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Electrochemical Capacitor Power Performance at Low Temperature: Commercial Product Differences

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Electric Double Layer Capacitors (EDLCs) rely on physical processes to store charge and thus do not exhibit strong temperature dependence of their charge/discharge rate, as usually seen in batteries. Consequently, EDLCs can offer exceptional performance and safe operation at very low temperatures, typically to temperatures well below –40 °C depending on the electrolyte. Nevertheless, two-terminal electrical performance does change at low temperatures and this is due to lower ionic conductivity of the electrolyte.

Figure 1 shows a complex-plane impedance plot of a 3000 F, 2.7 V commercial EDLC cell over the temperature range –38 °C to +60 °C. The ESR (intersection point with the real axis) is relatively constant at all temperatures but ionic resistance contributions (length of the projection of the 45° region onto the real axis) significantly increases at low temperatures. Thus, power performance of this particular EDLC product is dominated by its porous electrode behavior at low temperatures

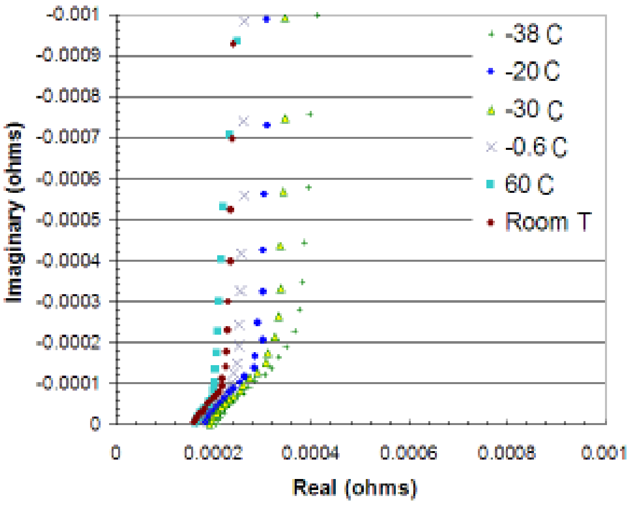

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***Figure 1**: Complex-plane impedance plot of a 3 kF, 2.7 V commercial EDLC cell at six temperatures. Differences at low temperature are due to increased ionic resistance in the porous electrodes. ESR change with temperature is minor.*

A similar complex-plane impedance plot for a different commercial EDLC cell (1200 F, 2.7 V) is shown in **Figure 2** over a similar temperature range. Only small increases in the ionic resistance are observed with a temperature reduction while ESR increases are much greater. Clearly, power performance limitations of this EDLC product at low temperature result from ionic resistance in the separator.

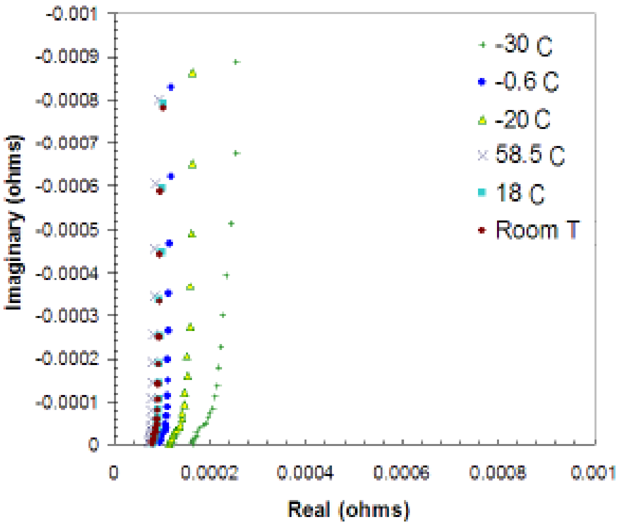

***Figure 2**: Complex-plane plots of the impedance of a 1.2 kF, 2.7 V commercial EDLC cell. Temperature-related resistance changes at low temperature are due primarily to increased ionic resistance of the separator. Porous electrode contributions to the series resistance increase are small.*

Figure 3 shows a complex-plane plot of an asymmetric electrochemical capacitor, that of a so called lithium-ion capacitor (LIC), rated at 1100 F and 3.8 V. As shown, there are major differences in behavior at –20 C and lower temperatures compared with higher temperature. At these low temperatures, charge-transfer resistance dominates, not unlike the behavior observed in batteries. Charge transfer resistance is never observed in EDLCs because they do not rely on electron transfer across the electric double layer. Observed LIC behavior is not surprising because one of its electrodes is a battery electrode, while the other is an EDLC electrode. Thus, dynamic performance of this asymmetric electrochemical capacitor at low temperatures is dominated by chemical reaction rates and not by ionic conductivity of the separator or by porous electrode behavior as observed in pure EDLCs.

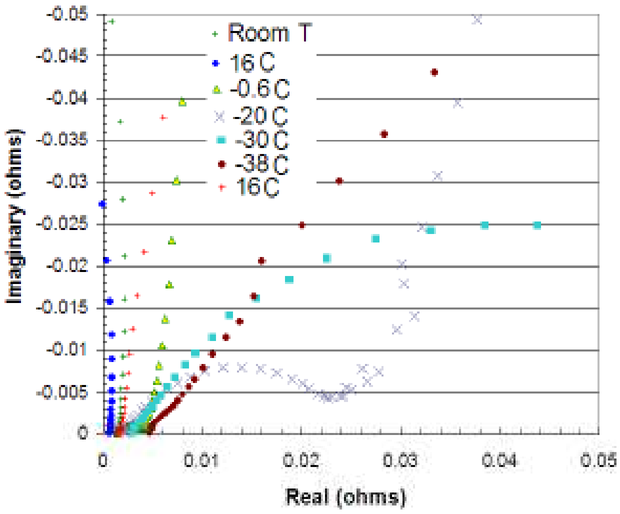

***Figure 3**: Complex-plane plots of the impedance of a 1.1 kF, 3.8 V rated commercial lithium-ion capacitor (LIC). Notice the charge transfer resistance that appears below 0 C.*

Three additional commercial electrochemical capacitor cells were examined in this study. Their electrical behavior at low temperatures was similar to one the three shown. Test procedures and results from this study are presented. Equivalent circuit models were derived for these six commercial capacitors and used to help illustrate design differences with the associated power limitations at low temperatures.