Supercapacitor Lifetime Explained

Abracon

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As with any other energy storage component, many variables in the surrounding environment can adversely affect the components' ability to store energy when designing systems with supercapacitors. Some of these variables may be in the system designer's control, while others may not. Regardless, these variables must be considered under worst-case scenarios.

The most common of these variables include Voltage and Temperature. When introduced to overvoltage, supercapacitors can be damaged and certainly shortened in life. In other words, any voltage above the rated voltage for the capacitor will shorten its lifetime. In fact, it is better design practice to back off the system voltage, feeding the supercapacitor to a slightly lower value.

Temperature is another variable that can be detrimental to energy storage components. Unless the supercapacitor is designed into a well-controlled temperature environment, like an actively cooled chassis, handling temperature fluctuations can be tricky. For example, a laptop battery with active cooling (fans) may still become overheated depending on the user's activity. The system's heat is generated by the CPU, memory, etc., and the battery itself. As a result, the laptop includes complex thermal management circuitry and load management schemes to maintain battery health.

Luckily, supercapacitors aren't troubled with internally generated heat. Their charge and discharge cycles are short-lived, and there are little to no increases in temperature. However, they are very sensitive to elevated temperatures of the ambient environment.

Fig. 1 illustrates the logarithmic graph of the expected lifetime for a 6.0V supercapacitor within the temperature specification of 25°C - 70°C. Each line represents the benefit of derating the voltage in 0.2V decrements.

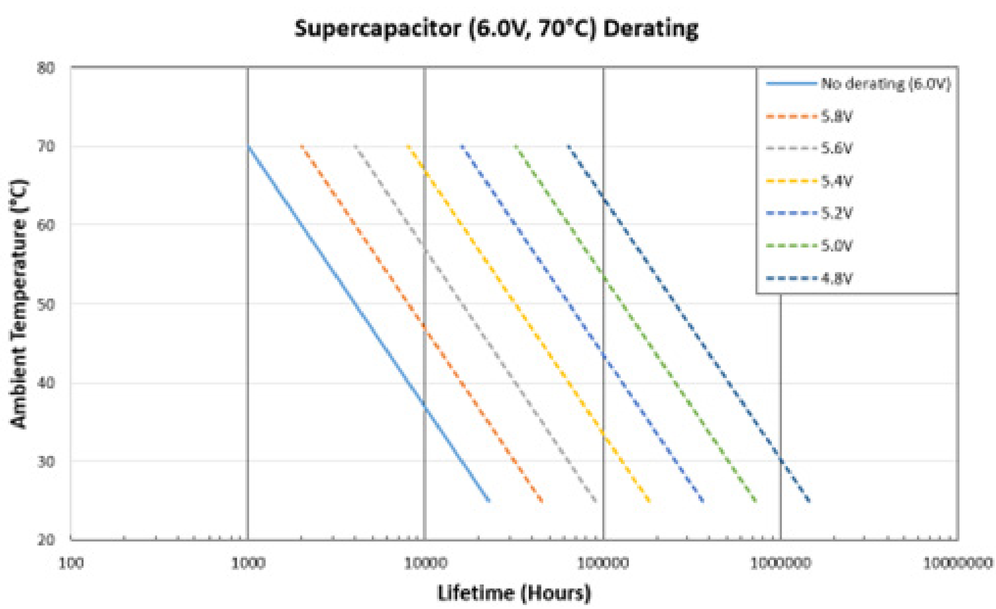

Fig. 1 Example of Derating Temperature and Voltage to Extend Lifetime.

Abracon does not recommend operating supercapacitors out of their specified ranges. For example, designing a 0-70^{0}C supercapacitor into a system that will experience 85^{0}C ambient temperature is not recommended, regardless of whether the temperature increase is temporary.

Industry Standards to Calculate Supercapacitor Longevity

The industry has adopted a few standards to help determine the expected life of a supercapacitor based on the materials used and the design of the component. In other words, using ‘X’ materials, how many ‘Y’ hours will the supercapacitor function while operating within the rated voltage and rated temperature.

$$L = L_0 * M_{(T)}^{(T_{max} - T_a)/a} * M_{(V)}^{(V_{max} - V_a)/b}$$

L_0 is the baseline lifetime of 1000 hours

$M_{(T)}$ is a coefficient for the material as it relates to changes in temperature.

T_{max} is the rated operating temperature.

T_a is the ambient temperature the supercapacitor will experience. Component life can be extended by keeping the ambient lower than the rated operating temperature maximum.

‘a’ is simply for scaling the impact that temperature has on the material.

$M_{(V)}$ is a coefficient for the material as it relates to different operating voltages.

V_{max} is the rated operating voltage.

V_a is the actual operating voltage. This value can be the derated voltage when extending the life of the supercapacitor.

‘b’ is simply for scaling the impact that voltage has on the material.

By utilizing the above equation and using some common coefficients for M(T), a, M(V), and b, the lifetime can be calculated for different values of derated voltage and derated temperature. The data for the graph in Fig.1 can be found below in Table 1.

Calculated Lifetime in Hours

Derated Temperature	Derated Voltage: 4.8	5	5.2	5.4	5.6	5.8	6
25	1,448,155	724,077	362,039	181,019	90,510	45,255	22,627
30	1,024,000	512,000	256,000	128,000	64,000	32,000	16,000
35	724,077	362,039	181,019	90,510	45,255	22,627	11,314
40	512,000	256,000	128,000	64,000	32,000	16,000	8,000
45	362,039	181,019	90,510	45,255	22,627	11,314	5,657
50	256,000	128,000	64,000	32,000	16,000	8,000	4,000
55	181,019	90,510	45,255	22,627	11,314	5,657	2,828
60	128,000	64,000	32,000	16,000	8,000	4,000	2,000
65	90,510	45,255	22,627	11,314	5,657	2,828	1,414
70	64,000	32,000	16,000	8,000	4,000	2,000	1,000

Table 1. Calculated lifetime (in hours) based on derated voltage and derated temperature (Supercapacitor Rated at 6.0V / 70°C)

In theory, this table represents the lifetime of the supercapacitor, ranging from a little over one month of life to over 165 years! More realistic applications running the supercapacitor at full 6.0V and room temperature would achieve over 2.5 years of operation. Derating the voltage by only 0.2V will double that lifetime to over 5 years. That equals a ~3% derating of voltage delivering double the lifetime.

Derating the temperature does not have such a strong impact as voltage, but it can help extend the lifetime if the application circumstances preclude the derating of voltage. For example, every 10°C reduction in ambient temperature yields double the lifetime.

What does Supercapacitor Lifetime Actually Mean?

As previously discussed, the lifetime was given as 1000hrs when operating the supercapacitor at the rated voltage in an environment with an ambient temperature equal to the component's rated temperature. This is represented by the bold numbers in the bottom right corner of Table 1.

What is the state of the supercapacitor at the end of its life? It is still operational, just not optimal. In fact, with a little forethought, the supercapacitor can go beyond its expected lifetime if the system is designed to compensate for a supercapacitor in its twilight years while not performing at 100%.

As the supercapacitor ages, the effective capacitance decreases and the ESR increases. When comparing datasheets from one company to another, everyone measures these to bound the lifetime of the supercapacitor - or at least they should. However, there is no industry standard that states the supercapacitor has expired when capacitance has decreased by X% and ESR has increased by Y%. In most cases, the lifetime of the supercapacitor is considered expired when the capacitance has reduced by 30%, or the ESR has increased by 2-3X, whichever is achieved first.

These limits, used to determine the end of life, also apply to Cycle Life, which is how many charge/discharge cycles the supercapacitor can complete before meeting the ESR or capacitance limits. The typical Cycle Life for EDLC supercapacitors is usually in the 100's of thousands of cycles. More than not, this is such a large number it's usually not an issue that needs consideration. However, it's a race to expiration between Cycle Life and calculated lifetime. Whichever gets to the finish line first claims the capacitor limits have been met and is end of life.

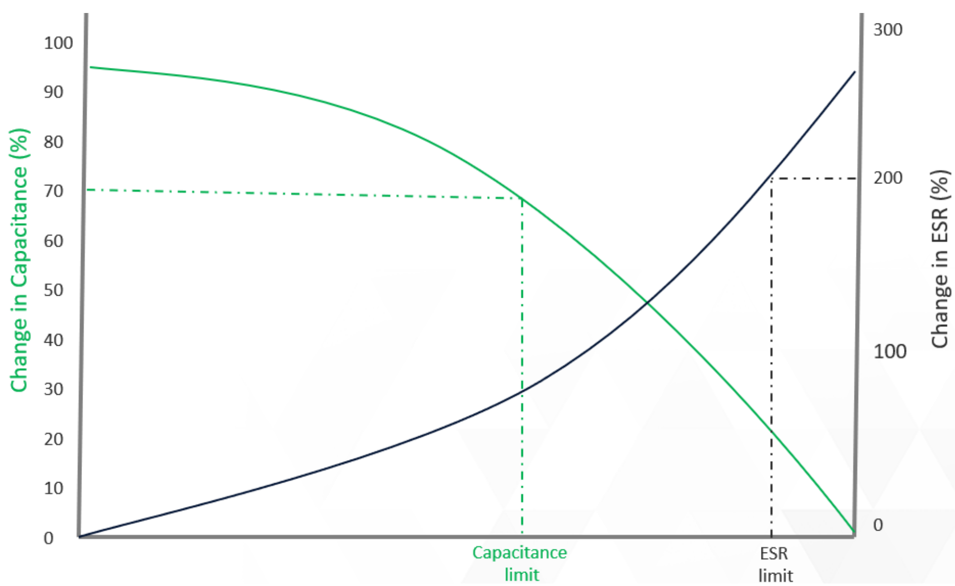

Fig. 2 General relationship of degradation in capacitance and increase in ESR.

The example in Fig. 2 shows the capacitor meeting its loss of capacity before the ESR has increased 2X. This is not always the case and is only for illustration purposes.

Conclusion

The lifetime of the supercapacitor is finite. However, if the limits defined in the datasheet are followed, the supercapacitor performance should follow the predictions in this application note very closely. Keep in mind that derating voltage is much more beneficial than derating temperature. The end of life does not mean ‘inoperable’, it means the performance is non-optimal. With some forethought in design, supercapacitors can live beyond these limits.