Chapter II

Energy storage

II.1. Definition and general information on energy storage

Energy storage depends on the type of energy;

- Fossil fuels "coal, gas and oil" are stored naturally in reservoirs, once extracted, they can easily be transformed or transported from a technical point of view.
- Storage for intermittent energies mainly concerns the storage of electricity and heat. It is more complex, because of the dependence of their production on energy vectors such as electricity, heat or hydrogen.

Note: The main purpose of energy storage is to balance demand and electricity production "it allows adaptation over time between supply and demand for energy",

One of the major drawbacks of renewable energies in general is its intermittency due to the intermittent nature of wind, sun or geothermal energy. This is why storage systems will play an important role in the development of these energies in the future.

Storage is differentiated according to its capacity "quantity of available electrical charge":

− storage is said to be low capacity when it is of the order of kWh,

− high capacity if it is greater than 10 MWh. In this case, we speak of massive energy storage.

II.2. Electricity storage

II.2.1. Direct electricity storage

Direct storage of electricity is achieved by using large capacitors "electrical components consisting of two conductive plates storing opposite electrical charges", whose capacity is measured on the microfarad scale, which have limited storage capacities and whose costs are more or less high.

Another avenue for direct electricity storage is storage by supercapacitors "capacitors made from superconducting materials". However, these "superconductors" require operating temperatures close to absolute zero "- 273°C" which are technically as difficult as they are expensive to maintain.

However, SUPERCAPACITORS intervene more in terms of power than energy "capable of delivering high power for a very short time". They can therefore represent an interesting complement to batteries. The battery/Supercapacitor combination can prove particularly effective in the case of hybrid vehicles.

II.2.2. Indirect storage of electricity

Except in capacitors or Supercapacitors, electricity cannot be stored directly. It is therefore necessary to convert electricity into another energy that can be controlled. The different storage methods are classified according to the primary conversion energies.

II.2.2.1. Mechanical storage mode

A- Pumped storage energy transfer stations "PEST":

This storage system is based on the principle of gravity energy "hydraulic energy therefore at dams". This is the most widely used solution for storing energy from power plants and it allows large quantities of electrical energy to be stored, it uses two basins at different altitudes. The surplus electricity from the network is used to pump water from the lower basin into the upper basin. In the event of a deficit in electricity production, the water pumped into the upper basin turns a turbine by gravity and restores the accumulated energy.

Fig 2. The pumping energy transfer station (PETS), a proven solution for mass storage.

B- Compressed Air Energy Storage CAES

Compressed air energy storage stations are designed, quite simply, to store compressed air “in the form of pressure in underground cavities instead of pumping water”, using a compressor, during off-peak hours. This air is released to turn turbines that produce electricity, to deliver it during peak hours.

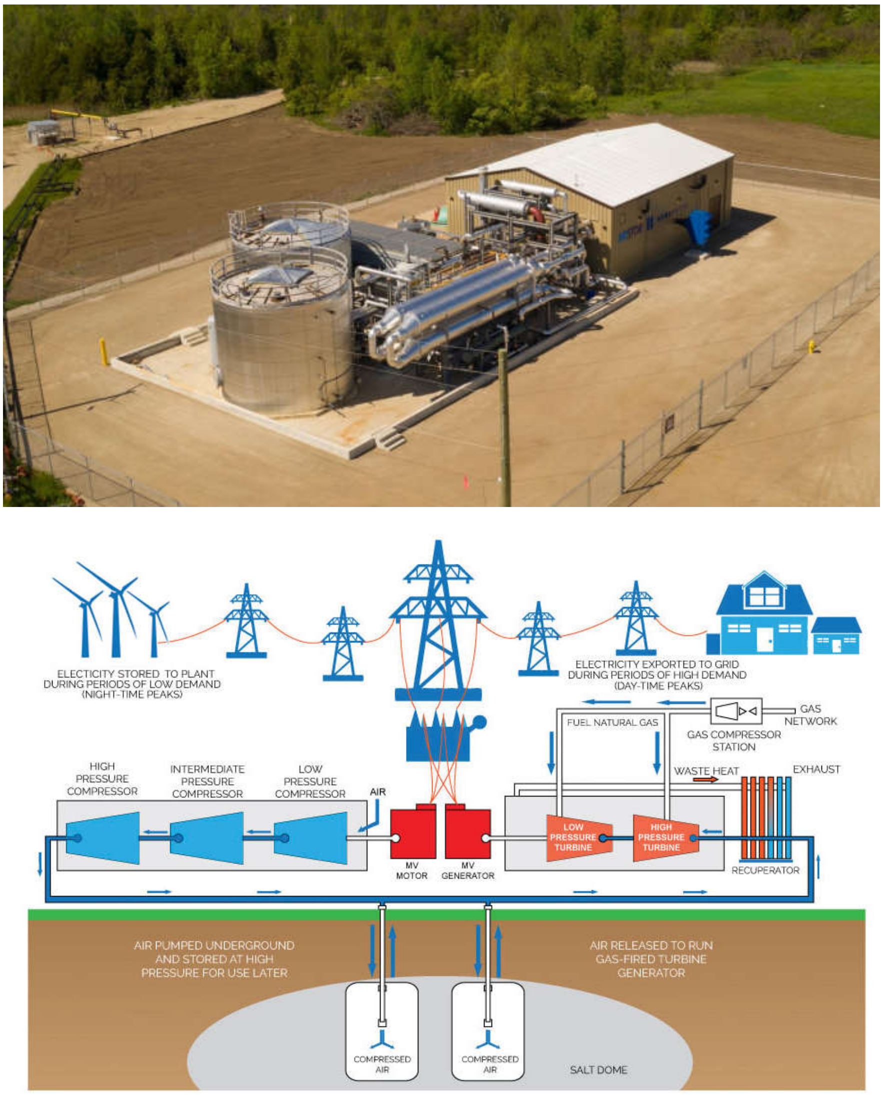

Fig 2. Compressed Air Energy Storage CAES

C- Flywheels

Flywheels have long been used to regulate steam engines. Today, their principle allows energy to be stored in the form of mechanical rotation. Electricity rotates a mass at very high speed around a cylindrical axis in an insulated box, which converts electrical energy "in the case of surplus production" into kinetic energy. This conserved kinetic energy can then be recovered in the form of electricity using an alternator "dynamo principle"

Fig 3. Flywheels

Fig 4. A project in China, claimed as the largest flywheel energy storage system in the world, has been connected to the grid.

II.2.2.2. Chemical storage mode

The principle of this electricity storage mode is based on the conversion of chemical energy into electrical energy, mainly concerns batteries and the hydrogen vector.

A- Batteries

Electricity storage is achieved through electrochemical reactions that involve circulating ions and electrons between two electrodes. The chemical components can be different from one technology to another, thus creating a wide variety of batteries.

- **Flow batteries**

These batteries are rechargeable batteries, allow the storage of electrochemical couples "electrolytes" outside the reaction cell, in reservoirs separated by a membrane, in the liquid state. The electrolytes circulate through an ion exchange cell.

Flow batteries represent the advantages of being able to quickly recharge "the system replaces the electrolytes with reservoirs". They can support more than 10,000 charge cycles, plus the self-discharge effect is almost zero

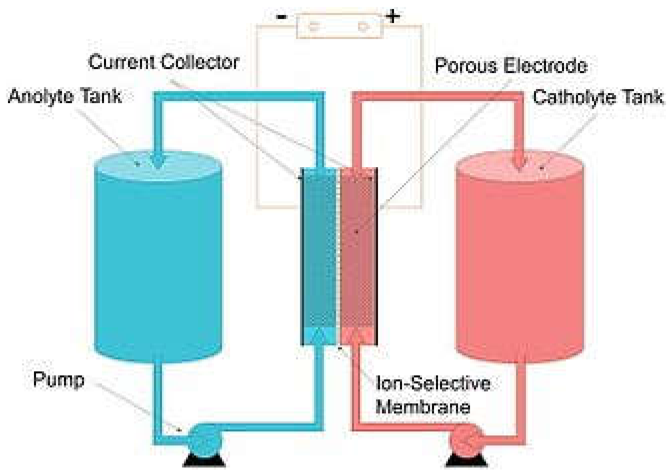

Fig.5. A typical flow battery consists of two tanks of liquids which are pumped past a membrane held between two electrodes

- **Advanced" lithium-ion batteries**

The operation of the lithium-ion battery is based on the reversible exchange of the lithium ion between a positive electrode and a negative electrode. Thus, we can cite as an example, the most important system, to date, which is in Zhangbei "China" in 2011, with a capacity of 20 to 36 MW over 4 to 6 hours with a wind production of 100 MW and a solar production of 40 MW.

Fig.6.Batteries lithium-ion

- **Zn-Br batteries**

A zinc-bromine battery is a rechargeable battery system that uses the reaction between zinc metal and bromine to produce electric current, with an electrolyte composed of an aqueous solution of zinc bromide. Zinc has long been used as the negative electrode of primary cells. It is a widely available, relatively inexpensive metal. It is rather stable in contact with neutral and alkaline aqueous solutions. For this reason, it is used today in zinc–carbon and alkaline primaries.

The leading potential application is stationary energy storage, either for the grid, or for domestic or stand-alone power systems. The aqueous electrolyte makes the system less prone to overheating and fire compared with lithium-ion battery systems.

These batteries are based on the zinc/bromine couple "Zn+/Br-". Several demonstrators have been produced, for example a 400 kWh system produced in Akron "Michigan" USA, some commercial installations are now operational.

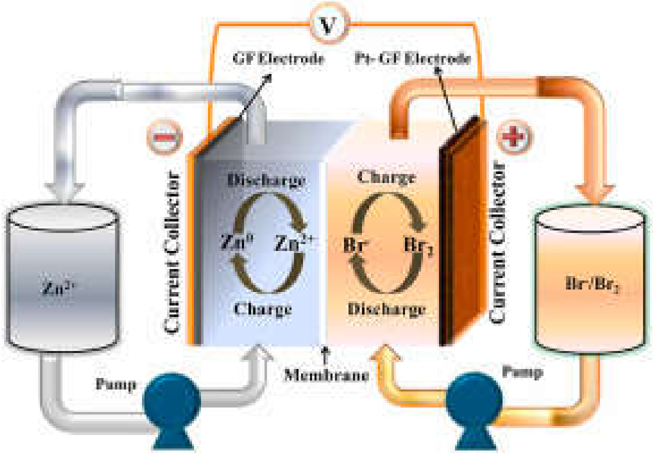

Fig.7 Zn-Br batteries

Zinc–bromine batteries share six advantages over lithium-ion storage systems:

100% depth of discharge capability on a daily basis.

Little capacity degradation, enabling 5000+ cycles

Low fire risk, since the electrolytes are non-flammable

No need for cooling systems

Low-cost and readily available battery materials

Easy end-of-life recycling using existing processes

They share four disadvantages:

Lower energy density

Lower round-trip efficiency (partially offset by the energy needed to run cooling systems).

The need to be fully discharged every few days to prevent zinc dendrites, which can puncture the separator.

Lower charge and discharge rates

These features make zinc-bromine batteries unsuitable for many mobile applications (that typically require high charge/discharge rates and low weight), but suitable for stationary energy storage applications such as daily cycling to support solar power generation, off-grid systems, and load shifting.

B-Hydrogen vector

Hydrogen does not represent a direct energy source like wind energy for example, but an energy vector. It is not found in pure form in nature, but must be extracted from water "H2O" by electrolysis. Hydrogen gas can be directly used "as fuel" or stored and converted back into electricity "by a fuel cell". The principle of the fuel cell is to convert chemical energy into electrical energy from hydrogen that will be used as fuel. The overall efficiency is less than 50% and their lifespan is insufficient in the context of applications coupled to the electricity grid.

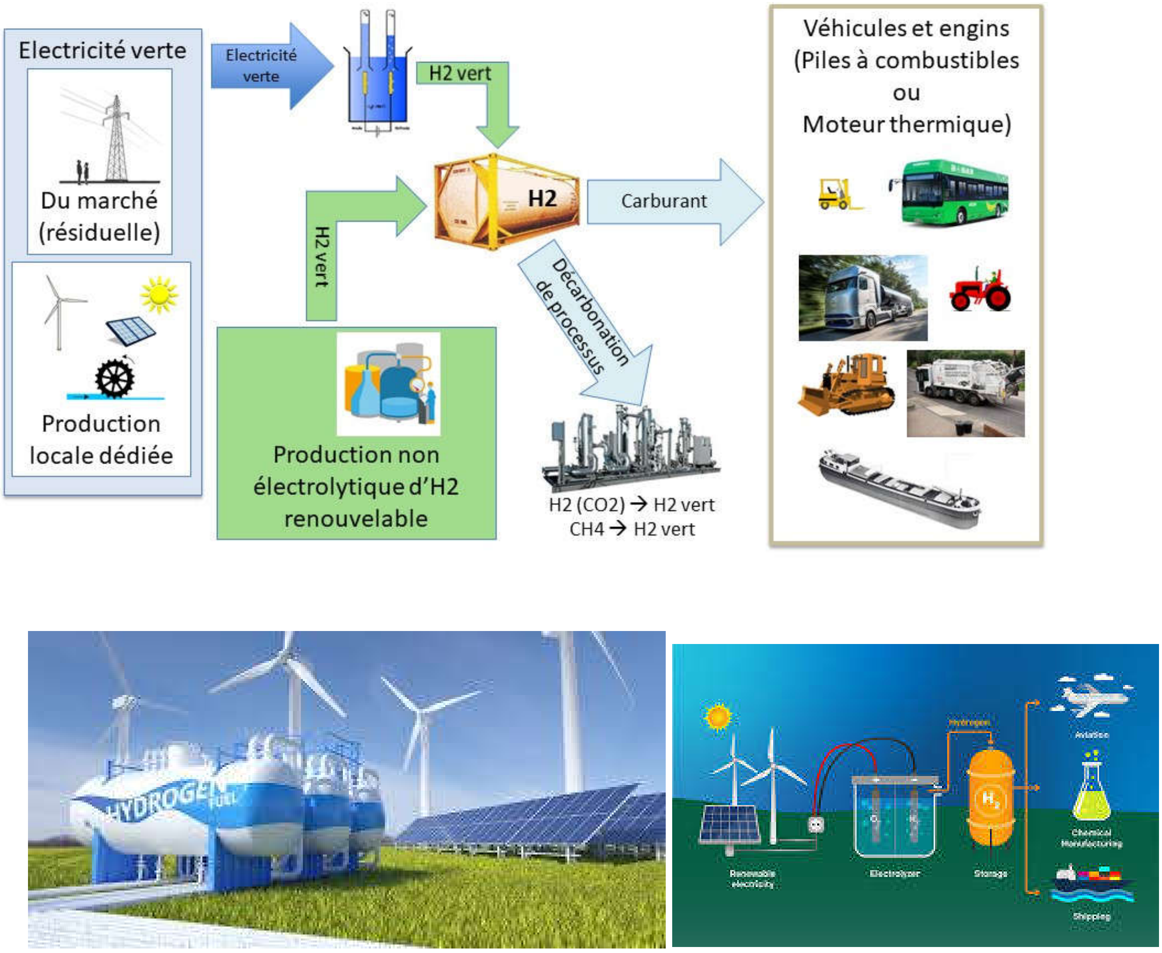

Fig.8. Green hydrogen

I.2.2.3. Thermal storage of "heat"

The development of thermal storage is directly linked to the development of thermodynamic solar farms. Storing this thermodynamic solar heat would reduce the effects of its intermittency and the gap between the most productive periods "day/summer" compared to the periods of greatest demand "evening/winter". This storage mainly concerns the heating "or air conditioning" of buildings. Any material has the capacity to release or store heat via thermal transfer. This transfer can be:

A-Storage by sensible heat

Raising the temperature of a material allows energy to be stored in the form of heat. This is the case, for example, of a stone placed near a fireplace, once it has stored the heat, it can be moved and release its heat. This principle is the same for solar water heaters: they recover the heat during the day to then restore it, with an average efficiency of around 40% for the most recent systems. The preferred materials are water, synthetic oil, rock or concrete.

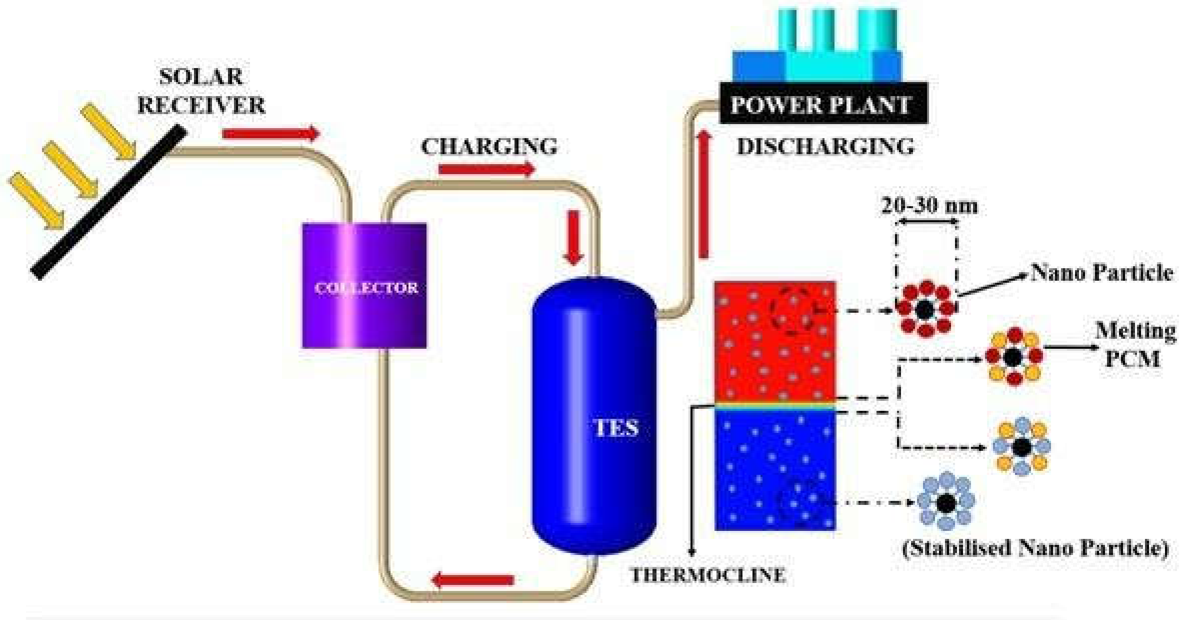

Fig.9. Sensible heat thermal storage system.

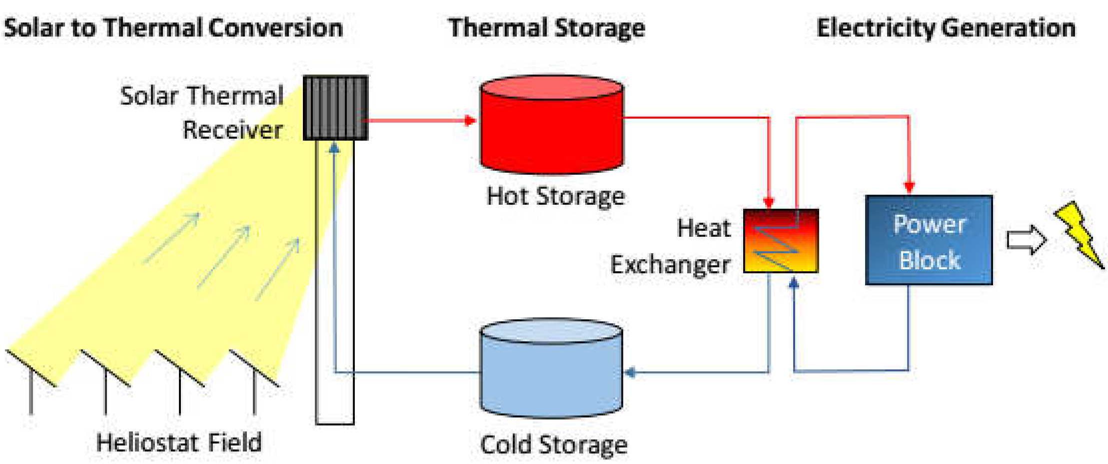

Fig.10. Top: 110 MW Crescent Dunes CSP plant with 1.1 GWh of thermal storage using molten nitrate salt [15]. Bottom: Schematic of sensible two-tank thermal storage system in a CSP plant

B-Latent heat storage

This storage method is based on phase change materials "PCMs", these materials store energy when they change their state "for example solid-liquid". The reverse transformation allows the accumulated energy to be released in the form of heat or cold, with an efficiency of around 60%. Several types of these materials "organic fatty acids and paraffins or inorganic hydrated salts" serve as a thermal regulator depending on the heat provided by the sun, to temper buildings. There are currently no large-capacity storage facilities based on this principle but many projects are underway.