CHAPTER-5

Forms of Energy Storage

Energy storage is the capture of energy produced at one time for use at a later time. A device that stores energy is generally called an accumulator or battery. Energy comes in multiple forms including radiation, chemical, gravitational potential, electrical potential, electricity, elevated temperature, latent heat and kinetic. Energy storage involves converting energy from forms that are difficult to store to more conveniently or economically storable forms.

Some technologies provide short-term energy storage, while others can endure for much longer. Bulk energy storage is currently dominated by hydroelectric dams, both conventional as well as pumped.

Common examples of energy storage are the rechargeable battery, which stores chemical energy readily convertible to electricity to operate a mobile phone, the hydroelectric dam, which stores energy in a reservoir as gravitational potential energy, and ice storage tanks, which store ice frozen by cheaper energy at night to meet peak daytime demand for cooling. Fossil fuels such as coal and gasoline store ancient energy derived from sunlight by organisms that later died, became buried and over time were then converted into these fuels. Food (which is made by the same process as fossil fuels) is a form of energy stored in chemical form.

Hybrid Vehicles

A hybrid vehicle uses two or more distinct types of power, such as internal combustion engine to drive an electric generator that powers an electric motor e.g. in diesel-electric trains using diesel engines to drive an electric generator that powers an electric motor, and submarines that use diesels when surfaced and batteries when submerged. Other means to store energy include pressurized fluid in hydraulic hybrids.

The basic principle with hybrid vehicles is that the different motors work better at different speeds; the electric motor is more efficient at producing torque, or turning power, and the combustion engine is better for maintaining high speed (better than typical electric motor). Switching from one to the other at the proper time while speeding up yields a win-win in terms of energy efficiency, as such that translates into greater fuel efficiency, for example

- Mopeds, electric bicycles, and even electric kick scooters are a simple form of a hybrid, powered by an internal combustion engine or electric motor and the rider's muscles. Early prototype motorcycles in the late 19th century used the same principle.
    - In a **parallel hybrid bicycle** human and motor torques are mechanically coupled at the pedal or one of the wheels, e.g. using a hub motor, a roller pressing onto a tire, or a connection to a wheel using a transmission element. Most motorized bicycles, mopeds are of this

type.
    - In a **series hybrid bicycle (SHB)** (a kind of chainless bicycle) the user pedals a generator, charging a battery or feeding the motor, which delivers all of the torque required. They are commercially available, being simple in theory and manufacturing.
- Hybrid power trains use diesel-electric or turbo-electric to power railway locomotives, buses, heavy goods vehicles, mobile hydraulic machinery, and ships.

Advantages of Hybrid Vechile

1. Environmentally Friendly: One of the biggest advantage of hybrid car over gasoline powered car is that it runs cleaner and has better gas mileage which makes it environmentally friendly. A hybrid vehicle runs on twin powered engine (gasoline engine and electric motor) that cuts fuel consumption and conserves energy.

2. Financial Benefits: Hybrid cars are supported by many credits and incentives that help to make them affordable. Lower annual tax bills and exemption from congestion charges comes in the form of less amount of money spent on the fuel.

3. Less dependence on Fossil Fuels: A Hybrid car is much cleaner and requires less fuel to run which means less emissions and less dependence on fossil fuels. This in turn also helps to reduce the price of gasoline in domestic market.

4. Regenerative Braking System: Each time you apply brake while driving a hybrid vehicle helps you to recharge your battery a little. An internal mechanism kicks in that captures the energy released and uses it to charge the battery which in turn eliminates the amount of time and need for stopping to recharge the battery periodically.

5. Built From Light Materials: Hybrid vehicles are made up of lighter materials which means less energy is required to run. The engine is also smaller and lighter which also saves much energy.

6. Higher Resale Value: With continuous increase in price of gasoline, more and more people are turning towards hybrid cars. The result is that these green vehicles have started commanding higher than average resale values. So, in case you are not satisfied with your vehicle, you can always sell it at a premium price to buyers looking for it.

Disadvantages of Hybrid vechile

1. Less Power: Hybrid cars are twin powered engine. The gasoline engine which is primary source of power is much smaller as compared to what you get in single engine powered car and electric motor is low power. The combined power of both is often less than that of gas powered engine. It is therefore suited for city driving and not for speed and acceleration.

2. Can be Expensive: The biggest drawback of having a hybrid car is that it can burn a hole in your pocket. Hybrid cars are comparatively expensive than a regular petrol car and can cost $5000 to $10000 more than a standard version. However, that extra amount can be offset with lower running cost and tax exemptions.

3. Poorer Handling: A hybrid car houses an gasoline powered engine, a lighter electric engine and a pack of powerful batteries. This adds weight and eats up the extra space in the car. Extra weight results in fuel inefficiency and manufacturers cut down weight which has resulted in motor and battery downsizing and less support in the suspension and body.

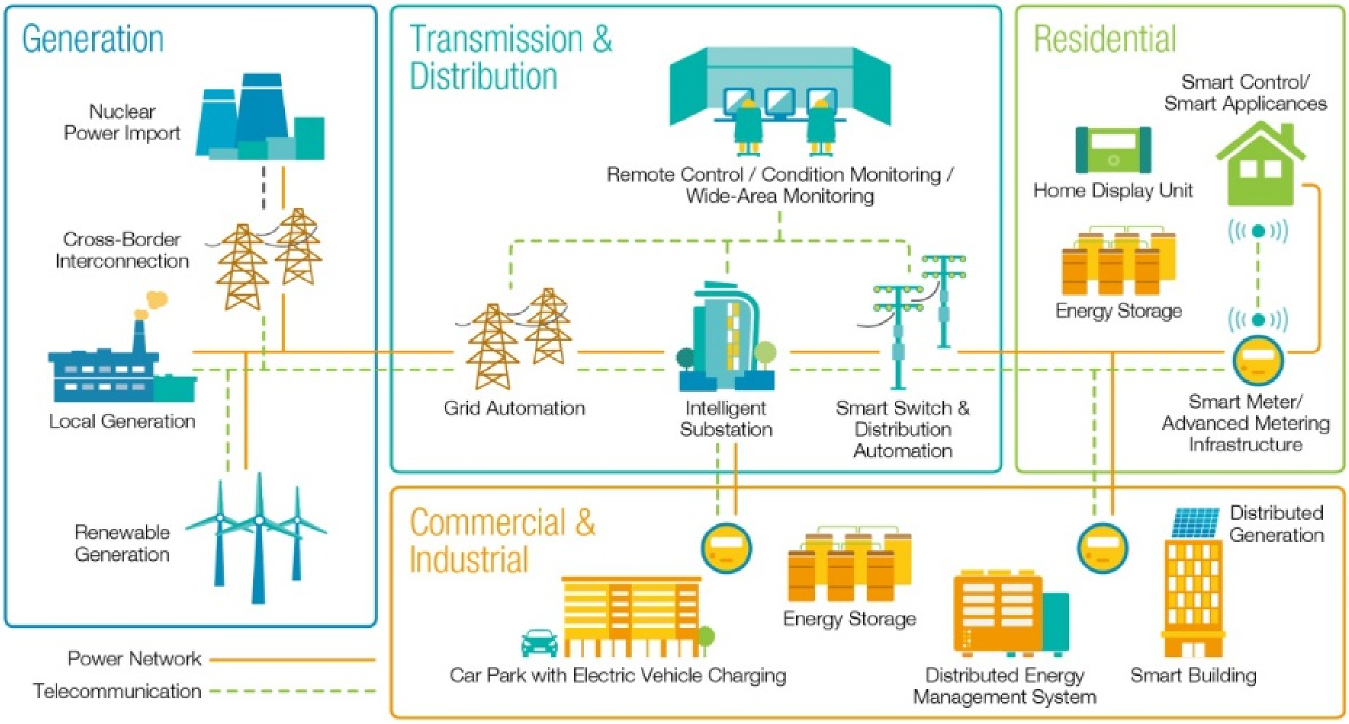
4. Higher Maintenance Costs: The presence of dual engine, continuous improvement in technology, and higher maintenance cost can make it difficult for mechanics to repair the car. It is also difficult to find a mechanic with such an expertise.

5. Presence of High Voltage in Batteries: In case of an accident, the high voltage present inside the batteries can prove lethal for you. There is a high chance of you getting electrocuted in such cases which can also make the task difficult for rescuers to get other passengers and driver out of the car.

Smart Grid System

Nowadays, the electric power system is facing a radical transformation in worldwide with the decarbonise electricity supply to replace aging assets and control the natural resources with new information and communication technologies (ICT). A smart grid technology is an essential to provide easy integration and reliable service to the consumers.

A smart grid system is a self-sufficient electricity network system based on digital automation technology for monitoring, control, and analysis within the supply chain. This system can find the solution to the problems very quickly in an existed system that can reduce the workforce and it will targets sustainable, reliable, safe and quality electricity to all consumers.



Smart Grid Components

To achieve a modernized smart grid, a wide range of technologies should be developed and must be implemented. These technologies generally grouped into following key technology areas as discussed below.

- **Intelligent Appliances:** Intelligent appliances have capable of deciding when to consume energy based on customer pre-set preferences. This can lead to going away along toward reducing peak loads which have an impact on electricity generation costs. For example, smart sensors, like temperature sensor which is used in thermal stations to control the boiler temperature based on predefined temperature levels.

- **Smart Power Meters:** The smart meters provide two-way communication between power providers and the end user consumers to automate billing data collections, detect device failures and dispatch repair crews to the exact location much faster.

- **Smart Substations:** substations are included monitoring and control non-critical and critical operational data such as power status, power factor performance, breaker, security, transformer status, etc. substations are used to transform voltage at several times in many locations, that providing safe and reliable delivery of energy. Smart substations are also necessary for splitting the path of electricity flow into many directions. Substations require large and very expensive equipment to operate, including transformers, switches, capacitor banks, circuit breakers, a network protected relays and several others.

- **Super Conducting Cables:** These are used to provide long distance power transmission, and automated monitoring and analysis tools capable of detecting faults itself or even predicting cable and failures based on real-time data weather, and the outage history.

- **Integrated communications:** The key to a smart grid technology is integrated communications. It must be as fast as enough to real-time needs of the system. Depending upon the need, Many different technologies are used in smart grid communication like Programmable Logic Controller (PLC), wireless, cellular, SCADA (Supervisory Control and Data Acquisition), and BPL.Key Considerations for Integrated Communication.

Key Considerations for Integrated Communication

Ease of deployment

Standards

Data carrying capacity

Secure

Network coverage capability

Benefits of Smart Grid

- Integrate isolated technologies: smart grid enables better energy management
- Protective management of electrical network during emergency

situation

- Better demand, supply/ demand response
- Better power quality
- Reduce carbon emissions
- Increased demand for energy: Requires more complex and critical solutions with better energy management
- Renewables Integration

Further Reading

The Smart Grid

Maybe you have heard of the Smart Grid on the news or from your energy provider. But not everyone knows what the grid is, let alone the Smart Grid. "The grid," refers to the electric grid, a network of transmission lines, substations, transformers and more that deliver electricity from the power plant to your home or business. It's what you plug into when you flip on your light switch or power up your computer. Our current electric grid was built in the 1890s and improved upon as technology advanced through each decade. Today, it consists of more than 9,200 electric generating units with more than 1 million megawatts of generating capacity connected to more than 300,000 miles of transmission lines. Although the electric grid is considered an engineering marvel, we are stretching its patchwork nature to its capacity. To move forward, we need a new kind of electric grid, one that is built from the bottom up to handle the groundswell of digital and computerized equipment and technology dependent on it—and one that can automate and manage the increasing complexity and needs of electricity in the 21st Century.

What Makes a Grid "Smart?"

In short, the digital technology that allows for two-way communication between the utility and its customers, and the sensing along the transmission lines is what makes the grid smart. Like the Internet, the Smart Grid will consist of controls, computers, automation, and new technologies and equipment working together, but in this case, these technologies will work with the electrical grid to respond digitally to our quickly changing electric demand.

What does a Smart Grid do?

The Smart Grid represents an unprecedented opportunity to move the energy industry into a new era of reliability, availability, and efficiency that will contribute to our economic and environmental health. During the transition period, it will be critical to carry out testing, technology improvements, consumer education, development of standards and regulations, and information sharing between projects to ensure that the benefits we envision from the Smart Grid become a reality. The benefits associated with the Smart Grid include:

More efficient transmission of electricity

Quicker restoration of electricity after power disturbances

Reduced operations and management costs for utilities, and ultimately lower power costs for consumers

Reduced peak demand, which will also help lower electricity rates

Increased integration of large-scale renewable energy systems

Better integration of customer-owner power generation systems, including renewable energy systems

Improved security

Today, an electricity disruption such as a blackout can have a domino effect—a series of failures that can affect banking, communications, traffic, and security. This is a particular threat in the winter, when homeowners can be left without heat. A smarter grid will add resiliency to our electric power System and make it better prepared to address emergencies such as severe storms, earthquakes, large solar flares, and terrorist attacks. Because of its two-way interactive capacity, the Smart Grid will allow for automatic rerouting when equipment fails or outages occur. This will minimize outages and minimize the effects when they do happen. When a power outage occurs, Smart Grid technologies will detect and isolate the outages, containing them before they become large-scale blackouts. The new technologies will also help ensure that electricity recovery resumes quickly and strategically after an emergency—routing electricity to emergency services first, for example.

In addition, the Smart Grid will take greater advantage of customer-owned power generators to produce power when it is not available from utilities. By combining these “distributed generation” resources, a community could keep its health center, police department, traffic lights, phone System, and grocery store operating during emergencies. In addition, the Smart Grid is a way to address an aging energy infrastructure that needs to be upgraded or replaced. It’s a way to address energy efficiency, to bring increased awareness to consumers about the connection between electricity use and the environment. And it’s a way to bring increased national security to our energy System—drawing on greater amounts of home-grown electricity that is more resistant to natural disasters and attack.

Giving Consumers Control

The Smart Grid is not just about utilities and technologies; it is about giving you the information and tools you need to make choices about your energy use. If you already manage activities such as personal banking from your home computer, imagine managing your electricity in a similar way. A smarter grid will enable an unprecedented level of consumer participation. For example, you will no longer have to wait for your monthly statement to know how much electricity you use. With a smarter grid, you can have a clear and timely picture of it. “Smart meters,” and other mechanisms, will allow you to see how much electricity you use, when you use it, and its cost. Combined with real-time pricing, this will allow you to save money by using less power when electricity is most expensive. While the potential benefits of the Smart Grid are usually discussed in terms of economics, national security, and renewable energy goals, the Smart Grid has the potential to help you save money by helping you to manage your electricity use and choose the best times to purchase electricity. And you can save even more by generating your own power.

Building and Testing the Smart Grid

The Smart Grid will consist of millions of pieces and parts—controls, computers, power lines, and new technologies and equipment. It will take some time for all the technologies to be perfected, equipment installed, and systems tested before it comes fully on line. And it won't happen all at once—the Smart Grid is evolving, piece by piece, over the next decade or so. Once mature, the Smart Grid will likely bring the same kind of transformation that the Internet has already brought to the way we live, work, play, and learn.

Super Capicators

Supercapacitors, which are often called electrical double-layer capacitors (EDLCs), pseudocapacitors, ultracapacitors, power capacitors, gold capacitors, or power caches, have attracted research interest worldwide because of their potential applications as energy storage devices in many fields. Supercapacitors have considerably higher specific powers and longer cycle lifetimes compared to most rechargeable batteries, such as lead-acid, nickel-metal hydride, and Li-ion batteries. Hence, supercapacitors have attracted considerable interest because of the ever-increasing demands of electric vehicles, portable electronic devices, and power sources for memory backup.

They typically store 10 to 100 times more energy per unit volume or mass than electrolytic capacitors, can accept and deliver charge much faster than batteries, and tolerate many more charge and discharge cycles than rechargeable batteries.

Supercapacitors are used in applications requiring many rapid charge/discharge cycles rather than long term compact energy storage: within cars, buses, trains, cranes and elevators, where they are used for regenerative braking, short-term energy storage or burst-mode power delivery. Smaller units are used as memory backup for static random-access memory (SRAM).

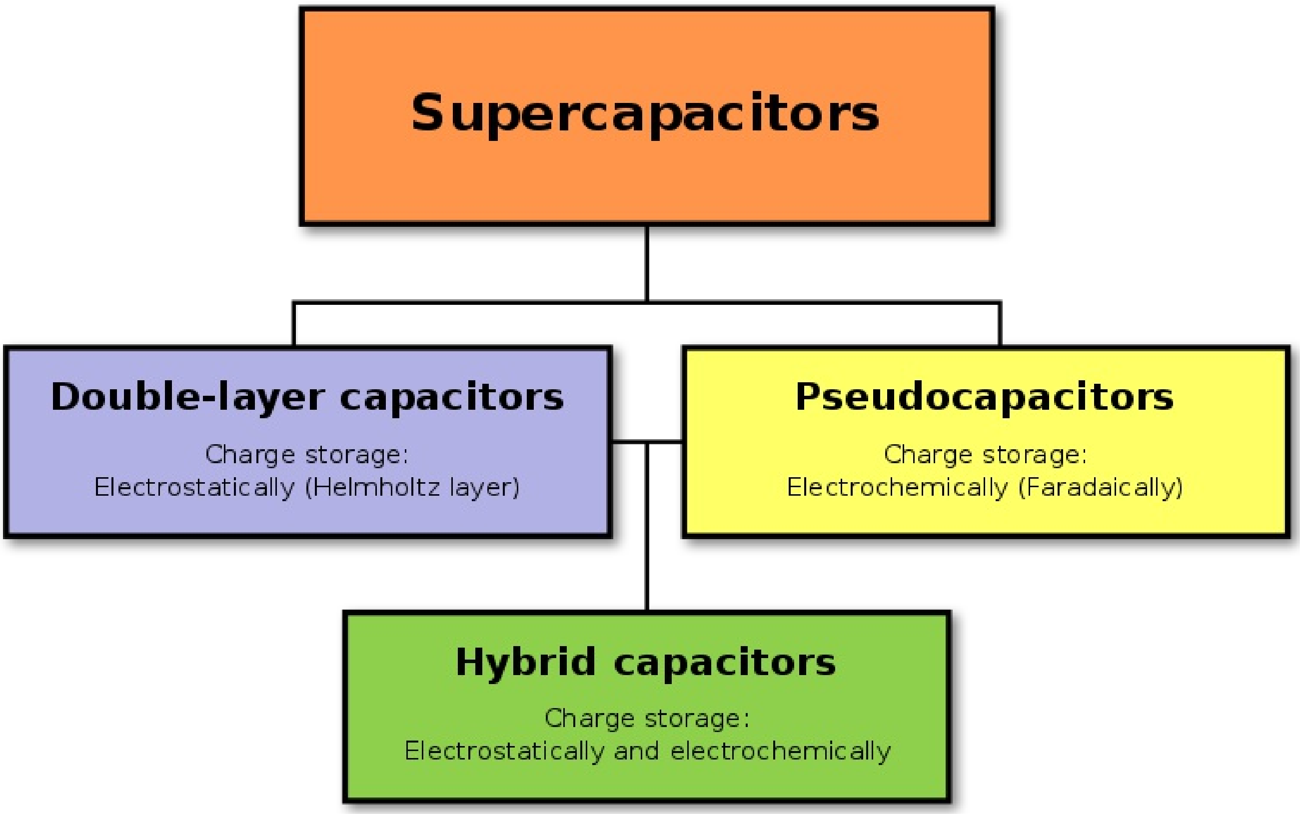
Unlike ordinary capacitors, supercapacitors do not use the conventional solid dielectric, but rather, they use electrostatic double-layer capacitance and electrochemical pseudocapacitance,[4] both of which contribute to the total capacitance of the capacitor, with a few differences:

- **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. The separation of charge is of the order of a few ångströms (0.3–0.8 nm), much smaller than in a conventional capacitor.
- **Electrochemical pseudocapacitors** use metal oxide or

conducting polymer electrodes with a high amount of electrochemical pseudocapacitance additional to the double-layer capacitance. Pseudocapacitance is achieved by Faradaic electron charge-transfer with redox reactions, intercalation or electrosorption.

- **Hybrid capacitors**, such as the lithium-ion capacitor, use electrodes with differing characteristics: one exhibiting mostly electrostatic capacitance and the other mostly electrochemical capacitance.

The electrolyte forms an ionic conductive connection between the two electrodes which distinguishes them from conventional electrolytic capacitors where a dielectric layer always exists, and the so-called electrolyte (e.g., MnO_2 or conducting polymer) is in fact part of the second electrode (the cathode, or more correctly the positive electrode). Supercapacitors are polarized by design with asymmetric electrodes, or, for symmetric electrodes, by a potential applied during manufacture.



Basic Design

Electrochemical capacitors (supercapacitors) consist of two electrodes separated by an ion-permeable membrane (separator), and an electrolyte ionically connecting both electrodes. When the electrodes are polarized by an applied voltage, ions in the electrolyte form electric double layers of opposite polarity to the electrode’s polarity. For example, positively polarized electrodes will have a layer of negative ions at the electrode/electrolyte interface along with a charge-balancing layer of positive ions adsorbing onto the negative layer. The opposite is true for the negatively polarized electrode.

Additionally, depending on electrode material and surface shape, some ions may permeate the double layer becoming specifically adsorbed ions and contribute with pseudocapacitance to the total capacitance of the supercapacitor

Capacitance distribution

The two electrodes form a series circuit of two individual capacitors C1 and C2. The total capacitance Ctotal is given by the formula

$$C_{total} = C1*C2/(C1+C2)$$

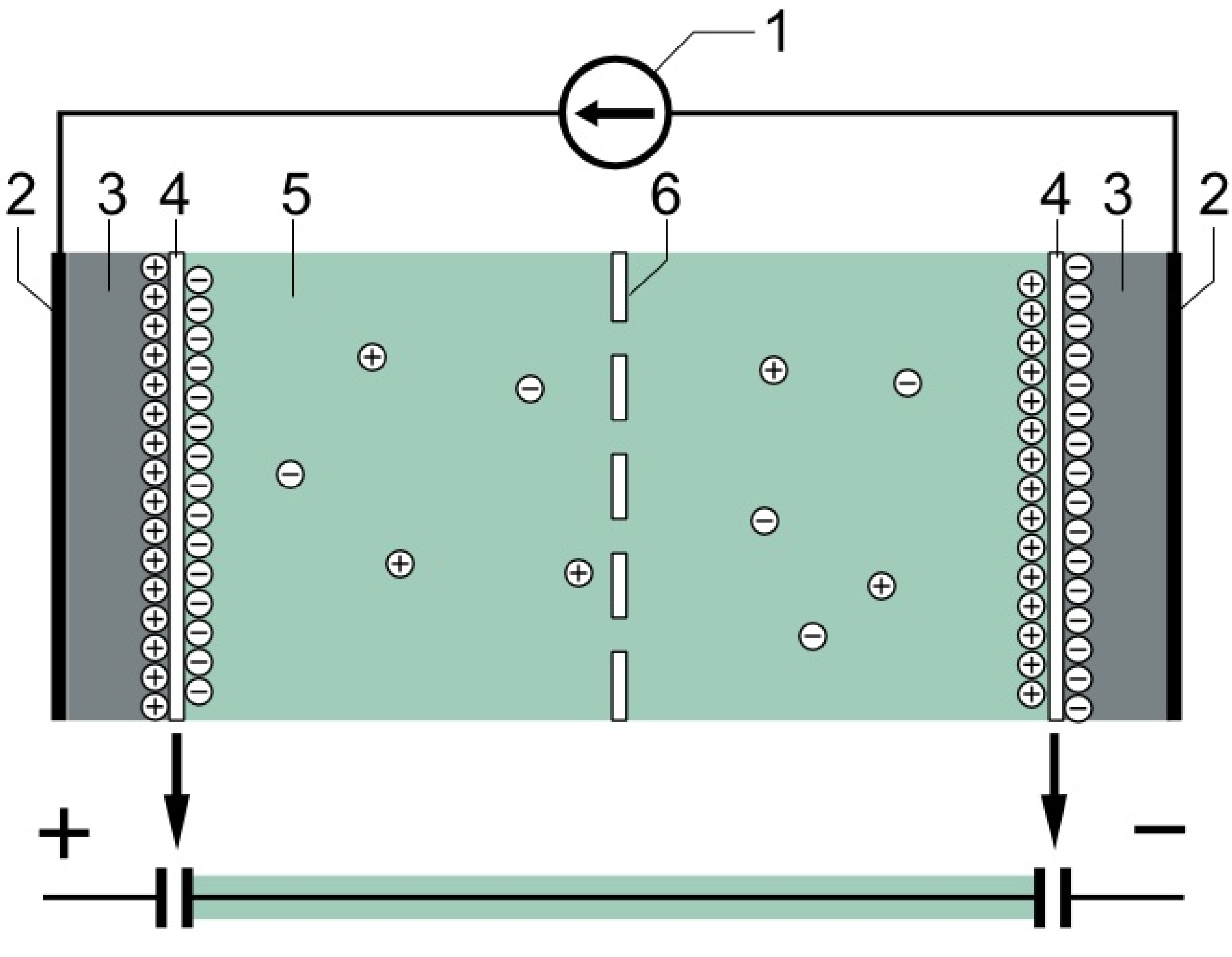
Supercapacitors may have either symmetric or asymmetric electrodes. Symmetry implies that both electrodes have the same capacitance value, yielding a total capacitance of half the value of each single electrode (if $C1 = C2$, then $C_{total} = \frac{1}{2} C1$). For asymmetric capacitors, the total capacitance can be taken as that of the electrode with the smaller capacitance (if $C1 \gg C2$, then $C_{total} \approx C2$).

Storage principles

Electrochemical capacitors use the double-layer effect to store electric energy; however, this double-layer has no conventional solid dielectric to separate the charges. There are two storage principles in the electric double-layer of the electrodes that contribute to the total capacitance of an electrochemical capacitor

Double-layer capacitance, electrostatic storage of the electrical energy achieved by separation of charge in a Helmholtz double layer.
Pseudocapacitance, electrochemical storage of the electrical energy achieved by faradaic redox reactions with charge-transfer.
Both capacitances are only separable by measurement techniques. The amount of charge stored per unit voltage in an electrochemical capacitor is primarily a function of the electrode size, although the amount of capacitance of each storage principle can vary extremely.

Practically, these storage principles yield a capacitor with a capacitance value in the order of 1 to 100 farad.



Typical construction of a supercapacitor: (1) power source, (2) collector, (3) polarized electrode, (4) Helmholtz double layer, (5) electrolyte having positive and negative ions, (6) separator.

Comparision Chart