Designing an Accurate, Multifunction Lithium-Ion Battery-Testing Solution

Shaury Anand
Systems Engineer, Test & Measurement
Texas Instruments

Taras Dudar
Systems Engineer, Data Converters
Texas Instruments

With lithium-ion (Li-ion) batteries found in both small electronic devices and much larger applications, they naturally span a wide range of sizes, voltages and form factors. But this breadth means that battery manufacturers have to buy and maintain testing solutions for each battery type, and the associated capital investment becomes significant, directly contributing as much as 20% to the final cost of the batteries.

There's a clear need for a single, flexible testing solution that can handle a broader range of battery voltages, capacities and physical sizes. Creating comprehensive multipurpose test equipment is challenging because the markets shown in **Figure 1** demand a cost-effective solution.

In this paper, we'll highlight the benefits of a discrete solution over an integrated solution in order to meet current and future battery testing challenges, and include an example of a highly flexible battery testing design.

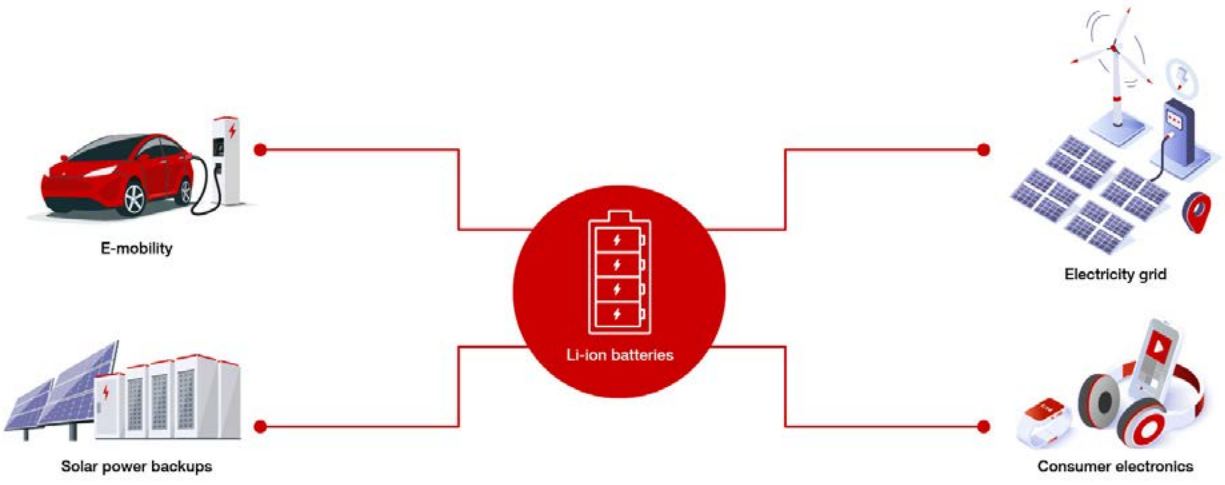

***Figure 1**. Li-ion battery applications.*

Battery testing challenges

After the cell assembly process, each Li-ion battery goes through gradual charging, during which it forms a solid electrolyte interphase (SEI) layer, which is critical for its long-term functionality. If this process is not well controlled, the battery can lose up to 50% of its capacity. Therefore, test equipment must be able to precisely control the thickness of the SEI layer, which can bring down capacity losses to below 5%.

Many applications use battery packs with multiple cells connected in series and parallel configurations to achieve higher output voltages and greater energy capacity. Testing cells designed for battery packs add their own complexity, since all of the cells in the pack need to be virtually identical—not only in size and capacity, but parameters such as impedance and life span. Given the inherent process variations in battery impedances and capacities, testing becomes critical—not only to eliminate defective batteries but also to sort out identical batteries for battery packs. And as with all things produced in mass quantities, there's always going to be a small percentage of batteries that prove defective.

The potentially explosive nature of Li-ion batteries and their energy storage density require a high level of operational safety when charging and discharging them in a testing environment. As a result, battery testers must include protection for various system failures, which in turn improves overall equipment robustness and reliability.

Today's test equipment is designed for a specific battery type. Testing larger batteries requires higher amounts of current and thus a battery tester with larger silicon, inductors, magnetics and routing, along with thicker wires. A battery manufacturer producing smaller batteries with lower current requirements will typically use the testers specifically optimized for lower current levels, leaving the high-current battery testers idle. Having a tester capable of testing both smaller and larger batteries will reduce this redundancy, which will bring down the overall cost of battery production.

In order to maximize the production yield and quality of the batteries, battery manufacturers are continuously improving the charging and discharging profiles during the formation process. And because it's possible to use testing equipment to develop new battery technologies, try new things, and gain a competitive advantage, battery manufacturers expect testing equipment manufacturers to provide additional capabilities.

Let's take a closer look at why it's so difficult to design an integrated solution for this application.

Integrated solution challenges

Battery tester requirements are rather unique, and no suitable technology node exists that enables designers to meet all of the requirements. Combining speed, power and precision in a single design runs the risk of sacrificing something else—not being fast enough, precise enough, or limited in high-current transfer efficiency.

On one hand, there are requirements that focus on the power aspect of the Li-ion battery. Since charging and discharging the battery entail the transfer of high levels of energy, the efficiency of this process is a key consideration. On the other hand, there's the precision aspect. It's not just converting the power and delivering it to and from the battery; the process must occur with extreme accuracy.

It has always been difficult to design a single product capable of delivering high power very precisely. The technology used in power products focuses on achieving a low drain-to-source on-resistance and gate capacitance in order to deliver higher power at a low cost. The technology

used in precision products focuses on achieving low offset and drift by introducing additional steps in the manufacturing process, which increases integrated circuit (IC) cost. Designing power products in precision technology may work for low power levels, where the area of the switching power field-effect transistors (FETs) is small relative to the rest of the circuit. For high-current applications above 1 A, however, integrating the power FETs with the rest of the precision circuit on the same die is not optimal, as the size of the power FETs is relatively large compared to the rest of the circuit. That's when discrete FETs—and perhaps even a discrete gate-driver IC—become a more logical solution.

Some IC designers choose to separate the gate driver from the system but integrate the rest of the functionality into one chip. This approach accelerates battery tester design cycles but also reduces flexibility, narrowing potential applications, limiting IC production volumes and therefore increasing the final cost.

A discrete solution design can solve the power and precision challenges independently. Although battery testing is not a very high-speed application, a discrete design is capable of switching between different current levels and charge and discharge states within 1 ms, which is fast enough for this application.

Designing a highly flexible solution

The Modular Battery Tester Reference Design for 50-A, 100-A and 200-A Applications uses multiple, independently controlled, low-current battery-tester channels connected in parallel to meet the different levels of high-current battery-tester needs. Because it provides a modular battery test solution, the architecture gives you the flexibility to test batteries at different current levels with one design.

The reference design uses the LM5170 current controller, a fully integrated power solution for bidirectional power supplies. This dual-phase synchronous buck/boost controller regulates average current flowing between high- and low-voltage power supplies. Each phase uses a separate current loop, which automatically balances the current between them. And considering that the current specifications for automotive cells may rise, the reference design enables the stacking of multiple devices to achieve currents >50 A. For example, adding a second controller in parallel extends the design from 50 A to 100 A, while connecting four LM5170 devices in an eight-phase daisy-chain configuration further extends the design to up as much as 200 A of charge and discharge current without compromising accuracy.

The LM5170 has robust protection schemes to ensure high system reliability—cycle-by-cycle current limiting prevents overcurrent failures, while overvoltage detection on both the high- and low-voltage sides ensures both input and output protection.

Figure 2 on the following page is a detailed block diagram of the discrete solution. Using a precision multiplexer-friendly operational amplifier such as the TLV2197-Q1 as an error amplifier achieves constant-current and constant-voltage control accuracy within 0.01%. The INA188 instrumentation amplifier senses the output current, while the TLV07 precision operational amplifier senses the output voltage. The battery current and voltage are then compared to a precision reference voltage generated by the DAC80508 digital-to-analog converter. A constant-current loop directly drives the current setting command pin of the LM5170 controller, while a constant-voltage loop amplifier is connected through a diode. The constant-voltage loop takes control by reducing current setting

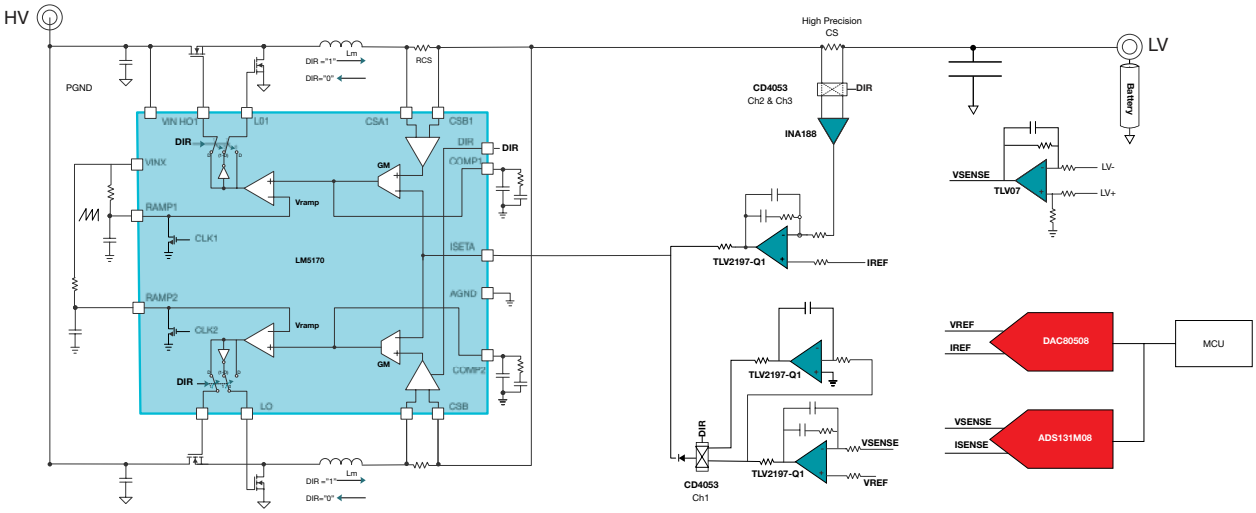

***Figure 2**. Discrete solution block diagram.*

command when the output voltage exceeds the reference in charge mode or goes below the reference in discharge mode. This achieves a smooth transition from constant-current mode to constant-voltage mode, which is critical for Li-ion batteries. The dual-stage control (with the LM5170 inner current loop and outer constant-current and constant-voltage loops) simplifies the compensation design. A simple Type I or II compensator achieves a fast and stable transient response.

Discrete constant-current and constant-voltage loops enable you to optimize different current and voltage specifications independently. For example, you can design a highly flexible system using a programmable instrumentation amplifier and digitally control the programmable gain amplifier to change the different output current levels. To learn about the benefits of a digital control loop battery tester, read our technical article, "How to design one battery tester for a wide range of sizes, voltages and form factors."

The ADS131M08 24-bit delta-sigma simultaneous-sampling analog-to-digital converter senses both output voltage and current and is connected to a host processor. Thus, it is possible to develop simple software for voltage and current calibration.

Having solved both the power and accuracy problems, the remaining challenge is the speed of transition, which is when a user tries to transition from either one level of current to another level of current, or switch from charge mode to discharge mode. Two cascaded control loops help achieve the goal of a 1-ms transition time. The inner current loop is designed for >10-kHz bandwidth, which ensures fast switching between the charge and discharge states. Keeping the outer current-loop bandwidth near 1 kHz guarantees speed of transition and precision. **Figure 3** on the following page demonstrates a current transition time of <0.5 ms when switching from the discharge state to the charge state.

Comprehensive, accurate testing without compromise

The wide range of Li-ion batteries available today requires testing equipment that's flexible and comprehensive, yet still highly accurate and without the prohibitive costs associated with larger batteries, multiple phases and additional components.

The modular battery tester reference design

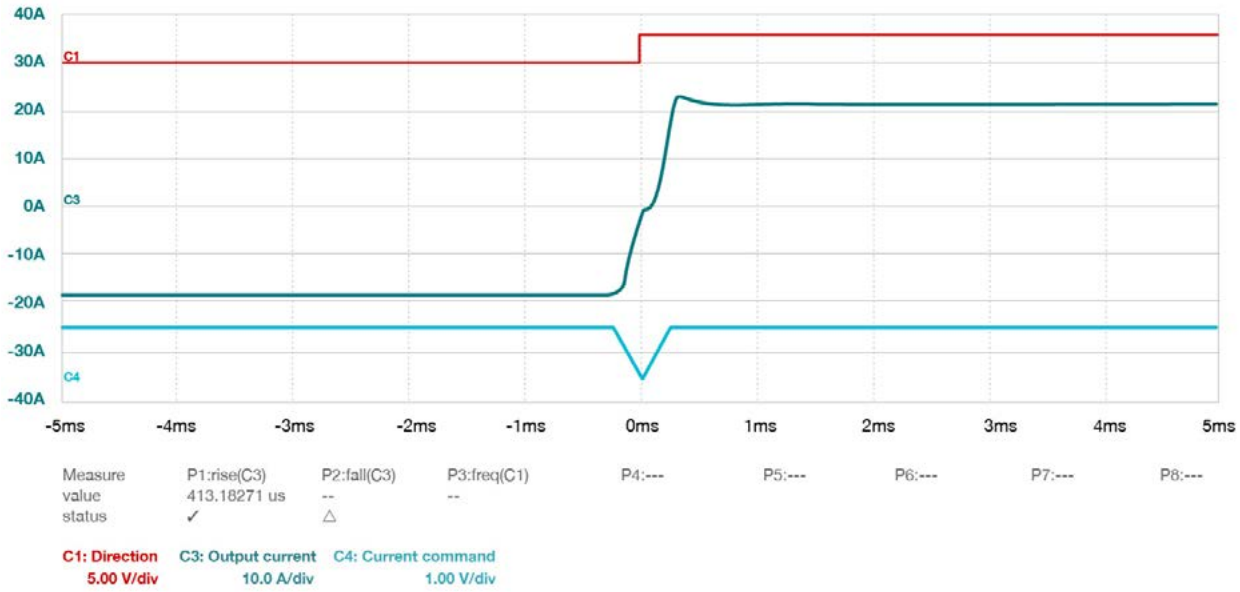

***Figure 3**. Current waveform during the transition from discharge to charge mode.*

demonstrates that it is possible to address high accuracy, high current, speed and flexibility without heavy capital investments in battery test equipment. Rather than investing in multiple architectures for different current levels, you can now test a range of currents so that your high-current equipment no longer remains idle when testing low-current batteries.

The reference design enables you to save money by investing in lower-current battery test equipment, while providing the capabilities and flexibility to test high-current applications without sacrificing accuracy.

Important Notice: The products and services of Texas Instruments Incorporated and its subsidiaries described herein are sold subject to TI's standard terms and conditions of sale. Customers are advised to obtain the most current and complete information about TI products and services before placing orders. TI assumes no liability for applications assistance, customer's applications or product designs, software performance, or infringement of patents. The publication of information regarding any other company's products or services does not constitute TI's approval, warranty or endorsement thereof.

All trademarks are the property of their respective owners.

© 2020 Texas Instruments Incorporated

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATASHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES “AS IS” AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, or other requirements. These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI’s products are provided subject to TI’s Terms of Sale (www.ti.com/legal/termsofsale.html) or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI’s provision of these resources does not expand or otherwise alter TI’s applicable warranties or warranty disclaimers for TI products.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2020, Texas Instruments Incorporated