6.3. How to Manage Leakage Current and Self Discharge of EDLC Capacitors

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Abstract

Electric double-layer capacitors (EDLCs) combine the exceptionally large surface area of activated carbon, a liquid, highly conductive electrolyte, and the physical phenomenon of double layers to achieve extremely high capacitance. With their high capacitance and ability to deliver high discharge currents, EDLCs fill the gap in energy storage between traditional aluminum electrolytic capacitors and rechargeable batteries.

In some applications, a bridging time of hours, days, or even months is required after the power supply has been switched off. In these cases, it is very important to understand and account for the EDLC's inevitable self-discharge due to leakage current and its inherent temperature dependence. Typical characteristics and design considerations are discussed in this paper.

Introduction

Supercapacitors, or electric double-layer capacitors (EDLCs), have been available for more than 50 years. EDLCs are energy storage systems and can be used to supplement or replace conventional batteries.

With their high capacitance and ability to deliver high discharge currents, EDLCs fill the gap in energy storage between traditional aluminum electrolytic capacitors and rechargeable batteries. The most widely used EDLC technology combines the exceptionally large surface area of activated carbon, a liquid, highly conductive electrolyte, and the physical phenomenon of double layers to build a capacitor with extremely high capacitance.

EDLCs can store more energy than conventional capacitor technologies. The main reason for this is the double-layer effect. This effect is based on separating existing charges on the electrode surface into a double layer with atomic dimensions. In this way, a large amount of charge can be stored on the surface of the activated carbon layer. This surface is distributed inside the porous carbon layer and is accessible to specific liquid electrolytes.

As a result, the charge exchange can take place quickly and reversibly. EDLC products are maintenance-free and allow a very high number of charging and discharging cycles without any significant reduction in performance: > 1 million cycles are typical.

Today, EDLCs can be found in applications such as energy storage, power outage support, and energy harvesting storage. In some applications, a bridging time of hours, days, or even months is required after the power supply is switched off. In these cases, it is very important to understand and consider the inevitable self-discharge effect due to leakage currents and their inherent temperature dependence.

Another essential property of EDLCs compared to batteries is their fast energy release as well as high power and current due to very low internal resistivities. In the event of a voltage drop in the supply, for example, an EDLC can discharge its energy within a very short timeframe with high peak power if required.

With the current technology, single cells work with a nominal voltage of up to 3 V. If higher voltages are required, several single cells can be connected in series. A parallel connection is possible to increase capacity and peak current.

Capacitance and power performance are scalable over a wide range. For example, larger EDLC modules are used for high-performance automotive applications, systems for renewable energy, and as backup systems for the medical and data sectors.

The Impact of Self-Discharge

Self-discharge is defined as voltage loss over time once the charged product is disconnected from the power source. This is caused by a residual leakage current, which is made up of various mechanisms.

Since temperature-dependent self-discharge effects can have a very large impact on the performance of supercapacitors, it is necessary to study the various aspects of this phenomenon. In addition, the study of self-discharge behavior in EDLC products is of great importance due to non-identical cells and the possible uneven temperature exposure of the products.

Normally, a fully charged EDLC capacitor discharges over a period of several weeks. At higher temperatures, the discharge rate increases, and the stored energy can be used up within hours.

The discharge rate depends on various factors like:

- Capacitor charging state before the energy source is disconnected
  - How long was the capacitor charged (charging history / conditioning)

    The longer the capacitor was charged, the better the self-discharge behavior
  - Which voltage was the capacitor charged to

    At higher voltages, the initial voltage drop will be higher
- Capacitor temperature during the self-discharge process
  - The higher the temperature, the faster the capacitor will discharge

The graph below shows the self-discharge curves after 24 h at different charging voltages with a 25 F / 3 V EDLC. The charging graph starts from 2 V up to 3 V in steps of 200mV.

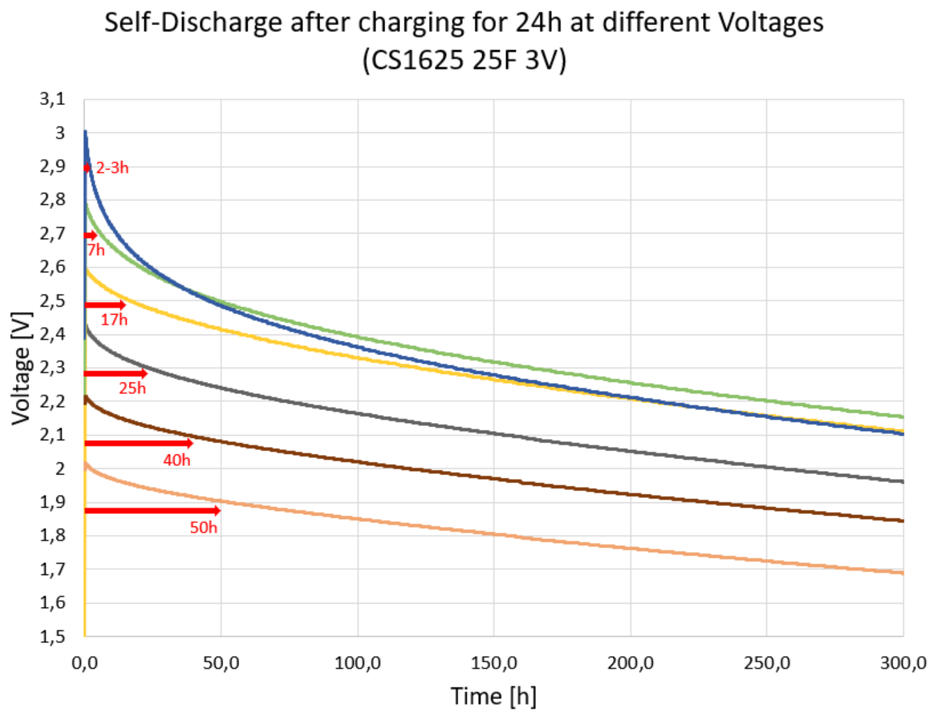

Fig. 1. Self-discharge after charging for 24 h at room temperature

Conclusion: The higher the charging voltage, the higher the initial self-discharge voltage drop. As shown in the graph, charging condition of the capacitor defines the time span for a 0.1 V drop. Understanding this behavior allows you to optimize the performance of your application.

The Role of Leakage Current

In an EDLC, leakage current is usually defined as the residual current which remains after a longer period of stabilization at a constant voltage.

The level of this current depends on different factors such as:

- Charging time at constant voltage
- Temperature
- Mechanisms and material interactions inside the capacitor (such as the electrode, electrolyte, aging, and testing / charging history)

At room temperature the leakage current is in the range of a few µA per Farad. After long charging times it may even reach values in the nA per Farad.

Leakage current is largely proportional to cell capacitance and applied charging voltage.

The current is initially high but declines exponentially with time.

The terms “leakage current” and “charging-current” should be distinguished from each other. Especially during the initial charging period (below 30 min), it does not make sense to talk about leakage current because the current is mainly caused by charge redistributions inside the porous electrode material.

For this reason, most EDLC manufacturers only specify the leakage current at 72 h and at room temperature.

In the graph below, leakage current was recorded for a 25 F / 3 V in a 16 mm x 25 mm EDLC.

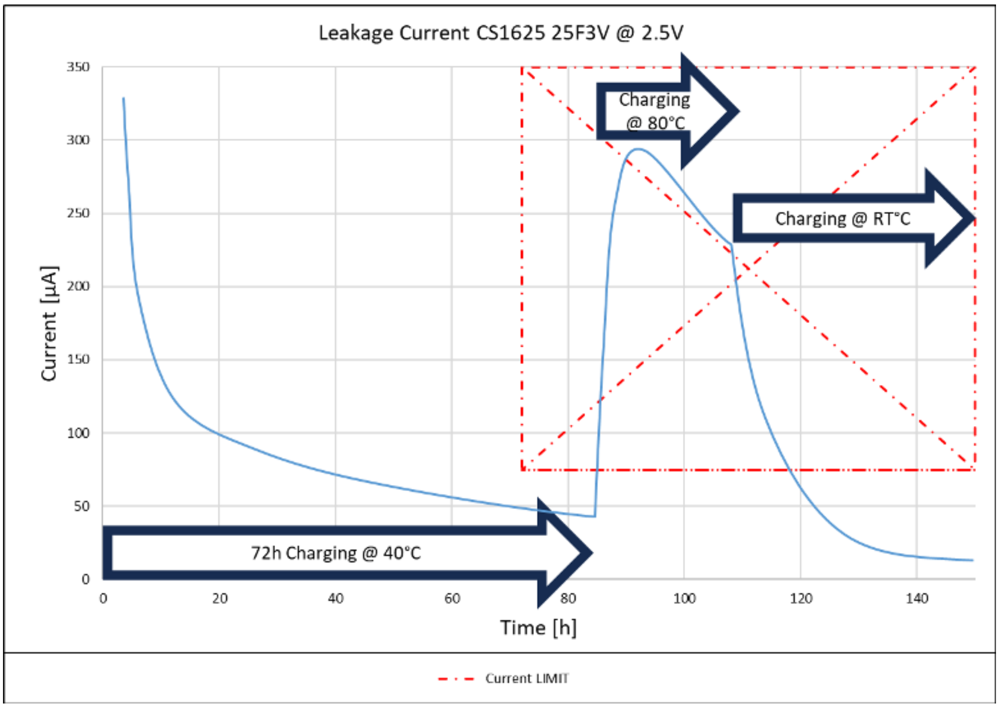

Fig. 2. Leakage current at different temperatures

The record starts with a charged product and shows the decline of the leakage current over 72 h at 40 °C. The leakage current is as low as 50 µA. While the product is kept on voltage (2.5 V), the temperature was changed from 40 °C to 80 °C. As discussed earlier, increasing temperature also increases the leakage current. This can be observed in the current peak, which also gives evidence that the current decreases over time at high temperatures too. As a final step, the temperature was reduced to room temperature (25 °C). The current returns to the expected level within a few hours.

The next graph demonstrates that leakage current is mainly “a function of time” and that temperature acts as a multiplier.

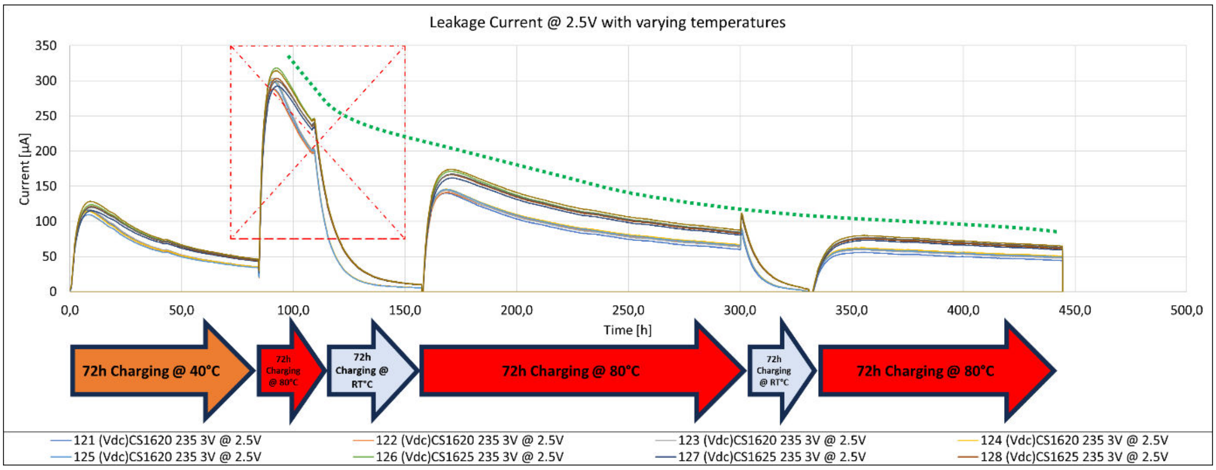

Fig. 3 leakage current, a function of time

Even though high temperatures increase the current, the overall decline does not depend on varying temperatures. There is no "reset" of the leakage current caused by changing temperatures.

As temperature is changed from high to low and back, the current returns to its former state at the respective temperature within a few hours.

SUMMARY AND CONCLUSION

This white paper has investigated the behavior of self-discharge and leakage current of EDLC supercapacitor products.

Self-discharge effects and leakage current are two distinct parameters which may have to be considered separately.

Developers must take the temperature-dependent leakage current behavior into account in their applications.

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