ELECTROCHEMICAL CAPACITOR CELL VOLTAGE BALANCE AT FLOAT-VOLTAGE

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INTRODUCTION

Electrochemical capacitors (ECs), sometimes called supercapacitors or ultracapacitors, are seeing more use in high-voltage systems. Since an EC cell operates in the one- to three-volt range, depending on its design, many cells must be series-connected in these systems to meet voltage requirements. As with any device comprised of a series-string, cell voltage uniformity is important for reliability, safety, and to achieve minimum system cost with maximum energy and power densities. This paper examines EC cell voltage balance in multi-cell strings under float-voltage conditions and relates uniformity to cell properties and tolerances. The impact of temperature on cell voltage uniformity is also reported.

APPROACH

Voltage balance in multi-cell ECs has been modeled using a series-RC equivalent circuit model with a shunt resistor across the capacitor to represent the leakage current[1,2]. Then variability in the value of the shunt resistors in a series string leads to a distribution of cell voltages under float-voltage conditions. This model poorly represents EC leakage current behavior. Conway[3] showed that the leakage current I(V) is properly represented by a current source with an exponential dependence on voltage as $I(V) = \Sigma\, i_n = \Sigma\, a_n e^{b_n V}$ where a_n is related to the exchange current density of the electron transfer process responsible for the current, b_n is a constant associated with the participating chemical reactants, and the summation is over all processes causing the leakage current. This equation correctly describes the behavior of currents arising from faradaic depolarization and parasitic impurity processes[4]. Then, the equivalent circuit model for an EC cell as is shown in Figure 1.

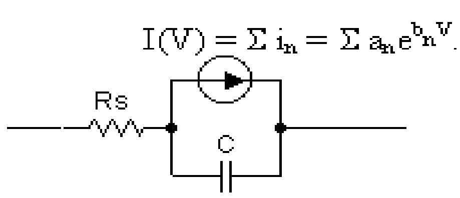

FIGURE 1: *Cell equivalent circuit model for float-voltage investigations of a series string of cells.*

Although multiple processes typically are responsible for the measured leakage current, just one usually dominants at any specific voltage. Then voltage variability of a series string can be derived by taking the differential of the current and setting it equal to zero with the assumption that a factors have variability and b factors are constant. This leads to the relationship $|dV/V| = (1/b_d V)(da_n/a_n)$ between the cell voltage tolerance and the tolerance in cell parameters that define the leakage current where b_d is the dominant leakage current mechanism at a given voltage.

RESULTS / CONCLUSIONS

Leakage current data were obtained under float-voltage conditions for several commercial EC products over a range of voltages at selected temperatures. The currents had exponential voltage dependence in all cases, some with a single mechanism while others with two, arising from faradaic depolarization currents and parasitic impurity currents. This data was used to determine cell voltage tolerance |dV/V| in a series string of cells.

Results show that EC cells under float-voltage conditions and made using an organic electrolyte generally will have a significantly wider cell voltage distribution than will those made using an aqueous electrolyte. Consequently without active or passive cell voltage balance means, ECs made with aqueous electrolyte should offer greater reliability in high-voltage applications than ECs made with organic electrolyte even though more cells are needed. Thus, voltage derating rules used to design high-voltage strings of cells will necessarily be different for aqueous than for non-aqueous EC technologies to achieve comparable reliability in float-voltage operation.

REFERENCES

1. J.R. Miller, Proc. 36th Int. Power Sources Sym., Cherry Hill, NJ, 15-18 (June 1994).
2. J.R. Miller, Exploratory Research and Development of Batteries for Electric and Hybrid Vehicles, W.A. Adams, A.R. Landgrebe, and B. Scrosati Editors, PV96-14, pp16-30, The Electrochem. Soc. Proc. Series, Pennington, NJ (1996).
3. B.E. Conway, Proc. 5th Int. Seminar on Double Layer Capacitors and Similar Energy Storage Devices, Boca Raton, FL (December 4-6, 1995).
4. B.E. Conway, Electrochemical Supercapacitors: Scientific Fundamentals and Technological Applications, chap. 3 and 18, Klewer Academic/Plenum Publishers, NY (1999).