Tecate GROUP
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What is an Ultracapacitor?

Electric double-layer capacitors, also known as supercapacitors, electrochemical double layer capacitors (EDLCs) or ultracapacitors are electrochemical capacitors that have an unusually high energy density when compared to common capacitors, typically several orders of magnitude greater than a high-capacity electrolytic capacitor.

The electric double-layer capacitor effect was first noticed in 1957 by General Electric engineers experimenting with devices using porous carbon electrode. It was believed that the energy was stored in the carbon pores and it exhibited "exceptionally high capacitance", although the mechanism was unknown at that time.

General Electric did not immediately follow up on this work, and the modern version of the devices was eventually developed by researchers at Standard Oil of Ohio in 1966, after they accidentally re-discovered the effect while working on experimental fuel cell designs. Their cell design used two layers of activated charcoal separated by a thin porous insulator, and this basic mechanical design remains the basis of most electric double-layer capacitors to this day. With advances made on both materials and manufacturing process, today Tecate Group PowerBurst® product show a superior advantage amongst all other ultracapacitors in the market.

Generally, capacitors are constructed with a dielectric placed between opposed electrodes, functioning as capacitors by accumulating charges in the dielectric material. In a conventional capacitor, energy is stored by the removal of charge carriers, typically electrons from one metal plate and depositing them on another. This charge separation creates a potential between the two plates, which can be harnessed in an external circuit. The total energy stored in this fashion is a combination of the number of charges stored and the potential between the plates. The former is essentially a function of size and the material properties of the plates, while the latter is limited by the dielectric breakdown between the plates. Various materials can be inserted between the plates to allow higher voltages to be stored, leading to higher energy densities for any given size. For example aluminum electrolytic and tantalum electrolytic capacitors, use an aluminum oxide film and a tantalum oxide film as the dielectric, respectively. In contrast, Electric Double Layer Capacitors do not have any dielectrics in general, but rather utilize the phenomena typically referred to as the electric double layer. In the double layer, the effective thickness of the “dielectric” is exceedingly thin, and because of the porous nature of the carbon the surface area is extremely high, which translates to a very high capacitance. Generally, when two different phases come in contact with each other, positive and negative charges are set in array at the boundary. At every interface an array of charged particles and induced charges exist. This array is known as Electric Double Layer. The high capacitance of an EDLC arises from the charge stored at the interface by changing electric field between anode and cathodes.

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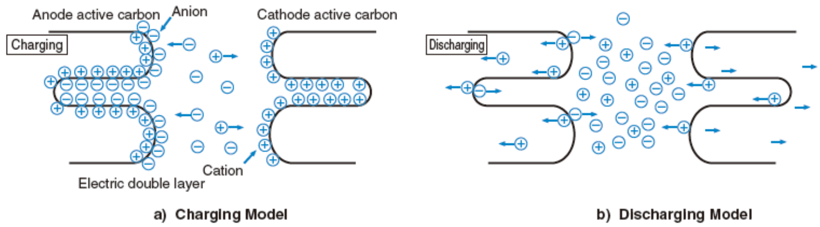

Figure 1: Ultracapacitor Charge Separation

However, the double layer capacitor can only withstand low voltages (typically less than 2.7V per cell), which means that electric double-layer capacitors rated for higher voltages must be made of matched series-connected individual capacitors, much like series-connected cells in higher-voltage batteries.

There are 2 types of electrolytes used by EDLC manufacturers. One is water-soluble and the other is non-water soluble. The non-water soluble electrolyte does increase the withstand voltage per cell compared to that of a water soluble electrolyte, hence producing a higher energy density. Tecate Group PowerBurst® cells are made with non-water soluble electrolytes, and feature a small size and light weight.

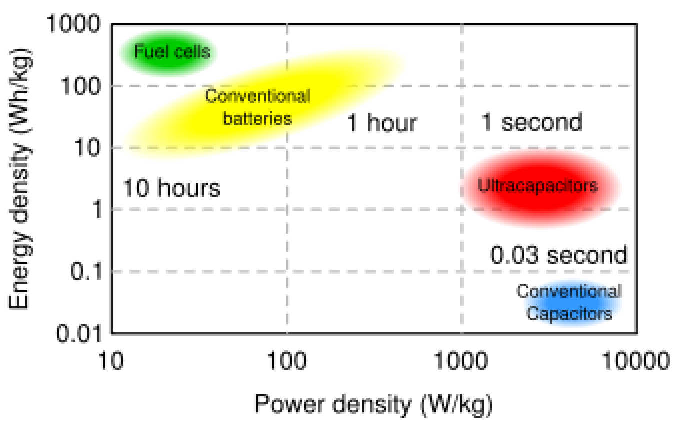

Figure 2: Ragone Plot

As can be seen in Figure 2, the Ultracapacitors reside in between conventional batteries and conventional capacitors. They are typically used in applications where batteries have a short fall when it comes to high power and life, and conventional capacitors cannot be used because of a lack of energy. EDLCs offer a high power density along with adequate energy density for most short term high power applications. Many users compare EDLCs with other energy storage devices including batteries and conventional capacitor technology. Each product has its own advantages and disadvantages compared to other technologies as can be seen from the chart below:

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Available Performance	Lead Acid Battery	Ultracapacitor	Conventional Capacitor
Charge Time	1 to 5 hrs	0.3 to 30 s	10^{-3} to 10^{-6} s
Discharge Time	0.3 to 3 hrs	0.3 to 30 s	10^{-3} to 10^{-6} s
Energy (Wh/kg)	10 to 100	1 to 10	< 0.1
Cycle Life	1,000	>500,000	>500,000
Specific Power (W/kg)	<1000	<10,000	<100,000
Charge/discharge efficiency	0.7 to 0.85	0.85 to 0.98	>0.95
Operating Temperature	-20 to 100 C	-40 to 65 C	-20 to 65 C

Figure 3: Ultracapacitors vs. Battery and Conventional Capacitors

Each application needs to be evaluated based on its requirements. Below are some of the advantages and disadvantages when considering the use of EDLCs:

Advantages:

- ***High energy storage***. Compared to conventional capacitor technologies, EDLCs possesses orders of magnitude higher energy density. This is a result of using a porous activated carbon electrode to achieve a high surface area.
- ***Low Equivalent Series Resistance (ESR)***. Compared to batteries, EDLCs have a low internal resistance, hence providing high power density capability.
- ***Low Temperature performance***. Tecate Group PowerBurst® products, with their use of patented technology, are capable of delivering energy down to -40°C with minimal effect on efficiency.
- ***Fast charge/discharge.*** Since EDLCs achieve charging and discharging through the absorption and release of ions and coupled with its low ESR, high current charging and discharging is achievable without any damage to the parts.

Disadvantages:

- ***Low per cell voltage.*** EDLC cells have a typical voltage of 2.7V. Since, for most applications a higher voltage is needed, the cells have to be connected in series.
- ***Cannot be used in AC and high frequency circuits.*** Because of their time constant EDLCs are not suitable for use in AC or high frequency circuits.

The specifics of ultracapacitor construction are dependent on the manufacturer, and the intended application. The materials may also differ slightly between manufacturers or due to specific application requirements. The commonality among all ultracapacitors is that they consist of a positive electrode, a negative electrode, a separator between these two electrodes, and an electrolyte filling the porosities of the two electrodes and separators.

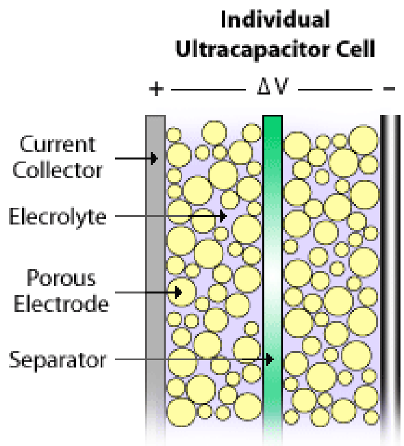

Figure 4: Internal Cell Construction

Today, in general, most manufacturers have adopted a cylindrical construction method for their EDLCs. However, there are still products in the market that use a prismatic design. Each method has its own advantages and disadvantages which may or may not affect their use in specific applications. Tecate's PowerBurst® products use the round or cylindrical construction method. The cells are constructed from activated carbon particles, mixed with a binder and then deposited on aluminum foil. In this method, as shown in the following figure, the electrodes are wound into a jellyroll configuration very similar to an aluminum electrolytic capacitor. The electrodes have foil extensions that are then welded to the terminals to enable a current path to the outside of the capacitor.

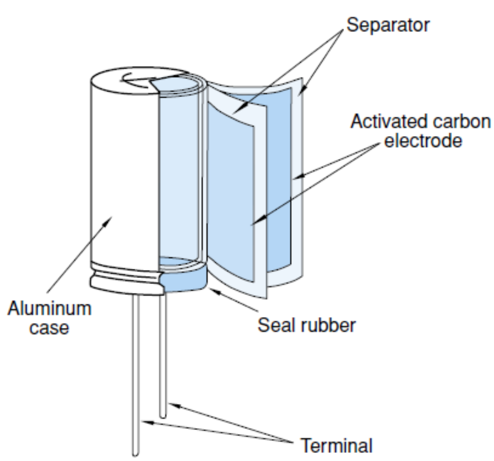

Figure 5: Cell Construction

EDLCs share the same equivalent circuit as conventional capacitors. The first order model is represented by the circuit below. It is comprised of four ideal components. The series resistance R_s which is also referred to as the equivalent series resistance (ESR). This is the main contributor to power loss during charging and discharging of the capacitor. It is also comprised of a parallel

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resistance R_p which affects the self-discharge, a capacitance C and a series inductor L_s that is normally very small as a result of the cell construction.

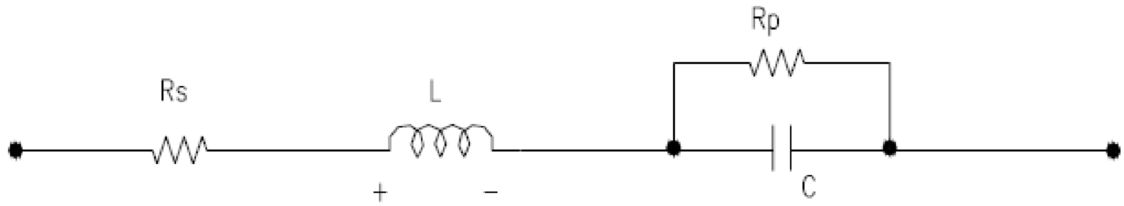

Figure 6: First Order Equivalent Circuit

Since R_p is always much larger than R_s it can be ignored. Also, because of the porous material used on the electrode of EDLCs, they exhibit non-ideal behavior which causes the capacitance and resistance to be distributed such that the electrical response mimics transmission line behavior. Therefore, it would be necessary to use a more general circuit, as shown in the figure 6, for representing the real electrical response.

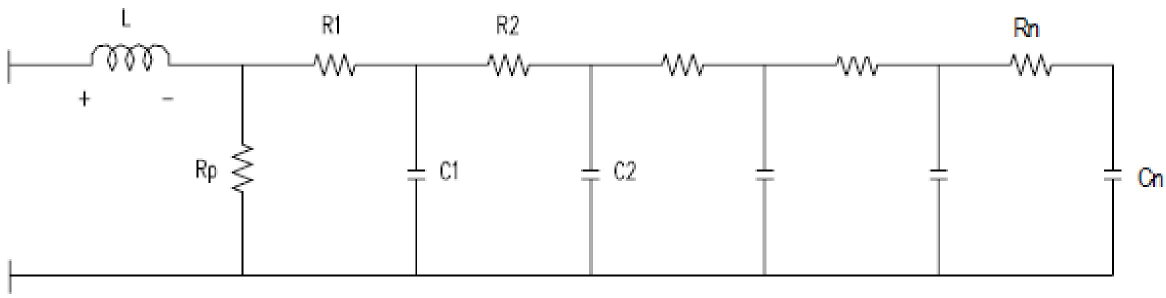

Figure 7: Ladder Network

However, to simplify the circuit we can model the EDLC as an RC circuit. In this case the charge stored is Q=CV. The energy stored in the capacitor in Joules (watt-second) = $1/2CV^2$. Other useful formulas are discussed more in the sizing section.

One final note to consider in regards to EDLC, is the discharge characteristics of the cells. Unlike batteries which can discharge a fairly constant voltage, the EDLC cells act very similar to traditional capacitors and will drop their voltage as they discharge their stored energy similar to what is shown in Figure 8.

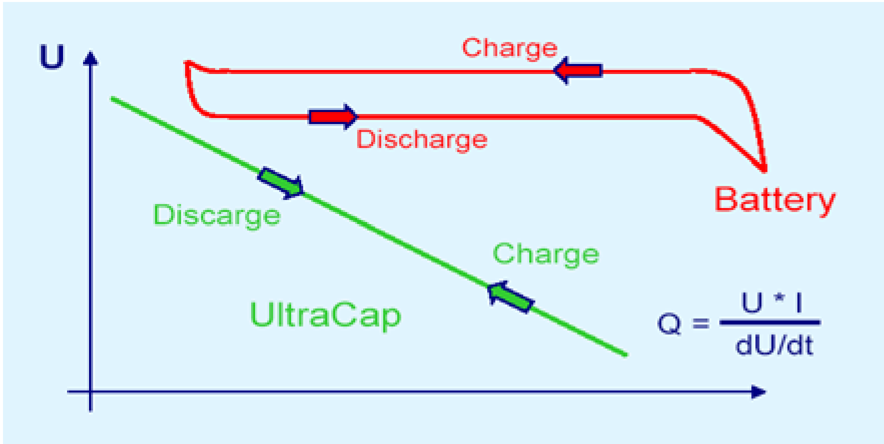

Figure 8: Ultracapacitor Discharge Curve