Characteristics that boost a supercapacitor’s power

There are many uses for supercapacitors beyond emergency power supplies, explains **Dr René Kalbitz, Product Manager Capacitors & Resistors Division at Würth Elektronik eiSos GmbH**

Supercapacitors feature very high charge storage capacity, long service life, short charging times, and fast power delivery. One application is emergency power supply units, but they can also be used for hot-swap and hybrid applications, for example, to support batteries during power peaks. Figure 1 illustrates the typical circuit for such applications.

Supercapacitors are energy storage devices, comparable to batteries in many respects. They can be charged from any current limiting energy source and drive electrical applications. Supercapacitors, like any other energy storage system, require a certain technical structure to store and supply energy, including a circuit for charging the supercapacitor under real conditions and an electronic application to be operated.

Characteristics

When it comes to charging and discharging, two characteristics of supercapacitors need to be considered. Firstly, unlike batteries, the voltage depends on the charged state. The voltage at the component rises or falls as soon as the supercapacitor is charged or discharged. This property is unfavourable for the discharging process, because electronic applications need a constant working voltage. Secondly, supercapacitors can be charged with relatively high currents, which might lead to a semi short-circuit condition for the power supply at the moment of switching on. Although the design-in process for supercapacitors may differ from case to case, the basic procedure is always as follows:

The required energy capacity is first calculated on the basis of the expected energy requirement. Determination of the required capacitance (C) depends on the specification of the load, as well as the efficiency of the DC/DC converter, its lowest operating voltage and the charging voltage. The maximum power output is limited by the equivalent series resistance (RESR) and any other resistance (Rp) caused by contacts or intentionally introduced for protection. The charging regime is then determined, and the corresponding charging times are calculated. In the case of constant voltage charging, a protective resistor is selected depending on the specification of the charger. Charging with constant current is more common, however, and has the advantage of shorter charging times.

The following example shows how supercapacitors - in this case electric double layer capacitors (EDLC) - can be used as a backup power source. In this scenario, both the actual current source and the application operate at higher voltages than the supercapacitor rated voltage. A step-down converter is used to charge the supercapacitors and a step-up converter to supply the test application. A wireless power transfer (WPT) is used for the application with a simple LED panel as the load.

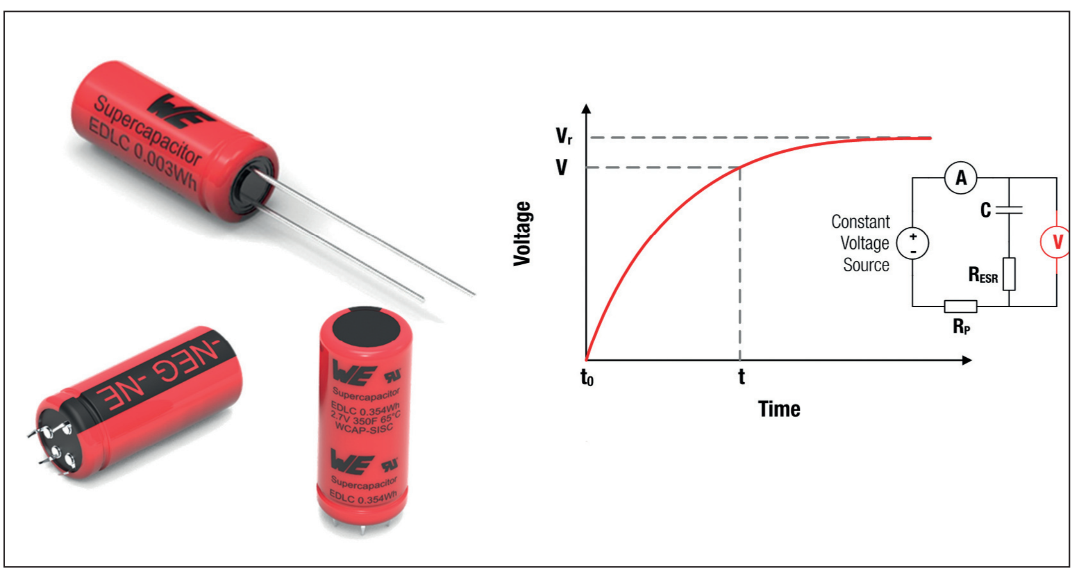
For the following measurements of the voltage and current characteristics during the charging and discharging process, the step-down converter (buck) and the step-up converter (boost) were separated from the supercapacitor. The aim is to operate the application with a power consumption of about P = 0.8W (including conversion losses) for about t = 5 min. A total energy of around E = P • t = 0.8W • 300s = 240J = 0.067Wh is therefore needed. As the converter used has a set charge-cutoff voltage of 2.7V, the capacitance must be at least:

$$C = 2 \cdot \frac{E}{V_1^2 - V_2^2} = 2 \cdot \frac{240\ \text{J}}{(2{,}7\ \text{V})^2 - (1\ \text{V})^2}$$

Where V1 = fully charged voltage, V2 = lowest useful voltage

In the typical circuit, two capacitors are charged in parallel, each with a capacitance of 50F. The total capacitance of the

Figure 1: EDLC supercapacitors can be used as a backup power source.



supercapacitor is therefore 100F at a rated voltage of 2.7V. As the minimum required capacitance is 76F, the unit will provide sufficient energy capacity. A step-down converter was selected as the current source for charging, which converts a DC input voltage of 12V to a DC output voltage of 2.7V.

The step-up converter used requires an input voltage of at least 1V. For this reason, the calculation must also be based on 1V for the lower supercapacitor voltage (Figure 3).

Figure 3 (top) shows the measured and calculated voltage charging characteristic for the supercapacitor as it is charged with a constant current of 3A from 0.95 to 2.7V. During the charging process, the load was switched off. The following parameters were selected for calculating the theoretical curves: RESR + Rp = 0.08Ω, C = 100F and V1 = 2.7V. The voltage increases linearly from the residual voltage of 0.95V to almost 2.7V. During this period, which lasts around 32 to 86 seconds, the current is constantly regulated to 3A. The loading time for this process given by

$$\frac{100\text{ F}}{3\text{ A}}(2.7\text{ V} - 0.95\text{ V}) \approx 53\text{ s.}$$

This constant current charging process is followed by a phase of constant voltage charging, as can be seen from the exponential fall in charging current in Figure 3 (bottom).

The discharging process

The measured data for the discharging process is also compared with the theoretical model. The step-up converter discharges the supercapacitor from = 2.7V to its cut-off voltage of 1V. It supplies a WPT system with a small array of LEDs at a voltage of 5V and a power consumption of approx. 0.75W. The efficiency of the systems is generally not constant, but changes with the input voltage, the ambient temperature, and various design factors. In this example, the efficiency changes from 90% at 2.7V to around 70% as soon as the converter approaches its cut-off voltage of 1V.

For simplicity, an average output power of Pc = 0.75W is used, calculated as:

$$\overline{P_c} = \frac{1}{\Delta t}\int P(t)dt.$$

The function P(t) was determined experimentally on the basis of the total current and voltage curves of the converter and the LED array. As the calculation was carried out on the basis of an average output power, only the current curve in Figure 4 deviates increasingly from the theoretical curve. The time required for this discharge process is given by:

$$\frac{100\text{ F}}{2 \cdot 0.75\text{ W}}((2.7\text{ V})^2 - (1\text{ V})^2) \approx 420\text{ s.}$$

This corresponds to the time after which the measured voltage has dropped from 2.7V to the cut-off voltage of 1V. The voltage curve is shown in Figure 4. A

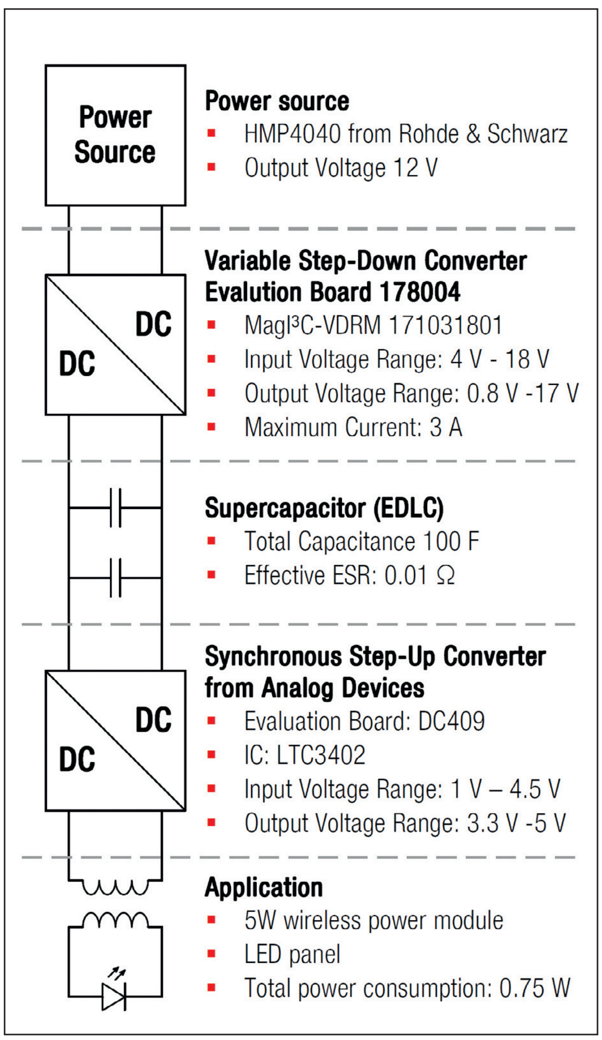


Figure 2: Example application using a supercapacitor in a wireless power module.

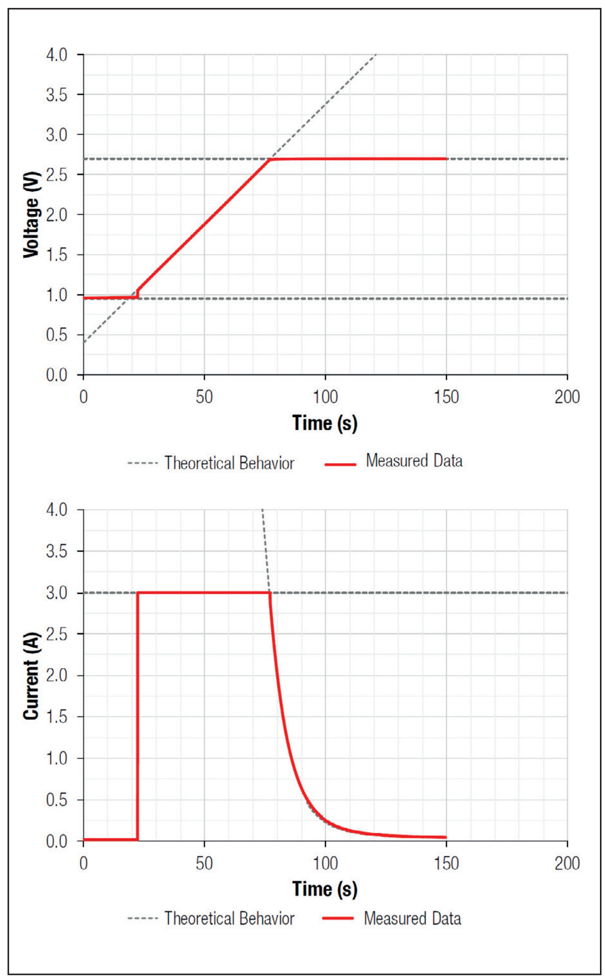


Figure 3: Voltage (top) and current (bottom) characteristics for charging the supercapacitor with constant current.

dashed line shows the theoretical discharging behaviour and a solid red line shows the actual measured data.

Supercapacitor blueprint

The circuit presented, with its charging and discharging behaviour, can serve as a blueprint for many applications in which "super" double-layer capacitors are to be used for short-term energy supply. It was shown that discharging with a step-up converter can be described very well as a discharging process with constant power. Capacitors are particularly suitable as energy storage devices, if it is possible to define exactly what power is required for what period of time.

Hot swap is a typical scenario here. More and more devices are classified as smart in that they have an operating system that should not be shut down and restarted with a change of power supply. Data loss or interruption of a wireless connection due to an interruption of the power supply can also be an argument in favour of a supercapacitor design. Such solutions are not only robust and technically easy to implement, but, as can be seen from the charging time, are quickly ready for use again.

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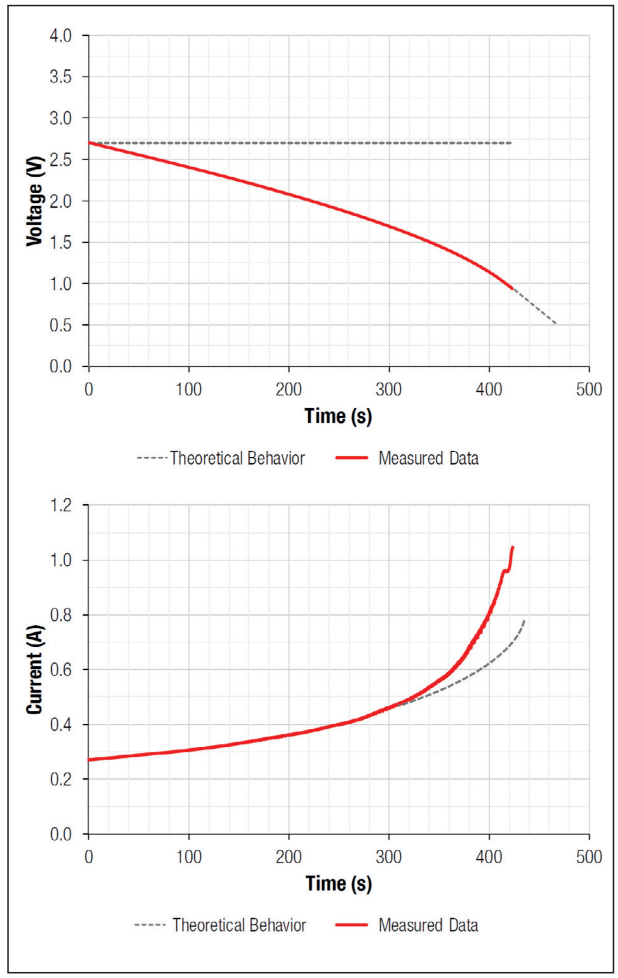
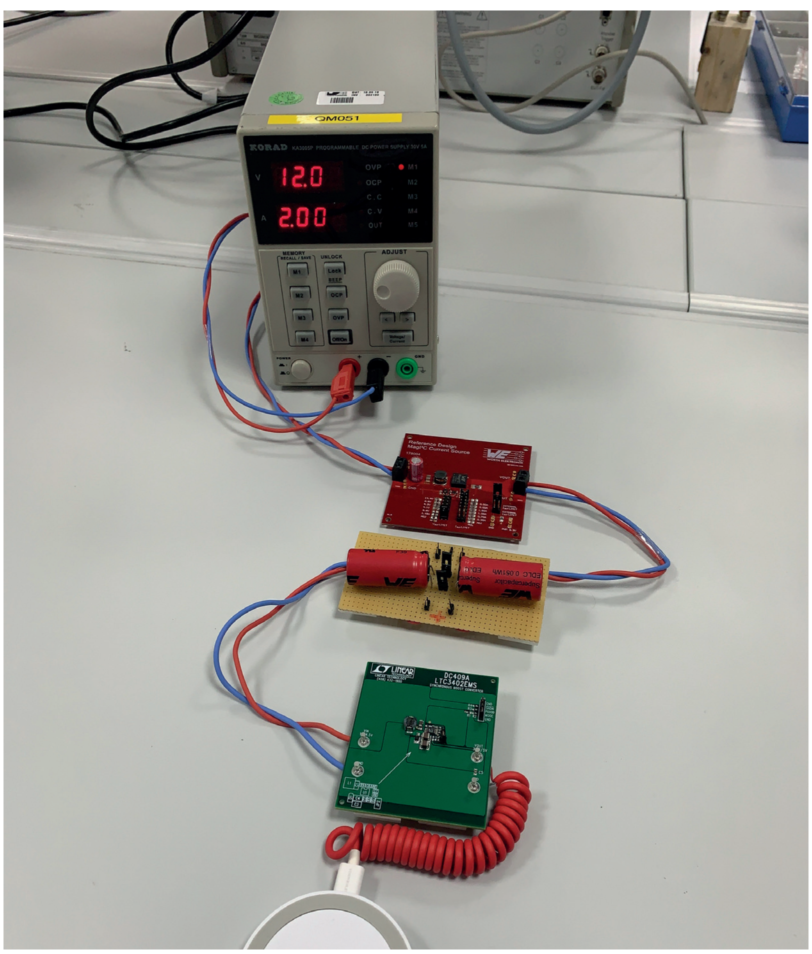


RIGHT Figure 4: Voltage (top) and current (bottom) characteristics for the supercapacitor for constant power discharge.



LEFT Figure 5: The complete application with the different power converters, the supercapacitor bank and the load (different voltage source than in the schematic representation).