Technical Article

Redefining battery accuracy: How the Dynamic Z-Track™ algorithm predicts unpredictable battery loads

As industrial and personal electronics add more advanced technologies, they create increasingly unpredictable loads on batteries, necessitating a more reliable and intelligent battery gauge. Whether in emerging artificial intelligence (AI)-enhanced devices or established systems such as drones, power tools and robotics, batteries experience highly dynamic load profiles. These unpredictable loads create a challenge for designers who rely on accurate gauging to shut systems down safely or prevent unexpected brownouts. While an unexpected shutdown in a cordless drill may only frustrate its user, a drone falling from the sky poses a serious safety risk.

What does a battery gauge do?

Battery gauges calculate essential parameters such as state of charge, state of health and remaining capacity using current and voltage measurements. Traditional Impedance Track™ technology-based battery gauges assume that the battery load varies slowly, which enables accurate resistance measurements while the battery is discharging to calculate a high-accuracy real-time state-of-charge prediction. Modeling the battery as a low-frequency resistor-capacitor (RC) model, as shown in Figure 1, is sufficient for these slowly varying battery loads. However, newer applications with variable or high-frequency load currents need a more comprehensive model and adaptive algorithm to maintain accurate state-of-charge estimations.

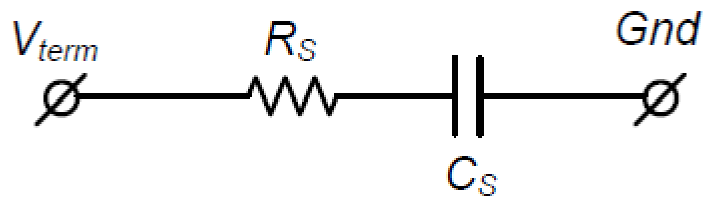

Figure 1. Low-frequency RC battery model

The Dynamic Z-Track algorithm is a battery-gauging method designed for devices such as the BQ41Z90 and BQ41Z50. As a successor to the traditional Impedance Track algorithm, which operates in devices such as the BQ40Z50 and BQ34Z100, the Dynamic Z-Track algorithm provides accurate state-of-charge, state-of-health and remaining capacity estimations of batteries under dynamic load-current conditions.

When an erratic or high-frequency load impacts the battery, an Impedance Track gauge's traditional RC modeling of the battery loses resolution for updating the resistance of the battery. The Dynamic Z-Track algorithm implements a broadband transient model that simulates the voltage transients and adapts to dynamic current profiles. This approach enables real-time resistance estimations even when the current is not stable.

Why is resistance important?

Tracking resistance is essential to deliver the highest accuracy state-of-charge calculation over the entire lifetime of the battery. As shown in Figure 2, a battery cell's resistance increases linearly with cycling and aging of the battery, until it hits a certain turning point where the resistance will exponentially increase toward the end of its life. The resistance also fluctuates significantly with temperature. There is an inverse relationship to battery cell resistance and temperature where the lower the temperature, the higher the resistance; therefore, the lower the capacity or energy that the battery cell can provide before reaching a 0% state of charge.

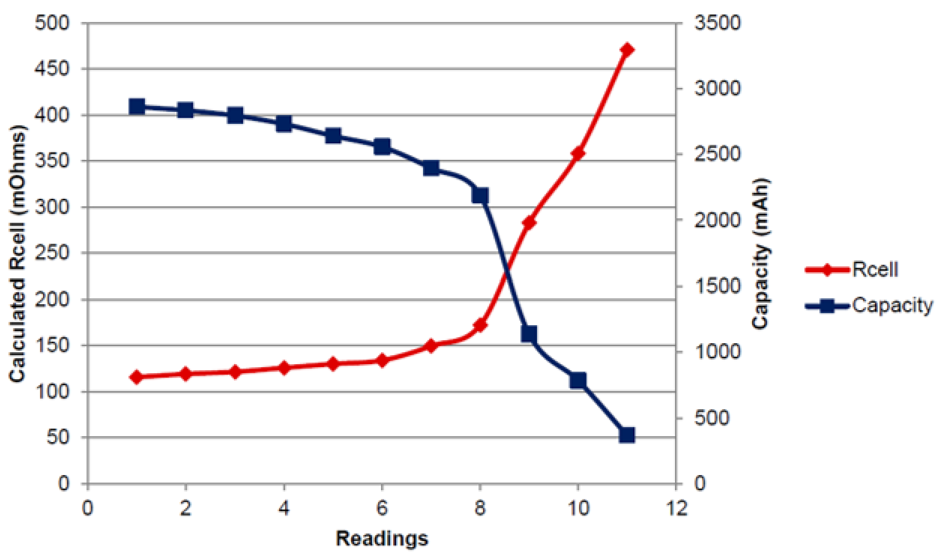

Figure 2. Resistance change of a lithium-ion battery cell over time

When the battery gauge cannot update resistance, the calculated state-of-charge error grows proportionally with battery aging. This error in state-of-charge and remaining capacity estimation can reach as high as 60% or as low as 10% without resistance updates in unpredictable and erratic loads. The end user experiences this as the state of charge decreases suddenly, and the device may shut down unexpectedly from an overestimation of capacity, as shown in Figure 3.

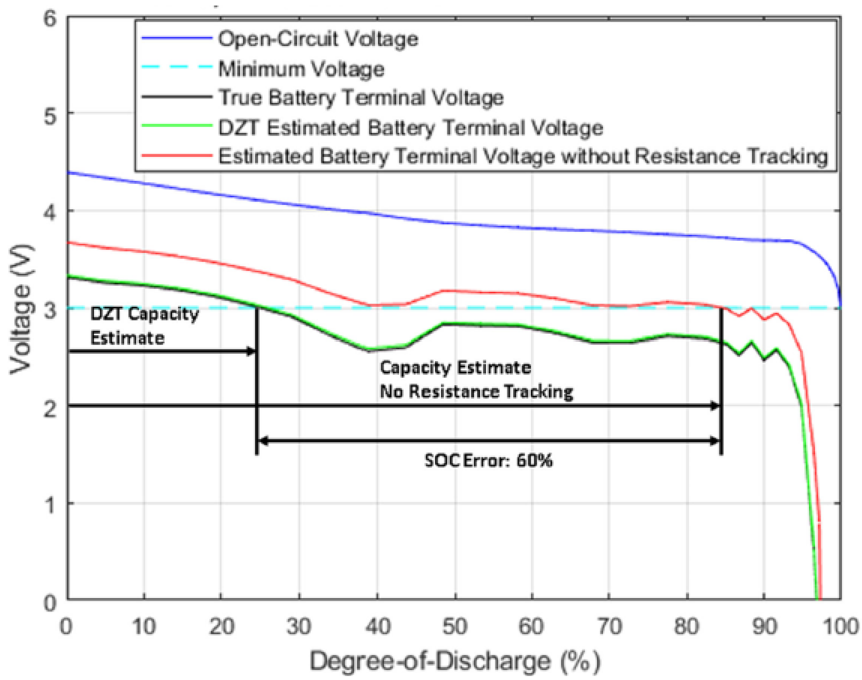

Figure 3. Remaining capacity estimation comparison: Impedance Track technology and Dynamic Z-Track technology vs. no resistance update at a 1.75C load

Use-case example

Imagine a person is riding their e-bike home. They check the state of charge, see 30% remaining, and decide to detour to the grocery store before going home. When they arrive at the store, the state of charge shows 15% remaining, but on the way home, the e-bike suddenly stops delivering power because the state of charge has dropped from 12% to 0%. Now the rider must either pedal home or call for a ride.

The Dynamic Z-Track algorithm prevents this situation. Unlike conventional battery gauges, TI's Dynamic Z-Track technology delivers up to 99% state-of-charge accuracy even under unpredictable loads, enabling manufacturers to optimize battery size and extend battery run time by as much as 30%. This ultimately provides end users more reliable performance in demanding applications such as drones, e-bikes, laptops and portable medical instrumentation.

Conclusion

While unpredictable battery loads present a significant design challenge, they don't have to dictate the limits of your system's reliability or end user experience. Tools such as the Dynamic Z-Track algorithm help enable designs where battery-powered devices simply work – a future where drones complete their flights without unexpected landings and e-bikes get riders home without fail.

Additional resources

For more detailed information on how Impedance Track Technology and Dynamic Z-Track technology works, see the application notes:

- Dynamic Z-Track™ Technology: An Advanced Battery Gauging Algorithm for Dynamic Load Applications.
- Theory and Implementation of Impedance Track Battery Fuel-Gauging Algorithm in BQ2750x Family.

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