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Implementation of Impedance Spectroscopy Genetic Programming (ISGP) for SCs and Inductive Systems

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Objective

Implementation and improvement of impedance spectroscopy analysis method developed in our research group - Impedance Spectroscopy Genetic Program (ISGP). The main objective is to apply ISGP to super-capacitors in order to gain better understanding of its physical features. Another objective is to improve ISGP to the point where it will be able to adequately analyze systems which exhibit, in addition to capacitive behavior, inductive behavior.

Introduction

Impedance Spectroscopy Genetic Program (ISGP) is a novel analysis technique to IS measurements. It finds a distribution function of relaxation times (DFRT) that its convolution with a given kernel fits best the measured data, according to:

$$Z(\omega) - Z(\infty) = R_{pol} \int_{-\infty}^{\infty} \frac{\Gamma(\log(\tau))}{1 + i\omega\tau} d(\log(\tau))$$

Where Z is the impedance, R_{pol} is the polarization resistance, ω is the frequency, τ is the relaxation time and Γ is the DFRT. ISGP seeks a suitable DFRT that is comprised of known mathematical peaks. The program uses genetic algorithm to find the DFRT, starting with an initial population of functions that evolve throughout the generations. At each generation the best fitted functions are multiplied and undergo mutation to achieve better fitting to the measured data.

Super-Capacitors Analysis with ISGP

Impedance data of a super-capacitor was received from Aurbach's group and analyzed using ISGP. Figure 3 shows the Cole-Cole plot (not in proper scale) of the measured data and the modeled data calculated by ISGP:

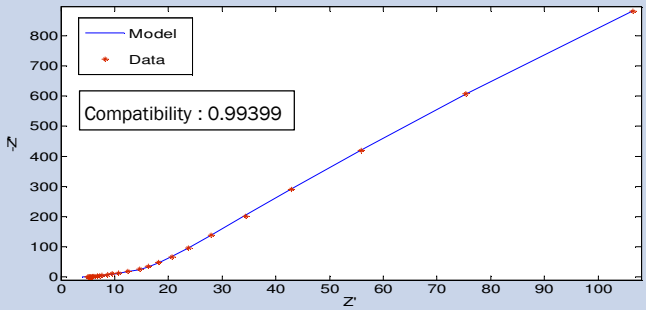

Figure 3 : Cole Cole plot of measured (red dots) and modeled impedance data (blue line)

The resulting DFRTs are presented in Figure 4 :

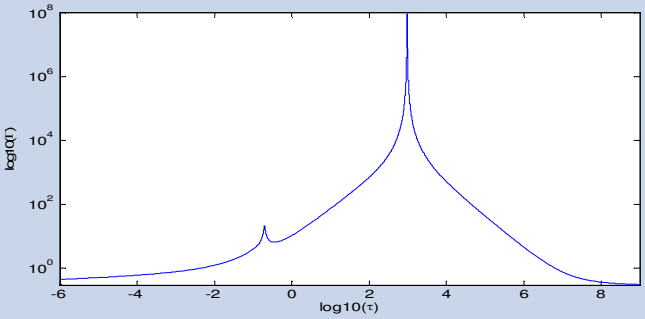

Figure 4: Distribution Function of Relaxation Times (log(Γ)) vs. $log_{10}(\tau)$

The model is comprised of two peaks: Havriliak-Negami (large peak) and Pearson VII (small peak).

Analysis of Inductive Systems with ISGP

Many electrochemical systems (e.g stacks of PEM fuel cells) show impedance behavior that can be modeled by equivalent circuits which contain both capacitors and inductors. In order to analyze those kind of systems using ISGP we introduced, in addition to the Debye Kernel that was already used to non-inductive systems, a different kind of kernel, derived from inductive-only systems. The ISGP now can convolute each one of the DFRTs in its bank with either one of these kernels, in order to obtain best possible fit to measured data.

Figure 1 shows the result of ISGP analysis of a synthetic data which contains 2 elements - inductor or capacitor parallel to a resistor connected in a series:

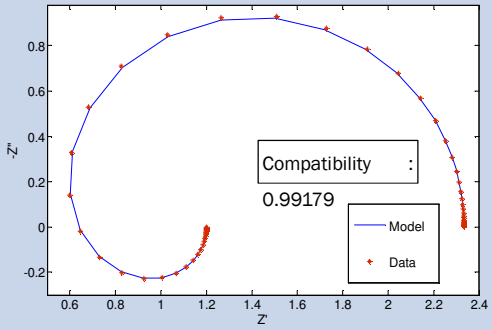

Figure 1: Cole Cole plot of synthetic (red dots) and modeled impedance data (blue line)

The resulting DFRTs are presented in Figure 2:

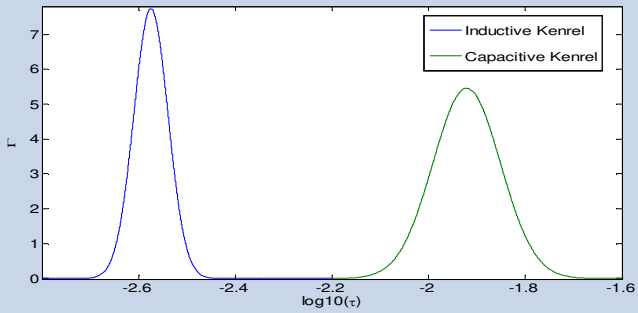

Figure 2: Distribution Function of Relaxation Times (Γ) vs. $log_{10}(\tau)$

The model is comprised of two Gaussians, the blue is convoluted with the new kernel and the green is convoluted with the old kernel.

Future Goals

- Investigate the possibility of analyzing results using modified ISGP for real data that contain both capacitive and inductive behavior.
- Further adaptation of ISGP for characterizing super-capacitors.
- Improve ISGP source code and reducing its processing runtime.