, but they can also buy energy efficient industrial equipment, like boilers, or use more efficient processes to produce products. Companies may get incentives like rebates or low interest loans from utilities or the government for the installation of energy efficient industrial equipment.
PORTABILITY

- This is the area of greatest success for current energy storage technologies. Single-use and rechargeable batteries can provide power for devices with demands as varied as digital watches and cars.

- Advances in battery technology have generally been slow, however, with much of the advance in battery life.

- Battery capacity has become an issue as pressure grows for alternatives to internal combustion engines in cars, trucks, buses, trains, ships, and airplanes.

- Converting electrical energy to carbon-based liquid fuel has potential to provide portable energy storage usable by the large existing stock of motor vehicles and other engine-driven equipment, without the difficulties of dealing with hydrogen or another exotic energy carrier.

- These synthetic pathways may attract attention in connection with attempts to improve energy security in nations that rely on imported petroleum.
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.
Thank You