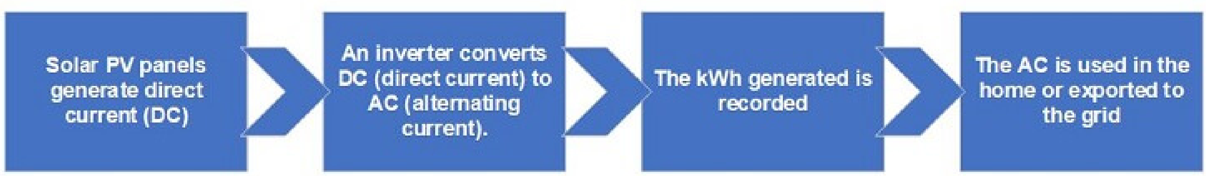
Unit – V: SOLAR PHOTOVOLTAIC SYSTEMS (10hrs) Energy storage in PV systems, Energy storage modes, electrochemical storage, Batteries, Primary and secondary, Solid-state battery, Molten solvent battery, lead acid battery and dry batteries, Mechanical storage – Flywheel, Electrical storage –Supercapacitor

1. **Explain the Energy storage in PV systems**

Energy storage in PV Systems

A fundamental characteristic of a photovoltaic system is that power is produced only while sunlight is available. The most common type of storage is chemical storage, in the form of a battery. The batteries become a central component of the overall system which significantly affect the cost, maintenance requirements, reliability, and design of the photovoltaic system.



Battery Types

There are many types of batteries that can be used in PV systems. The lead-acid type of the most common, but lithium-ion batteries are becoming more popular.

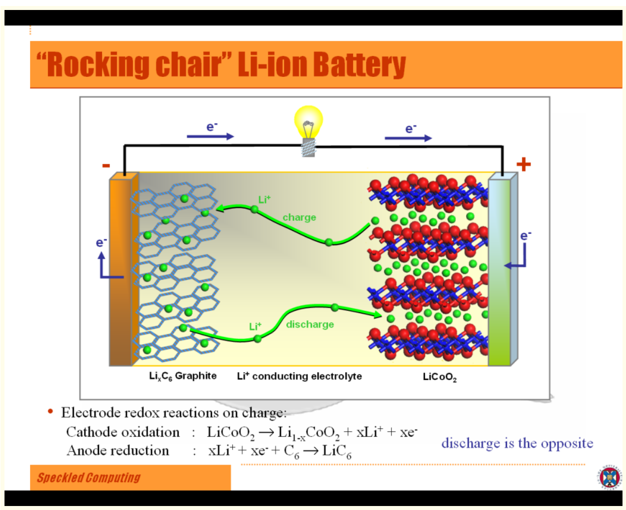
Two Most Common Types of Batteries for PV System Storage are given below

Lithium- ion batteries	Lead-acid batteries
Becoming more common in domestic grid-connected solar PV storage systems	Used for off-grid storage systems where additional storage is required
More expensive	Less expensive
Lighter and smaller	Heavier and larger
Requires integrated controller to manage charging and discharging	Requires good charging and discharging process to maintain battery health

More efficient	Less efficient
Can discharge more stored energy	
Longer expected lifetime	Shorter expected lifetime

Li-ion battery

Lithium is attractive as a battery negative electrode material because it is lightweight, high reduction potential and low resistance.



Flooded batteries have a liquid electrolyte solution. Vented lead-acid batteries release hydrogen and oxygen gas; therefore, adequate ventilation must be provided for both vented and sealed battery systems. It is usually advisable to provide adequate ventilation requirements similar to a combustion water heater.

2. **Explain various types of energy storage modes.**

Energy can be stored in the following categories. 1) electrochemical storage 2) mechanical storage 3) electrical storage

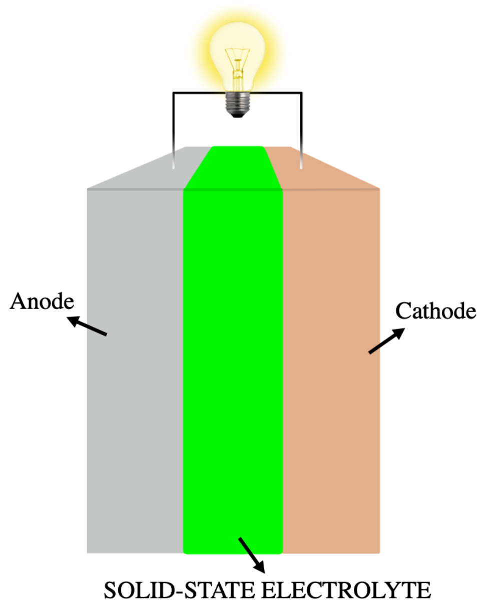
1) Electrochemical Storage

When electricity is fed into a battery, it causes a chemical reaction, and energy is stored. When a battery is discharged, that chemical reaction is reversed, which creates voltage between two electrical contacts, causing current to flow out of the battery. The most common chemistry for battery cells is lithium-ion, but other common options include lead-acid, sodium, and nickel-based batteries.

Batteries : Batteries are two types. They are primary and secondary batteries. Primary battery is single use and cannot be recharged. Secondary batteries are rechargeable. Examples for primary battery, Zinc-carbon cell, Alkaline cell, Lithium cell, Mercury cell, Silver oxide cell. Examples for secondary cell, Nickel-cadmium cell, Lithium-ion cell, Nickel-metal hydride cell. These are the types of batteries found in devices such as smartphones, electronic tablets, and automobiles.

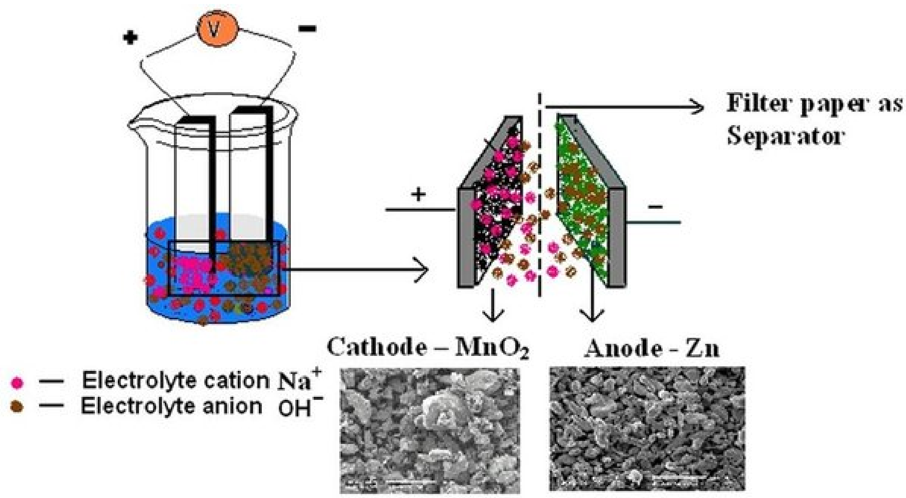
i) Solid State battery:

A solid-state battery uses solid electrodes and a solid electrolyte. Solid-state batteries can use metallic lithium for the anode and oxides or sulfides for the cathode.



The central layer is the solid-state separator which acts both as the separator between the anode and cathode and as the electrolyte. It therefore becomes the medium through which the ions move and also has electric insulating properties and as a mechanical separator between the anode and cathode.

ii) Molten Salt batteries: Molten salt batteries are a class of primary and secondary electric batteries that use molten salts as an electrolyte. A saltwater battery is a type of battery that uses a mixture of salt and water as its electrolyte. Unlike traditional batteries, saltwater batteries are safer to use because they are non-flammable and easier to recycle. This makes them an attractive option for sustainable and eco-friendly energy storage solutions.

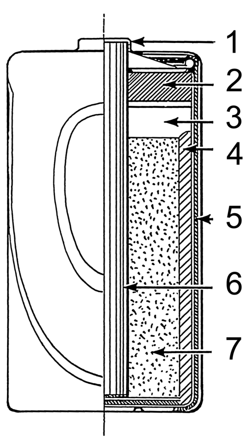


iii) Lead acid battery

Lead acid battery: These batteries are suitable for medium and large energy storage applications. It has a low price. Battery life is high.

Overall chemical reaction during discharge is $PbO_2 + Pb + 2H_2SO_4 \rightarrow 2PbSO_4 + 2H_2O$ $E_0 = +2.048$ V(1) Reaction proceeds in opposite direction during discharge.

iv) Dry Battery: A dry cell is a type of electric battery, commonly used for portable electrical devices. Unlike wet cell batteries, which have a liquid electrolyte, dry cells use an electrolyte in the form of a paste, and are thus less susceptible to leakage.



1. brass cap, 2. plastic seal, 3. expansion space, 4. porous cardboard, 5. zinc can, 6. carbon rod, 7. chemical mixture

2) **Mechanical storage**

a) **Flywheel Storage**

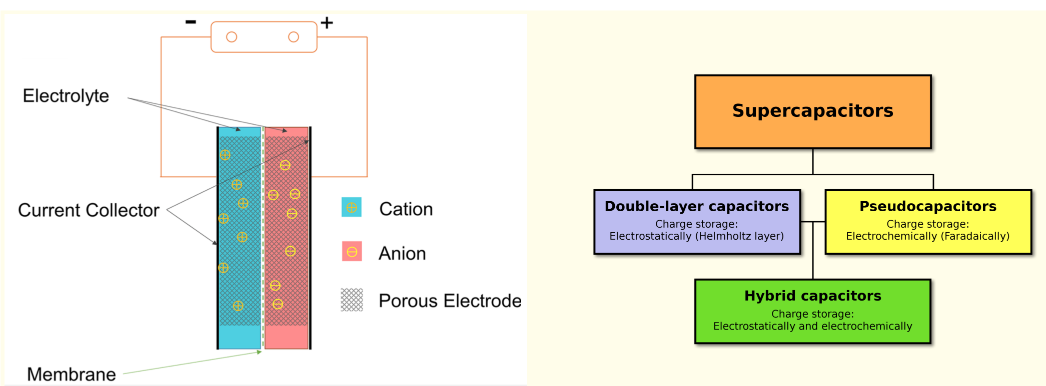
A flywheel is a heavy wheel attached to a rotating shaft. Expending energy can make the wheel turn faster. This energy can be extracted by attaching the wheel to an electrical generator, which uses electromagnetism to slow the wheel down and produce electricity.

b) **Pumped-Storage Hydropower**

Pumped-storage hydropower is an energy storage technology based on water. Electrical energy is used to pump water uphill into a reservoir when energy demand is low.

3) Electrical storage

A supercapacitor (SC), also called an ultracapacitor, is a high-capacity capacitor, with a capacitance value much higher than solid-state capacitors but with lower voltage limits. It bridges the gap between electrolytic capacitors and rechargeable batteries. It typically stores 10 to 100 times more energy per unit volume or mass than electrolytic capacitors, can accept and deliver charge much faster than batteries, and tolerates many more charge and discharge cycles than rechargeable batteries.



Electrostatic double-layer capacitors (EDLCs) use carbon electrodes or derivatives with much higher electrostatic double-layer capacitance than electrochemical pseudocapacitance, achieving separation of charge in a Helmholtz double layer at the interface between the surface of a conductive electrode and an electrolyte.

a) Electrostatic Double Layer Capacitors

These types of capacitor include two electrodes, a separator, and an electrolyte. The electrolyte is the mixture that constitutes positive and negative ions dissolved in water. The two electrodes are separated by a separator. These supercapacitors use carbon electrodes or derivatives with much higher electrostatic double-layer capacitance. The separation of charge in electrostatic double-layer capacitors is less than in a conventional capacitor; it ranges from 0.3–0.8 nm.

b) Pseudo Capacitors

Pseudo capacitors are also referred to as electrochemical pseudo-capacitors. These capacitors make use of metal oxide or conducting polymer electrodes with a high amount of electrochemical pseudocapacitance. These types of components store electrical energy by electron charge transfer between electrode and electrolyte. This can be done by a reduction-oxidation reaction commonly known as a redox reaction.

c) Hybrid capacitors

The hybrid capacitors are developed by using the techniques of double-layer capacitors and pseudo-capacitors. In these components, electrodes with different characteristics are used. One electrode with the capacity to display electrostatic capacitance, and the other electrode with electrochemical capacitance. Examples of hybrid capacitors: the lithium-ion capacitor

The positive electrode reaction is: Positive electrode: $LiCoO_2 \rightarrow Li_{1-x}CoO_2 + xLi^+ + xe^-$ Negative electrode: $xLi^+ + xe^- + C_6 \rightarrow Li_xC_6$ where x moves on the negative electrode from 0 to 1, on the positive electrode from 0 to 0.45.