Qeios

SUDA energy autárkeia system

Hongyu Li, Fuhuo Li, and Shigeru Kanemitsu

v1

Dec 29, 2023

https://doi.org/10.32388/NQA7IL

SUDA energy autárkeia system

F.-H. Li, S. Kanemitsu

Contents

Abstract: We propose a drastically new energy autarkeia system extracting full power of a quickly charging battery

1 ECaSS(R)

Definition 1. *A* **capacitor** *(or also called a* **condenser***) is a device for storing charge consisting of two conducting plates (or surfaces) of any shape, with one carrying positive charge* $+Q$*, say, and the other negative charge* $-Q$*. If the voltage difference between two plates is* V *and the positive charge is* Q*, then* $C = \frac{Q}{V}$ *is called the* **capacitance***, whence it follows that*

$$Q = CV. \tag{1.1}$$

A **parallel plate capacitor** *is a special type of capacitor with two conducting plates of the same shape and of area* A*, distance* d *apart. The capacitance* C *is given by* $C = \frac{A}{4\pi d}$*, whence the shorter the distance, the bigger the capacitance, and the bigger the amount of charge.*

An **electric double layer** *generally means an aggregate of electric dipoles on two thin surfaces, close to each other, on one of which positive charges (holes) are uniformly distributed and on the other of which negative charges (electrons) are found, as discovered by Helmholz in* 1879.

Here we restrict the discussion to the electric double layer (EDL) occurring naturally on the **interface** of each of a pair of conductive poles (electrodes) and the electrolyte. Statistically, there is a thin layer on the immediate interface (consisting of inner and outer layers, see below) and outside there is a diffused layer, constituting a double layer. For a water electrolyte, the BDM model describes the detailed structure of the EDL, [Okamura (1999), pp. 28-29]. The Inner Helmholtz Layer (IHL) is the layer next to the interface of width d_1, which consists of molecules of the electrolyte and specifically adsorbed ions (and other molecules). The Outer Helmholtz Layer (OHL) is the next outer layer of the IHL of width d_2, which is the radius of those solvated (electrolyte) ions that are attached to the surface of the IHL. From the data on the voltage V_d of the diffused layer and V_h of the layer to d_2, the capacitance C_d of the diffused layer and the capacitance C_h of the Helmholtz layer can be found. It turns out that the higher the density of the electrolyte (and hence the smaller d_2), the smaller the voltage V_d, and that C_d is negligible compared with C_h.

We define the **breakdown voltage** V to be the maximum voltage difference that can be applied across the insulator before it starts conducting. If a higher voltage than V is exerted, then **electrolysis** occurs, but **within the breakdown voltage, the poles and the electrolyte are insulated by the double layer, and it works as a capacitor**. For an EDL capacitor to have a higher energy density, we find from (1.5) below that the one with a smaller d_2 and a bigger breakdown voltage is what is wanted.

M. Okamura [Okamura (1999)] was led to the great discovery of an electric double layer super-capacitor, ECaSS(R), by the **similarity** between a *parallel-plate capacitor* and an *electric double layer*.

ECaSS(R)—energy capacitor system, neé ECS—is a *(super-)capacitor controlled by an electronic circuit* that was invented by M. Okamura, and it stores electricity as electric energy, whence almost no loss of energy occurs under transformation. And the cycle life can be as long as its calendar year. The problem is that it is high-cost. But one could argue that a towncar-type compact EV having an ECaSS(R) as the source of electricity is to have a very long life. It can have a *large output density* and can absorb most of the electric energy generated by regenerative braking, thus prolonging the driving range. The only defect is the smaller energy density, and the original driving range is similar to that of a lead acid EV. A compact EV with ECaSS(R) can compete with other vehicles and supersede them in many respects. The driving range is not as long as that of LIB EVs, but as it so happened in 1996-1999 with the GM EV1, drivers will find that normally they drive a maximum of 50 km per day. And when they come home, the super-capacitor can be charged in a few minutes. It will turn out that they just drive their EVs rather than other cars.

Below we shall dwell on some details of ECaSS(R). To emphasize the energy-aspect, we write electric energy for power. The electric energy spent by the resistance for a time period t is

$$W_R = W_R(t) = \int_0^t i^2 R \,\mathrm{d}t \tag{1.2}$$

The limit as $t \to \infty$ of $W_R(t)$ is the total energy spent in the resistance, which is the total electric energy W stored in the capacitor

$$W = \lim_{t\to\infty} W_R(t) = \int_0^\infty i^2 R \,\mathrm{d}t. \tag{1.3}$$

In the case where the capacitor is **charged by a constant voltage** V, the current i at time t is given by

$$i = i(t) = \frac{V}{R} e^{-\frac{t}{CR}}. \tag{1.4}$$

Then (1.3) amounts to

$$W = \int_0^\infty i^2 R \,\mathrm{d}t = \int_0^\infty R \frac{V^2}{R^2} e^{-\frac{2t}{CR}} \,\mathrm{d}t = \frac{CR}{2}\frac{V^2}{R} = \frac{1}{2} C V^2. \tag{1.5}$$

By (1.1), (1.5) reads

$$W = \frac{1}{2}\frac{Q^2}{C}, \tag{1.6}$$

which is the energy stored in the capacitor when charged by a constant **current source** (which is used in ECaSS(R)). The charge Q charged/discharged by a constant current i for a time period t is

$$Q = i \cdot t. \tag{1.7}$$

and (1.2) reads

$$W_R = i^2 R \cdot t = R \frac{Q^2}{t}, \tag{1.8}$$

on substituting from (1.7). Hence the ratio of the loss is $\frac{W_R}{W} = \frac{2CR}{t}$, whence the loss is smaller if the charging time is longer. However, the ratio of the loss of charge and discharge by a voltage source is $\frac{1}{2} \cdot \frac{1}{2} = \frac{1}{4}$ by (1.5).

As is seen in (1.5) and (1.8), only capacitors do not work because of high internal resistance, and one needs magic to get rid of i^2R. Okamura's idea is to **combine the capacitors in a series connection with an ingenious electronic circuit**, [Okamura (1999)]. As mentioned above, all capacitors have the property that their efficiency is $\leq 50\%$ if charged/discharged by a voltage source by (1.5). To use a current source, the current pump (switching converter) is to be installed in the circuit (step-down chopper), which charges the capacitor by current. A hint is indicated in [Okamura (1999), p. 129, footnote] as to how one can get a current source: here again, one has to have masterly knowledge about (circuit) elements C and L such that C stores energy as voltage and L stores energy as current. For discharging, we note that (1.5) leads to $V = \sqrt{\frac{2}{C}}\sqrt{W}$, i.e., the voltage varies too much, and to avoid this, another current pump (output converter) is to be installed, which allows one to get a constant output voltage with efficiency S.

In order to connect capacitors of the same capacitance in series effectively, there is a problem of different allotted voltages because of the different amounts of leak current of each capacitor. In ECaSS(R), each capacitor is squeezed by a parallel monitor, having the effect of initialization.

Thus, Okamura's ECaSS(R) is an ingenious combination of EDL capacitors in a series connection charged by a current source, which can be utilized up to $\frac{15}{16} \approx 94\%$ efficiency until the energy is spent to $\frac{1}{4}$ of the full charged voltage (by (1.5)).

For a real ECaSS(R) model, the energy is a modified form of (1.5):

$$W = \frac{1}{2}PSCV^2, \tag{1.9}$$

where P resp. S is the efficiency of power resp. the integration efficiency of the current pump. For the data $P = \frac{15}{16}$, $S = 83\%$, we have 28.2 Wh, [Okamura (1999), p. 173].

Once the principle is established by Okamura, there can be a lot of improvements possible since ECaSS(R) has the flexibility of replacing the electrodes and electrolyte. There are many experimental results on improved ECaSS(R) which hopefully will be realized as commercial products.

2 Nanogate capacitor

In a nanocapacitor, the electrolyte is Et_4NBF_4 (tetraethylammonium tetrafluoroborate) and the electrodes are activated non-porous carbons. The energy density is 15 Wh/kg, and the output density is 13.5 Wh/kg. Then, with 10 capacitors in serial connection, the system will surpass the ordinary energy density of secondary batteries.

References

[Okamura (1999)] Okamura, M. (1999). *Electric double layer capacitor and energy capacitor system (ECS)*, Nikkan-kogyo-shinbun-sha, Tokyo.

[Takeuchi (1998)] Takeuchi, M., Maruyama, T., Koike, K., and Okamura, M. (1998). *Electrochemical intercalation of tetraethylammonium tetrafluoroborate into the KOH-treated carbon consisting of multi-graphene sheets for the electric double layer capacitor*, *Electrochemistry*, **55**, No. 12.