Renewable Energy Systems

EE—325

Storage of Electric Energy

- Energy demand fluctuates thorough the day mostly in a predictable way.
- Base load power plants with less generation cost essentially meet off peak hour demand.
- During peak hours, however, they are complemented with thermal power plants fuelled by oil and gas with higher generation cost.
- The generation economy can be improved by eliminating costlier generation technologies by storing electrical energy during off-peak hours and then retrieving it during peak hours.
- It is possible to operate base load power plants at their full generation capacity and store surplus energy in storage devices to be retrieved during peak hours.

Storage of Electric Energy

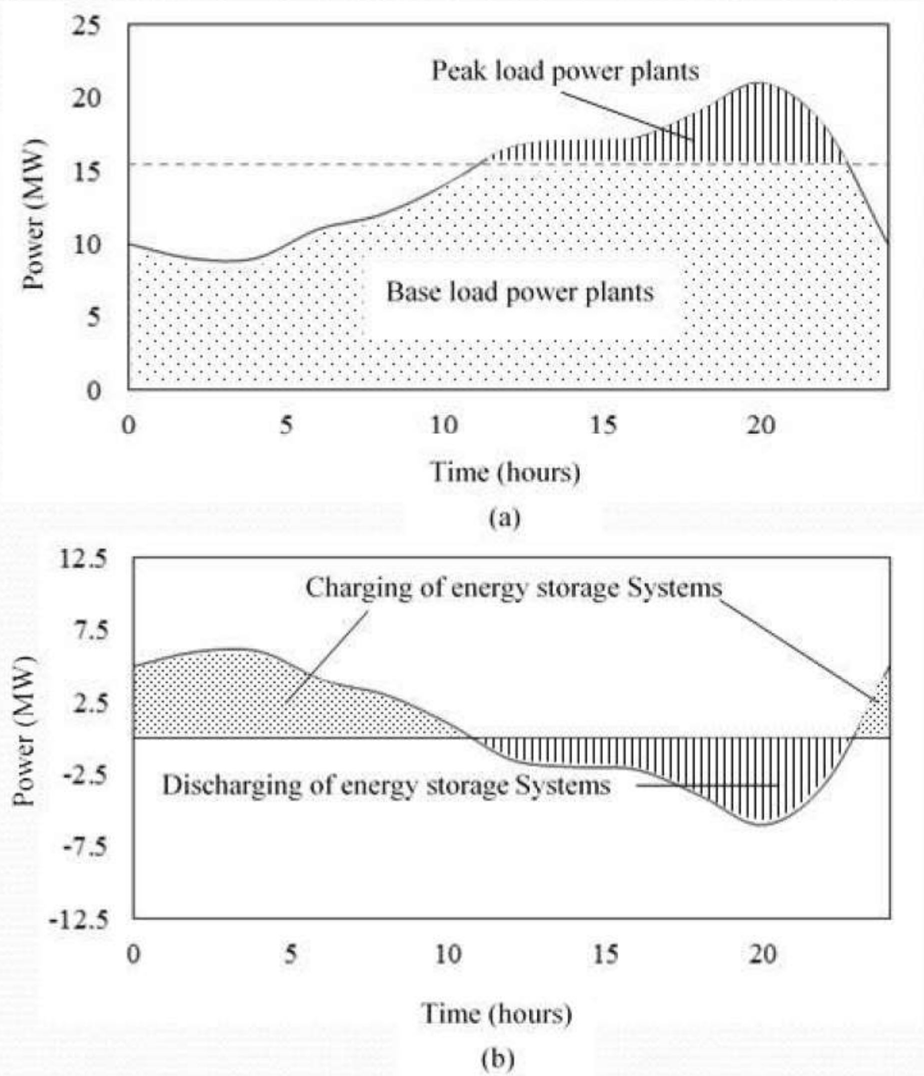

Figure 4.31. a) Daily load curve and charging, and b) discharging of energy storage devices.

Storage of Electric Energy

- Advantages of loading shifting or load management
  - Optimal operation of base load power plants
  - Reduction in equipment wear and tear
  - Deferral to up-gradation of generation, transmission, and distribution capacity
  - Compensation for temporary loss of production of a generating unit
  - Supplying short time bridging power while switching energy sources without interruption such as transition from grid power to diesel generators in blackouts
  - Reduction in the hazardous emissions and overall improvement in power quality and grid reliability.
  - Storage of surplus energy cost-free energy from renewables when available to supply times when production is less or not available.

Electric Energy Storage Technologies

- Energy storage technologies are classified into the following categories:
  - Mechanical include pumped hydro, compressed air, and flywheel storage systems
  - Electromagnetic include superconductors
  - Electrostatic include super-capacitors
  - Electrochemical include hydrogen and batteries
- Each of these technologies is characterized by its storage capacity, charging rate and discharging rate, efficiency, number of charging discharging cycles, cost, etc.

Pumped Hydro Energy Storage (PHS)

With more that 127GW storage capacity worldwide, the share of PHS systems in energy storage technologies is about 99%.

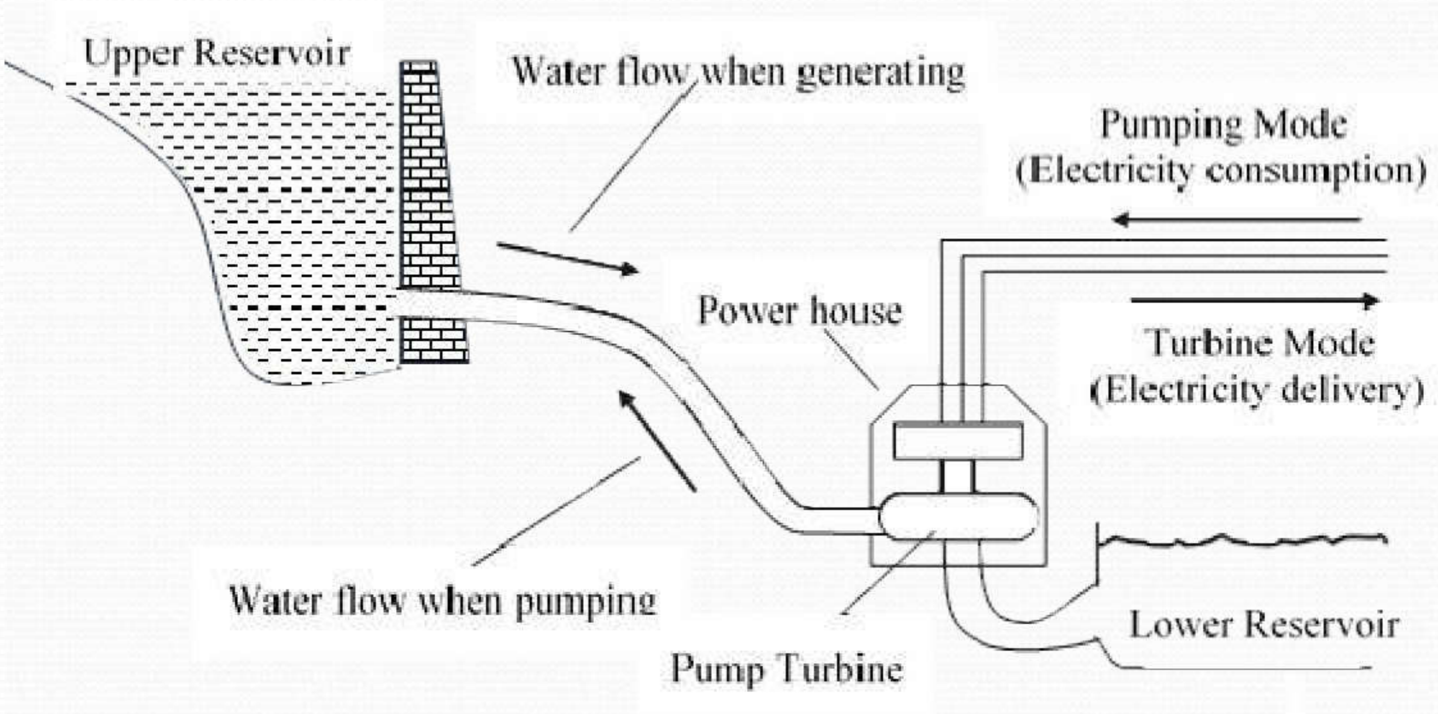

Figure 3.30. Schematic diagram of pumped storage hydroelectric power plant.

Compressed Air Energy Storage (CAES)

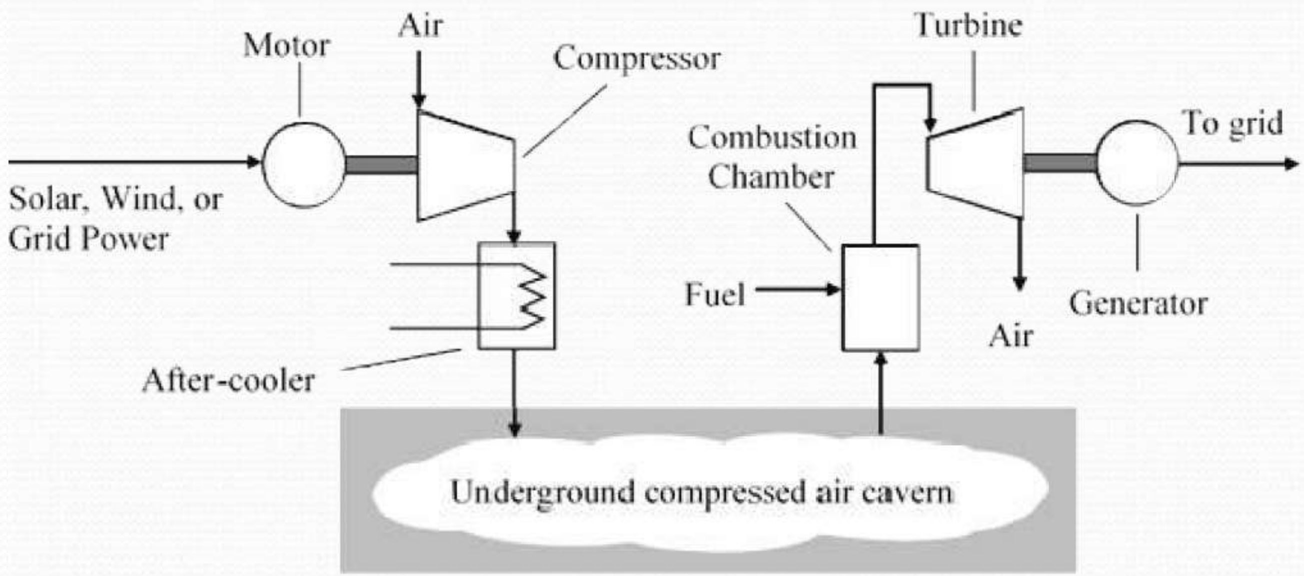

Figure 4.32. Schematic diagram of compressed air energy storage system.

- Round-trip efficiency of CAES systems is about 60%-70%.
- AES systems of 300MW capacity have been developed in Morocco and Israel. Germany and Albania also have 150 MW capacity CAES systems.
- In Ohio, USA, CAES systems with a total capacity of 2700 MW have been planned.

Flywheel Energy Storage (FES)

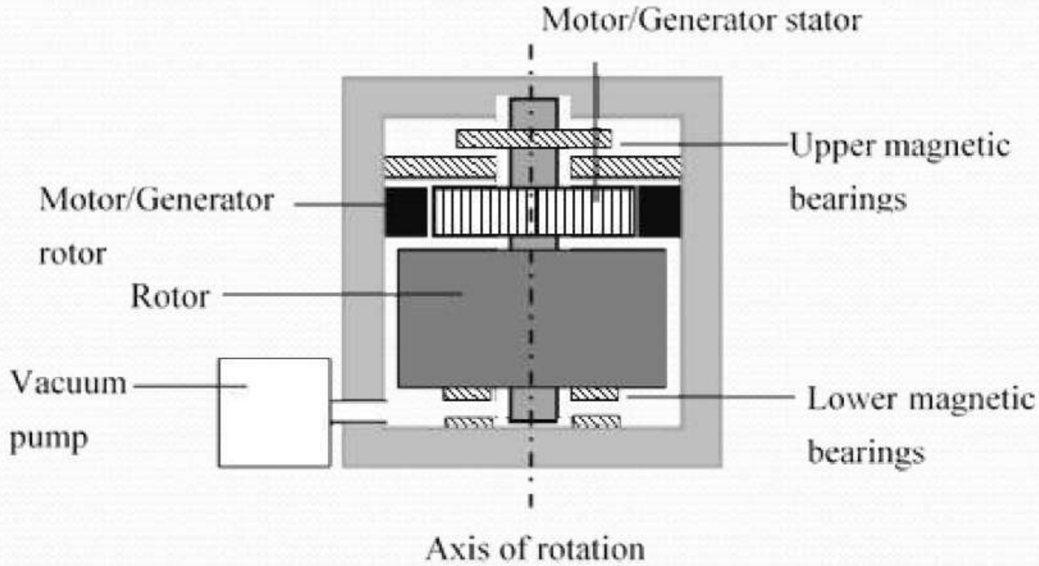

Figure 4.33. Topology of flywheel energy storage.

- They are long life and can provide several million charge-discharge cycles with freedom from depth-of-discharge effects.
- They find their applications where high power is required for short duration with a high number of charging-discharging cycles.
- Efficiency of flywheel energy storage systems: 90-95%.

Hydrogen Energy Storage (HES) and Fuel Cells

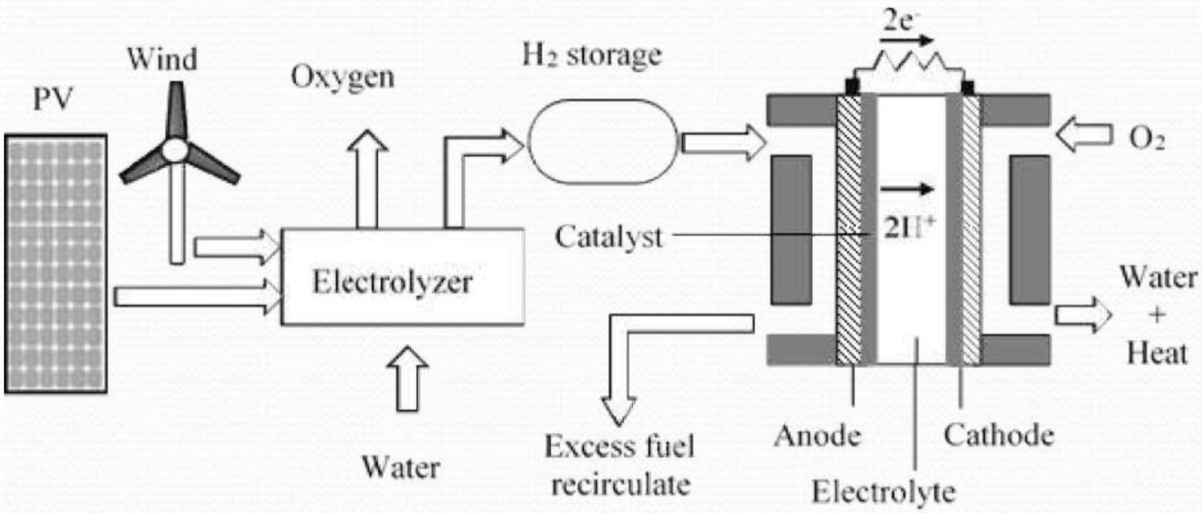

Figure 4.34. Topology of hydrogen storage and fuel cell.

$$\text{At anode: } H_2 \rightarrow 2H^+ + 2e^-$$

$$\text{At cathode: } \frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O$$

- Fuel to electricity conversion efficiency of fuels cells may be 50-60% depending upon their type and details of operation.
- Efficiencies of fuel cell co-generation systems can exceed 80%.

Battery Energy Storage (BES)

- Rechargeable batteries are the oldest and most widely used electrochemical devices for the storage of electrical energy.
- Batteries store electrical energy by transforming it into chemical energy and convert this energy into electricity when needed.
- The term battery applies to an assortment of technologies differing in their operational principles and materials.
- In the most basic form, a battery consists of one or more than one electrochemical cells. Each cell consists of two electrodes immersed in an electrolyte. Cells are connected in series or parallel or both in order to get desired level of voltage and power.
- Technologies of batteries which include lead acid, nickel-cadmium, lithium ion, sodium sulphur, sodium nickel chloride, etc.

Battery Energy Storage (BES)

- Fundamental characteristics of energy storage devices: charge-discharge cycles, depth of discharge, energy density, self-discharge rate, cycle efficiency, maintenance requirements, cost, etc.
- Capacity of a battery: Energy available after charging.
- The energy retrievable depends on depth of discharge.
- On the basis of their depth of discharge, batteries are classified either deep-cycle or shallow-cycle.
- Number of charge-discharge cycles of a battery define its life which is function of depth of discharge meaning that deeper the discharge the shorter will be the life of battery.
- Overcharging or undercharging will shorten battery life either by the shedding of active material or by the sulfation of battery.
- Enhanced temperatures accelerate their aging and self-discharge.

Battery Energy Storage (BES)

- Lead-acid batteries:
  - Efficiencies of are in the range of 85% and 90%.
  - Self-discharge rates of about 2% of rated capacity per month.
  - Charge/discharge cycles are between 1200 and 1800 which will decrease with depth of discharge and temperature.
  - Low cost and widely used for power quality applications, UPs, and in standalone systems.
- Lithium ion batteries:
  - Widely used in consumer electronics
  - Long life cycle with 3000 cycles at 80% depth of discharge.
  - Efficiency is nearly 100%.
  - On the downside, they have relatively high daily self-discharge (between 1 and 5%) and costly.

Battery Energy Storage (BES)

- Nickle Cadmium batteries:
  - Long life with more than 3500 cycles which may reach more than 50,000 cycles with 10% depth of discharge.
  - Their maintenance requirements are also low.
  - However they are several times costlier than lead-acid batteries.
  - They also suffer from memory effect and are highly toxic.
- Besides above three main conventional battery types, flow batteries, sodium sulphur (NaS) batteries, and the metal–air batteries are also in use but their market penetration is low.

Battery Energy Storage (BES)

Advantages of flow batteries:

can be fully discharged without any damage; their energy capacity is easily scalable as it depends on the capacity of storage tanks; and they have low self-discharging since electrolytes are stored in separate tanks.

Main disadvantages of flow batteries:

manufacturing and maintenance cost, efficiency losses due to auxiliary equipment, and construction complexity.

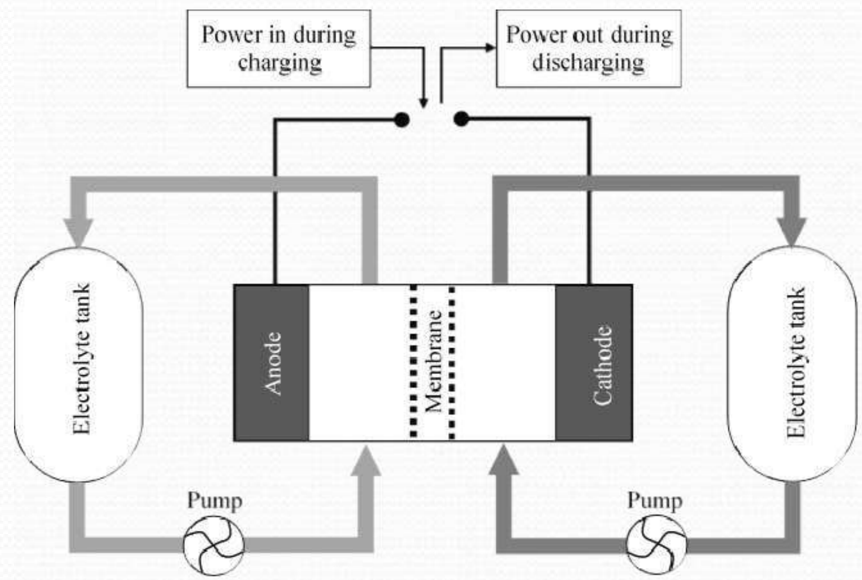

Figure 4.38. Principle of flow battery system.

Battery Energy Storage (BES)

Example 4.5 How many 12V 60Ah lead-acid batteries will be required to store the energy of pumped water in the upper reservoir of example 4.4?

Solution

Energy stored in the upper reservoir = 19600kWh = 7.056×10^{10} J

Energy stored in a single battery = $60\times12\times3600$= 2.592×10^{6}J

Number of batteries = $7.056\times10^{10}/2.592\times10^{6}$ = 27223

Observe that the option of lead-acid batteries as an alternative to pump storage will be highly uneconomical due their low charging-discharging cycles leading to their frequent replacement.

Superconductor Energy Storage Systems

- Near absolute zero temperature conductors lose their electrical resistance and are called superconductors.
- The concept of storing electrical energy in superconducting coils is that once current is established in a superconducting coil, energy will be stored in its magnetic field.
- Since resistance of the coil is zero, current will not decay and no energy will be lost. The stored energy can be retrieved from the coil by discharging it.
- Superconductors hardly used for bulk energy storage in commercial applications since the cost of maintaining the temperature of superconducting coils below critical temperature is prohibitively high.
- There exist, however, 1-MW magnetic storage systems around the world for power quality control in installations.
- Cycle efficiencies of these systems are about 95%.

Supercapacitor Energy Storage systems

- Ordinary capacitors have low energy density since their capacitance is low. For large capacity, the area of the dielectric medium has to be very large which makes them bulky and uneconomical.
- A supercapacitors consists of two electrodes of porous carbon or some other material of high surface area and an aqueous or non-aqueous electrolyte rather than a dielectric medium between them.
- Very large capacitance (up to 5000F) results from very large surface area of activated carbon (up to 2000m^2/gm) and very small distance (less than 1 nm) between electrodes. As a result, their energy density is very high.
- Charged faster with tens of thousands charge-discharge cycles at 100% depth of discharge with virtually no maintenance and energy efficiency of about 75%-80%.
- Due to their high self-discharging rate, supercapacitors are well-suited for short term storage applications only.

Thermal Energy Storage

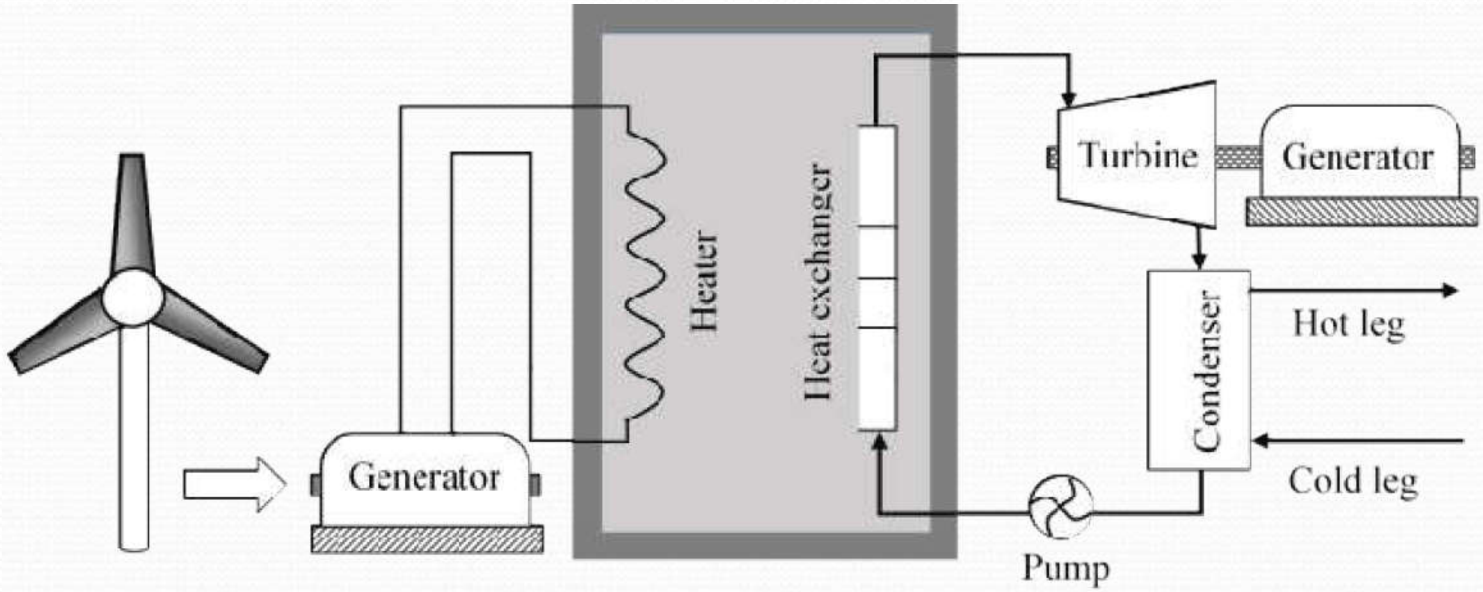

Figure 4.39. A typical thermal energy storage system with wind turbine.

Energy Storage Technology Options

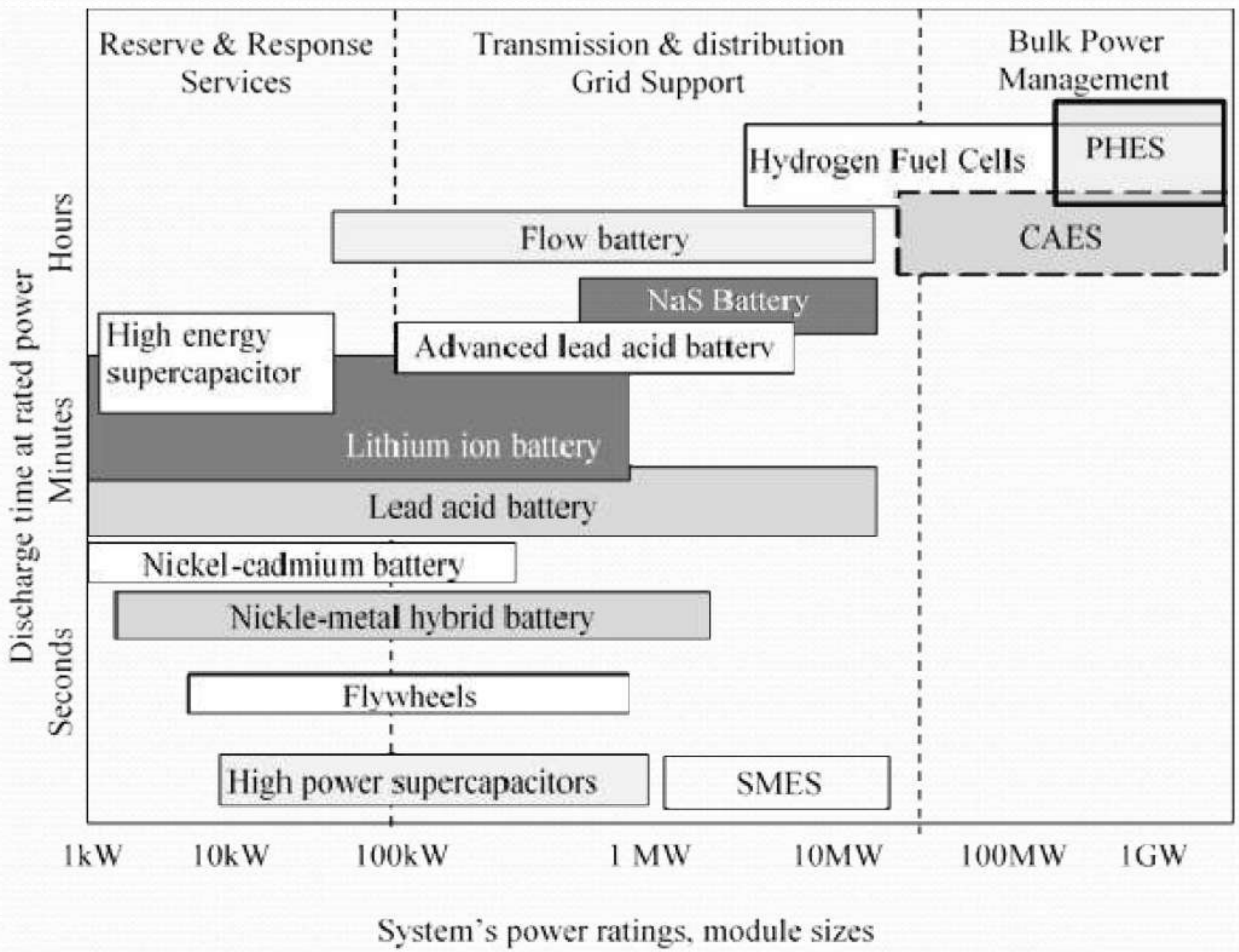

Figure 4.35. Electrical energy storage technology options [10].