Miniature tool for characterization of supercapacitive charge storage

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INTRODUCTION

A new protocol to characterize supercapacitive charge storage parameters from discharge voltage measurement and using an electrical model is presented. A distribution of capacitances and resistances in three charge storing time domains (fast, medium, and slow) are derived through this protocol. The method relies on recording the self-discharge data (open circuit discharge) and using it along with the charge redistribution within the supercapacitor to obtain the parameters for the equivalent circuit model. The results are validated using the galvanostatic charge discharge cycling. The method proposed here uses comparatively lesser number of variables, thereby making it easier to compute and the validation shows a good match between the experimental and the simulated results.

Background and Applications

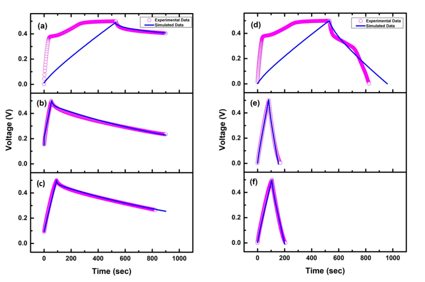
The charge storage mechanism and performance are routinely evaluated using electrochemical techniques such as cyclic voltammetry (CV), charge-discharge cycling (CDC), and electrochemical impedance spectroscopy (EIS) using a potentiosat-galvanostat, which are time consuming and tedious and often lead in inconsistent results. An alternative method to prompt characterization and charge storage capacity estimation from single measurements is highly desirable both for academic research (at least as validation of results) and large industrial scale testing.

Simulation

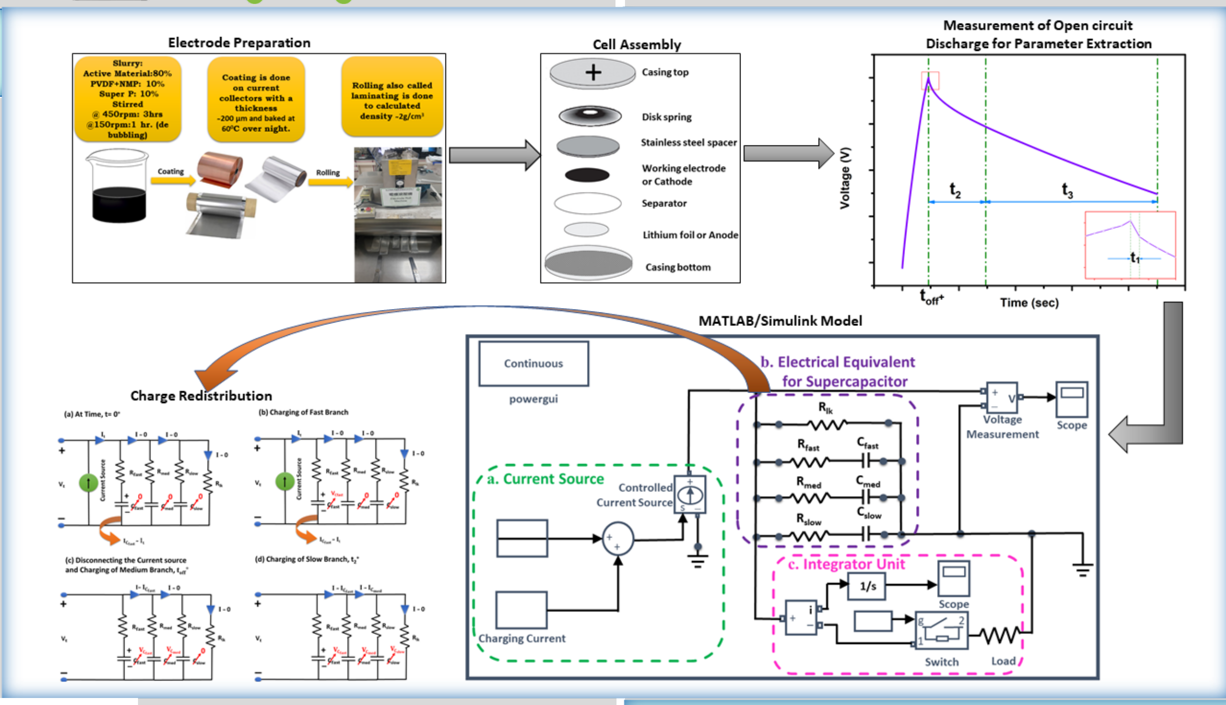
We have used the three-branch model of supercapacitors consisting of a fast branch, a medium branch, a slow branch and a leakage resistance. The parameters of the equivalent circuit model is extracted by using the self-discharge (open circuit discharge) voltage measurements. This is done by using the charge redistribution in the circuit (shown in the figure below). In a self-discharge model, we let the device to charge under a constant current source until they reach their peak voltage. Next the current source is removed, and it is left to discharge the device on its own. This helps us finding the parameters. Once the model has been successfully verified to be correct, it can also be used to find out the charge storage capacity for a given SC system. To achieve that, the MATLAB/Simulink model is modified to include a load resistance which will now be used to discharge the circuit instead of a negative pulse current (the discharge current is set to zero).

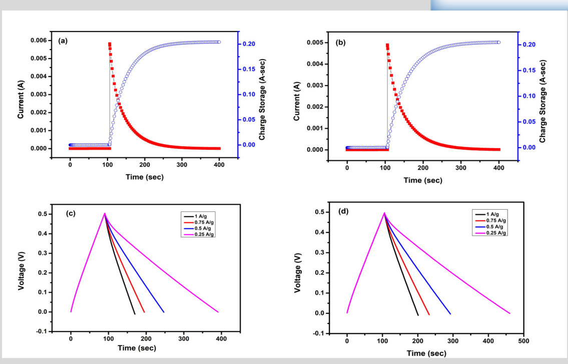
Results

Self-discharge & CDC data



Plots above show good agreement between simulated & experimental plot of Na_2SO_4 & Li_2SO_4 (b-c,e-f), but not for KOH (a,d), which shows battery-type behavior.





The figures on the left (a,b) show the current flow and the total dissipated charge through the system with a load connection. Fig (c,d) show the different constant current discharge curve when different amplitudes of current is supplied to them. Higher the discharge current, lesser the losses.

Conclusion

Mathematical & electrical modelling of a metal-oxide-nanofiber material showing supercapacitive charge with storage mechanism with 1M Na_2SO_4 and 1M Li_2SO_4 but not with 1 M KOH. The model is then used to compute the parameters of the equivalent circuit model elements. The validation of is done using several runs of the experiment in the lab & matching it with the the simulations using the parameters extracted. The model can be used to characterize the charge storage mechanism & estimate the charge stored.

Research Information

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The final model has been designed and validated using lab experiments and simulations. It has been prepared as per the targeted standards and has been tested for use successfully. Research papers have already been submitted to journals for publishing. Work on full-scale prototype in progress.

Commercial Uses

Energy Storage Systems market is expected to grow from USD 2.9 Billion in 2020 to USD 12.1 Billion by 2021, registering a growth of 32.8% Y-o-Y.

- With the development of a full scale prototype, assessment of a SC system will require a few milligrams of the active material, and it could then be scaled up for a commercial size SC device, without actually making one. This can save a lot of time & millions of dollars to laboratories & institutions across the globe.
- Researchers with unavailability of potentiostat-galvanostat can do basic characterization of their materials and know its storage capacity by recording the open-circuit voltage using a breadboard current measurement system.
- We plan to get a patent protection on our innovation, and a wide-scale use of our methodology will be commercially beneficial for the researchers as well as UMP.

Publications

1. R. Kunwar et al., "Pseudocapacitive Charge Storage in Thin Nanobelts," Adv. Fiber Mater., vol. 1, no. 3, pp. 205–213, 2019, doi: 10.1007/s42765-019-00015-w.
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3. R. Kunwar et al., "Characterization of Supercapacitor Electrode using Discharge Current Measurements & Modeling", submitted to Applied Energy (Manuscript No.: APEN-D-21-01951)
4. B. Pal, A. Yasin, R. Kunwar et al., "Polymer versus cation of gel polymer electrolytes in the charge storage of asymmetric supercapacitors", Industrial & Engineering Chemistry Research, 58 (2), 654-664