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CONTENTS

EDITORS WORD

What a year!

2023 will be a year I'll remember for a long time. Various forms of artificial intelligence (AI) have entered our lives over the past few years, but none have made an impression on the collective consciousness as much as ChatGPT. Even my 93-year-old mother waffles on about it, for goodness' sake.

It's amazing to think ChatGPT was launched in November 2022, which is only one year ago as I pen these words. Since that time, different incarnations of this form of generative AI have popped up all over the place (search Google for "Chatsimple," "GitHub Copilot," and "Metabob," for example).

I was recently talking with the folks at Flux.ai about their Flux CoPilot. This is an AI-powered PCB design tool that can read hundred-page data sheets in seconds, after which it automatically connects the components (microprocessors, sensors, displays…) in the schematic and in the layout in real time while you watch in awe.

I just got off a video call with a friend. We'll call him Joe (because that's his name). Joe told me how he was questioning ChatGPT about an error message he was receiving from his compiler. ChatGPT asked him to share the problem area in his code. When Joe did so, ChatGPT immediately responded with a description of what he was doing wrong and proffered a code snippet to fix the problem.

Now I can't wait to see what 2024 will bring. As always, of course, all of us here at DENA will be here to help guide you on your way.

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Revolutionizing battery measurements

Dr. Gerald Morrison, CTO, **SigmaSense**

Introducing a non-destructive method to estimate the SoH and SoC of a battery

Battery measurements are crucial for energy storage, consumption, and transportation. Accurate and efficient techniques are essential for ensuring quality, estimating state of health (SoH) and state of charge (SoC), and predicting and preventing dangerous battery failures.

Electrochemical impedance spectroscopy (EIS) is a non-destructive method that can estimate the SoH and SoC of a battery without disassembly while under actual operating conditions. EIS is considered the gold standard for analyzing batteries and helps predict and prevent dangerous battery failures by measuring specific characteristics of a battery's impedance and internal state.

EIS measurements and today's limitations

EIS measurements supply valuable insights to manufacturers and system designers into the complex electrochemical nature of batteries. However, the widespread adoption of EIS is hindered by the limitations of traditional laboratory-based potentiostats, which are bulky, expensive, and not workable for wide-scale, in-the-field measurements.

The future of in-situ EIS lies in the development of semiconductor chips. A detailed article on the advantages and the reality of this future is found in the article *From Lab to Field: Scaling EIS Technology with Semiconductor Chips for Battery Systems* (https://bit.ly/3riVgMN).

How EIS works

EIS works by applying a small perturbation AC current (or voltage) to a battery and measuring the resulting AC voltage (or current) over a range of frequencies, typically from 0.01Hz to 8kHz. Small perturbation currents are preferred as some electrochemical systems, like batteries, can become non-linear at high currents, invalidating the analysis of certain parameters.

According to Ohm's law, the ratio of voltage to current at each frequency is impedance. For batteries, this is a complex number. Impedance data is plotted in several ways, such as Nyquist plots or Bode plots. This data can be used to find equivalent circuit models with quantitative parameters representing the battery's components and interactions, further aiding in understanding battery dynamics.

Nyquist plots and EIS analysis

The Nyquist plot is a preferred way of representing battery impedance data as it offers several practical advantages over other visualization methods, such as Bode plots. Some reasons include:

• Sensitivity to changes, making it easier to detect variations in the impedance data.
• Simplified interpretation of data, as some parameters can be read directly from the plot for certain equivalent circuit models.
• Evaluation of various phenomena in different parts of the battery through detailed analysis.

A real-world example of a Nyquist plot and a fitted candidate equivalent circuit model is shown in the figure. This data was collected from a SigmaSense EIS chip measuring an exceptionally low impedance 230Ah LiFePO4 battery.

The future of EIS and battery technology

EIS is a powerful, non-destructive method for estimating the SoH and SoC of batteries, as well as predicting and preventing dangerous battery failures. It provides valuable insights into the complex electrochemical nature of batteries, making it an essential tool for the development of sustainable battery storage systems.

With the development of semiconductor EIS chips, in-situ EIS measurements are now a reality. As the demand for efficient and reliable energy storage solutions continues to grow, the integration of EIS semiconductor chips into battery systems will play a crucial role in advancing the field of battery technology.

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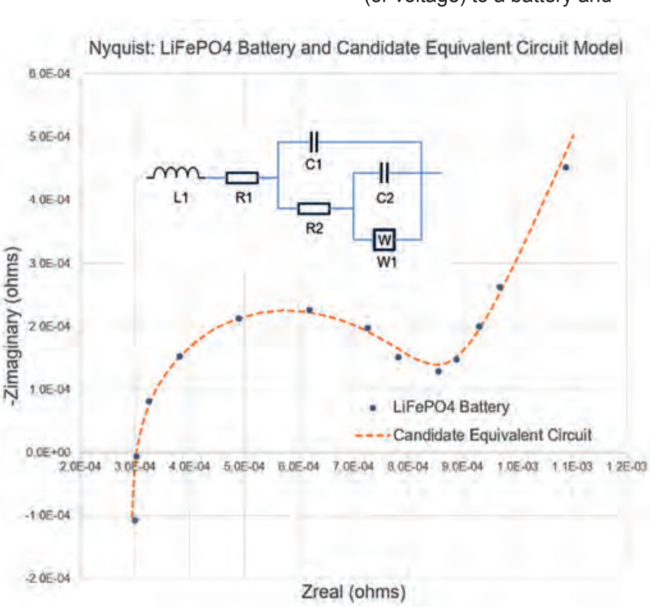

Real-world example of a Nyquist plot and a fitted candidate equivalent circuit model