Design considerations in selecting Eaton supercapacitors

Overview

Two major applications of Eaton supercapacitors are high pulse power applications and short-term hold-up power. Pulse power applications are characterized by very short, but high current delivery to a load, i.e. during the transmit period in a GSM mobile device. Hold-up applications are characterized by the requirement to continue to deliver load power for times on the order of seconds or minutes. An example of a hold-up application is the parking of the read/write head in a disk drive when power to the unit is shut off. Each of these applications emphasize different performance parameters of the device. High pulse power applications benefit primarily from the supercapacitor's low internal resistance (R), while hold-up power applications benefit from the supercapacitor's large capacitance (C) value.

This Marketing Bulletin presents the formulae used to calculate your application requirements and uses two examples to illustrate their use. A supercapacitor calculator program is also available for use at https://tools.eatonelectronics.com/

Definitions

The following definitions are used in this note:

Symbol	Unit of Measure	Description
C	Farads	Nominal capacitance value of the aerogel supercapacitor.
R	Ohms	The nominal internal resistance of the aerogel supercapacitor.
ESR	Ohms	Equivalent Series Resistance measured at 1 kHz.
V_{wv}	Volts	Normal or working charge voltage in the circuit application.
V_{min}	Volts	The minimum voltage required to operate the device.
I_{load}	Amps	In a hold-up application this is the average current that continues to be delivered to the load. It is an average as the load current will increase as the voltage decreases from V_{wv} to V_{min}.
t	Seconds	This is the required hold-up time in the circuit, or in pulse applications, t is the pulse duration.
V_{drop}	Volts	The total decrease in working voltage at the end of the discharge or high current pulse.

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Hold-up Power applications

An approximate calculation can estimate the value of a supercapacitor needed in most applications. This calculation equates the energy needed during the hold-up period to the energy decrease in the supercapacitor, starting at V_{wv} and ending at V_{min}.

Energy needed during hold-up period: $1/2\ I_{load} (V_{wv} + V_{min})\ t$

Energy decrease in supercapacitor: $1/2\ C(V_{wv}^2 – V_{min}^2)$

Therefore, the minimum capacitance value that guarantees hold-up to V_{min} (neglecting voltage drop due to IR) is:

$$C = \frac{I_{load}(V_{wv} + V_{min})t}{(V_{wv}^2 - V_{min}^2)} \quad \text{in Farads}$$

Example:

Suppose a tape drive supply is 5.0 V and can operate safely down to 3.0 V. If the DC motor requires up to 2 seconds of hold-up prior to safe shutdown at 0.5 A, then the use of the above equation predicts that the hold-up capacitor must be at least 0.5 F.

One A Series supercapacitor can supply the required capacitance. However, the nominal operating voltage of 2.5 V is exceeded by the 5 V requirement. Therefore, two supercapacitors must be configured in series. If two equal value supercapacitors are used, then the voltage across each device will be approximately 2.5 V, which is the nominal voltage rating.

In the data sheets the A1020-2R5105 supercapacitor is listed with a nominal capacitance of 1.0 F and when configured two in series, provides 1.0 F / 2 = 0.5 F. Theoretically this solution should work, but with a –20% end of the tolerance range, this solution does not provide significant margin. Stepping up to the next supercapacitor, the A1030-2R5155 would provide 1.5 F / 2 = 0.75 F at 5 V. With a –20% tolerance, the minimum value could be as low as 1.2 F / 2 = 0.6 F. This supercapacitor solution provides a sufficient safety margin. After the high current pulse, the tape drive goes into a very low current mode to hold up the electronics and uses the remaining energy in the supercapacitor.

In this example, balancing the voltage across the series combination is recommended to ensure neither device exceeds the maximum voltage rating.

Pulse power applications

Pulse power applications are characterized by a relatively low value of continuous current with brief, high current requirements. Applications have pulses that range from less than 1 millisecond to as high as a few seconds, and the pulse current can be orders of magnitude higher than the continuous or background current. The duty cycle of the pulses is usually low, typically less than 20%.

A worst-case design analysis assumes that the supercapacitor is the sole supplier of energy during the pulse. In this case the total drop in working voltage in the circuit consists of two components: the instantaneous voltage drop due to load current supplied through the internal resistance of the supercapacitor, and the drop in supercapacitor voltage at the end of the pulse period. This relationship is shown in the following equation.

$$V_{drop} = I_{load} (R + t/C)$$

Inspection of this equation shows that the supercapacitor must have low R and a high value of C if the voltage drop is to be small.

For most pulse power applications the value of R is more important than the value of C. This is illustrated using this equation for the A1030-2R5155 supercapacitor. Its internal resistance, R, can be estimated by using the DC ESR, nominally 0.075 Ohms (DC ESR = AC ESR x 1.5 = 0.060 Ohms x 1.5 = 0.090 Ohms). The specified capacitance is 1.5 F. For a 0.001 second pulse, t/C is less than 0.001 Ohms. Even for a 0.010 second pulse, t/C is only 0.0067 Ohms. Clearly the value of R (0.090 Ohms) dominates the outcome of V_{drop} in the equation above.

Example:

A GSM/GPRS wireless modem requires a pulse current of up to 2 A for 0.6 milliseconds every 4.6 milliseconds. Note the pulse width doubles or quadruples with GPRS. These modems are now available in a PCMCIA card for notebook computers. The constraints of the notebook and the PCMCIA connection are an output voltage of 3.3 +/- 0.3 V and a maximum current provided by the notebook of 1 A. Many power amplifiers (PA) have a minimum voltage requirement of 3.0 V. As it is possible for a notebook computer to output only 3.0 V, the voltage to the PA must first be boosted (3.6 V is common). With a working voltage of 3.6 V and a minimum voltage of 3.0 V, the allowable voltage drop due to resistance is 0.6 V.

Choosing the F Series Flat Pack FC-3R6334-R supercapacitor yields 0.33 F with 0.200 Ohms AC impedance or 0.25 Ohms DC impedance, R. During a 2 A transmit pulse the battery provides approximately 1 A and the supercapacitor provides the remaining 1 A of current. Using the above formula, the voltage drop, IR, due to resistance is 1 A x 0.25 Ohms = 0.25 V. The capacitive component, I(t/C), is small at 0.002 V compared to the resistive voltage drop.

Conclusions

Both hold-up power applications and pulse power applications can be designed by using the simple equations presented above. When the working voltage of the circuit exceeds the maximum operating voltage rating of the supercapacitor, equal value supercapacitors should be put in series arrangement. Often, the series arrangement should be balanced to ensure equal voltage sharing. In pulse power applications the voltage drop across the internal resistance of the device is usually the critical factor. The supercapacitor's ultra-low internal resistance provides a new solution to the high impedance problems characteristic of most battery systems.

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