Theory and Applications of Ragone Plot as a Tool for Designing Electrochemical Energy Storage Devices

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Brought up by Ragone in 1968,[1] Ragone plot has become a standard approach to illustrate the performance of energy storage devices. It has been widely used to compare different technologies to cater for specific energy storage demand,[2] or the same energy storage technology (e.g. batteries) with different chemistries.[3] It has also been used to demonstrate the power-energy performance of a given energy storage device at different rates (operation time).

Experimentally, the Ragone plot of a given energy storage device can be obtained by discharging at constant power/current and record the deliverable energy. By plotting the obtainable energies at different applied power on a log-log diagram, one obtains the Ragone plot of the device. This practice has been widely used in industry to benchmark their products for various applications.

To interpretate the obtained Ragone plot and understand the underlying physics governing the power/energy performance of energy storage devices, some theoretical work is done. Specifically, Christen has modelled an battery with electric circuit, solved for the energy at given power, and obtained the theoretical Ragone plot for an ideal battery.[4] This approach provides insights in understanding the leakage, the internal resistance of batteries and supercapacitors, but the electric circuit model over simplifies the intrinsic physics, and the dynamics of multiple electrochemical process of a battery. Conway has considered ohmic resistance and charge transfer resistance(activation), but the concentration polarization, which is the controlling-step for high energy batteries, are not included.

Design of high performance batteries relies on both material innovation and electrode/cell engineering. A theoretical framework for obtaining Ragone plot for different electrode/cell design parameters would be of paramount significance. These design parameters include active material loading, weight ratios of active material,conductive carbon and binder, thickness, porosity, current collector and separator thickness. Previous theories only predict Ragone plot when the dynamic parameters are given(voltage, capacity and internal resistance), but these parameters are dependent on battery chemistry as well as electrode/cell design parameters. There is no Ragone plot theory that accounts how these design paramters affect the performance of a battery. In this work, we are goingt to present a simple theory for obtaining the Ragone plot of electrochemical energy storage devices(batteries,supercapacitors or hybrid) with different chemistries and design parameters, validated by experiment data. This theoretical framework will greatly benefit the future design of electrochemical energy storage devices.

References:

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