Battery-charge control: dedicated ICs or microcontrollers?

David Gunderson, Micro Power Electronics Inc - December 01, 2011

Battery-charger-control designers face a fundamental choice: to use a part from the rich selection of dedicated charge-control ICs available from many vendors or to use a programmable microcontroller. Because battery-charge control is a slow process, you can use inexpensive microcontrollers with embedded ADCs, signal conditioning, and PWM modules to directly control the charger’s power-conversion circuits. You can also use a microcontroller for charger-to-battery-management-system communication and interaction, such as in a smart charger; flexible user interfaces, such as those in charge-status displays; battery-conditioning control; and other flexible features. However, microcontroller circuits and firmware are normally more expensive to design and test and often cost more to produce than chargers employing dedicated charge-control ICs.

Charging requirements

Most recent battery-charger-design activity is for lithium-chemistry batteries. Lithium-ion, lithium-polymer, lithium-iron-phosphate, and related cell types have better volumetric and weight energy density than any other commercially available rechargeable cells. This feature makes them highly desirable for use in portable power systems, including electric vehicles; portable computing and communication devices, such as smartphones, PDAs, tablets, and laptop computers; military computer-assisted warrior systems; and medical-parameter monitors. Nickel-chemistry batteries are still in use, but they are rapidly being replaced by lithium-chemistry devices.

Charging lithium-chemistry cells requires that the charger controls both charge current and battery voltage. The initial part of a charge sources a CC (constant-current) mode into the cells until the battery voltage rises to the “float” voltage. Once the cell reaches the float voltage, the charger’s output voltage remains at the float value in CV (constant-voltage) mode until the charge current decreases to a fixed low value. Once the battery reaches the low current, the charger turns off (Figure 1). Unlike nickel- and lead-chemistry batteries, lithium-chemistry batteries are usually not trickle-charged after charge termination. Maintaining a low current after charge termination can actually damage some lithium cells.
You can derive a close estimate of the charge time of a lithium-chemistry battery using the standard CC/CV algorithm by dividing the battery capacity in ampere-hours by the constant-current-mode charge current in amperes and multiplying that figure by the charge time, 1.3 hours. With proper design and intelligent tuning of the CC/CV-mode algorithm, you can do a closer calculation than this one, but it’s a good starting point. You can also do much worse if the CC-to-CV-mode transition occurs too early due to poor design or inaccurate battery-voltage measurement.

The minimum requirement for a lithium-chemistry battery charger is that it must be able to control both the current into the battery and the voltage at the battery-charge terminals. For safety purposes, most lithium-chemistry battery chargers can disable charge if the battery temperature is too high or too low. In many cases, the charger can reduce the charge current when the battery voltage is low to safely recover an overdischarged battery.

The standard shorthand for the cell configuration in a lithium-chemistry battery is NSMP (N cells in series/M cells in parallel). When designing a charger, remember that the series number is critical because it determines the battery voltage. The parallel number determines battery capacity, and you use it only to calculate charge time at a specific charge current.

Battery-charger conversion efficiency is becoming a major issue due to regulations that the US DOE (Department of Energy) and other countries’ regulatory agencies are putting into place. As these new regulations go into effect, high efficiency will become a primary converter-type selection criterion.

**Dedicated charge ICs**

All dedicated charge-control ICs convert a dc voltage input—typically from an ac/dc power supply—to the required current and voltage for battery charging. Most dedicated charge ICs for lithium batteries support the previously noted requirements: CC- and CV-mode control, battery temperature enable/disable, and reduced-current low-voltage battery recovery. Examples are the
large selections from Texas Instruments, which offers approximately 160 parts; Linear Technology, which lists approximately 60 parts; Maxim, which offers about 70 devices; and Intersil, with approximately 50 parts. Other companies offering more limited selections of charger ICs include Fairchild, Analog Devices, Freescale, Micrel, On Semiconductor, and Torex Semiconductor.

When selecting a dedicated charge-control IC, you normally start with the battery chemistry; the number of serially connected cells, or maximum battery voltage; the desired charge current; and whether the device requires charge enable/disable on temperature. You must also consider whether the power source is a USB interface, along with the maximum and minimum input dc voltages. Most IC vendors have parametric-selection tools on their Web sites to narrow your choices once you make these selections.

Almost all dedicated charge-control ICs implement buck-type converters, in which the input voltage is higher than the maximum battery voltage. A few ICs support buck/boost-type voltage conversion. The head room required between the minimum input voltage and the maximum battery voltage is also an important selection consideration.

The two broad types of dedicated charge-control ICs are linear converters and switched-mode converters. Linear converters usually have less than 1A charge current and operate only in situations with similar input and output voltages. Otherwise, the power loss in the converter becomes unmanageable without expensive heat removal in the form of heat sinks, fans, or similar units. However, linear converters are inexpensive, small, and easy to design (Figure 2).

Switch-mode converters are more complex to design and implement but can support an almost-unlimited range of I/O voltages and charge current. Modern switch-mode converters run at such high switching frequencies that they can use small external inductors and ceramic capacitors, making the circuit small and relatively simple. You can use a switch-mode converter instead of a linear type to provide better conversion efficiency (Figure 3).

Using a microcontroller
At this point, you may wonder why you should not just select a dedicated charge-control IC in all cases instead of doing the expensive embedded firmware development and circuit design for using a microcontroller in a battery-charge-control application. Many microcontrollers have the built-in ADC, signal conditioning, and PWM control required for a battery-charge-control design. Examples include the PSoC line from Cypress, the MSP430 line from TI, PIC processors from Microchip, AVR processors from Atmel, and many others.

You can design a battery-charge controller using a cheap, relatively low-power microcontroller because charge control, unlike general-purpose power-supply control, is slow due to the battery’s electrochemical nature. Nothing much happens in a battery in less than a few hundred milliseconds other than protection trips, and battery chargers should never trip the protection. As a result, a software-implemented control loop works well for battery-charge control. You can implement the CC/CV-protocol charge control for lithium-ion battery charging in a few hundred lines of C.

The only required hardware-support circuits are voltage- and current-measurement amplifiers, an ADC, a PWM output, and a few general-purpose I/O ports; most available microcontrollers integrate many of these components. These processors often also include an I2C or an SMbus (system-management-bus) interface for designs requiring communication with the battery’s fuel gauge.

Vendors publish extensive application notes on how to use their products as battery-charge controllers. Some even offer evaluation systems for this application that can help you to start your circuit and firmware design. In most cases, microcontroller-based charge controllers are more costly to design and produce than designs that use dedicated controllers. Why go to all the cost and trouble?

**Single-cell batteries**

Charging a battery with a single series cell requires the simplest charge-control design. A large selection of dedicated charge-control ICs are available that handle as much as 3A charge current, have internal switching MOSFETs, and require few external parts. It is becoming common for designs to charge batteries using the 5V-dc, 500-mA-maximum, source on a USB interface. Single-series-cell batteries almost always use this approach, and a selection of dedicated linear and switch-mode controller ICs for this application is available.

Single-cell charging algorithms normally require no communication between the battery and the charger. As a result, designers typically implement single-cell battery chargers with dedicated charge-control ICs. Examples include cell-phone chargers, shaver chargers, and charger docks for smartphones and tablet computers. The core voltages of these portable devices are low enough that a single lithium-chemistry cell can supply their approximately 3V minimum input voltage from the battery. Many of these devices can be charged off USB power.

In some cases, however, a multibay charger better suits the application. These cases include medical and military applications in which several batteries are always on charge at a central site. Microcontrollers can often control more than one battery-charger bay because the required control algorithm is slow. The microcontroller’s ability to control multiple bays can yield a production-cost advantage, but it also complicates the firmware and makes the charger more difficult to design and test. Vendors such as Micro Power offer chargers with as many as four charge bays, which one inexpensive PSoC microcontroller can control.

**Two- to four-cell devices**
When the portable device requires more power than a single-cell lithium-chemistry battery can provide, you need to consider a battery with two to four cells in series. Charging these batteries is a more complex design problem because of cell balancing and CC/CV-algorithm tuning requirements. Higher-cell-count batteries must be charged so that the maximum cell voltage—not the battery voltage—is less than the specified float voltage. If the charger continues to push current into the battery when one or more cell voltages are too high, cell damage can result, reducing the life of the battery and even causing a safety issue in the most extreme case.

You can design batteries with internal cell-balancing circuits that either shunt current around some of the cells or push additional current into selected cells to keep the cells in balance. However, it’s sometimes necessary for the charger to participate in balancing, and to achieve this task, the charger must communicate with the battery-management system. Dedicated charge-control ICs typically don’t support this sort of interactive charge control, so the task requires a microcontroller.

To optimize charge time, you should tune the charge-control algorithm for battery temperature, internal battery voltage, and other parameters that only the battery-management system knows. For example, to optimize charge time, the charger should stay in CC mode for as long as possible. However, the battery-charge current path sometimes contains an antireverse diode, preventing the charger from measuring the actual cell-stack voltage. The battery-management system can measure the cell stack’s voltage in the battery and communicate that measurement to the charger, which can use the more accurate voltage in the CC-to-CV-mode-transition algorithm and keep the battery in CC mode for a longer time. This approach can significantly reduce the charge time.

A charger for a more complex battery usually has a status display, such as an LED bar graph or an LCD, for example. Implementing this feature usually requires a microcontroller because dedicated charge controllers have simple status-display support.

High-end chargers for the complex batteries in military and medical applications sometimes contain microcomputer systems for storing and communicating information—typically through a USB interface to a PC—about individual batteries. You can use this information for preventive maintenance and battery-fleet-status reporting.

**High-voltage batteries**

To reduce current requirements, designers of batteries for electric vehicles, large-system back power, and other high-power-requirement applications build batteries from high-series-count cell stacks. Electric-vehicle battery systems also support regenerative braking systems, active cooling and heating, and other advanced battery-management systems. As you might expect, high-cell-count batteries require complex cell-balancing circuits and algorithms. These complex, high-voltage batteries require the full integration of the battery-management system and the charging systems. Integrating the charger with the battery-management system into one system usually requires computer control for much of the battery-management-system function because dedicated charge-control ICs are too inflexible.

Battery-fleet management is common in these complex systems, so the charger/battery-management system must acquire and maintain information about battery health and history. The distributed energy storage in electric-vehicle and household- and business-backup power systems will likely find use for power-grid peak-load management when the nationwide smart grid becomes a reality. This situation will require that the charging system synchronize with the grid inverter so that the battery can both source and consume power to and from the grid. These integrated systems will require robust communication through the charger with the battery-management system so that the smart
grid can maintain information about battery status and capabilities. All of these developments shift the charger away from acting as a simple current-controlled voltage converter to acting as a subsystem in a complex, computer-controlled energy-management system.

**Making a decision**

Making a decision on the type of charge controller to use for a specific application goes as follows: If the battery is a one-cell lithium-chemistry type and the charge current is less than 500 mA or if charging from USB power is necessary, use a dedicated, linear or a minimum-function switch-mode charge controller, such as the TI bq24100 series. If the battery is a one- to three-cell, single-bay lithium-chemistry type and the charge current is less than 3A, use a dedicated, switch-mode charge controller, such as a TI bq24105 or bq24170. However, if the application requires charger-to-battery communication, an advanced user interface, or communication with a host computer, consider the use of a microcontroller. If the battery is a one- to three-cell, multibay lithium-chemistry type and the charge current is less than 3A, trade off the costs for a switch-mode charge controller with those of a microcontroller controlling more than one bay.

Batteries requiring more than 3A charge current or having more than three cells almost always require a switch-mode converter using a microcontroller because communication between the charger and the battery-management system is usually necessary for safety and optimal charge time. No matter how many cells the battery has, applications requiring battery-history and -status recording and communication must use a microcontroller or even a microcomputer in the charger.

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**Author’s biography**

David Gunderson is a senior electronics engineer at Micro Power Electronics. He is responsible for design electronics and embedded software for batteries and chargers. Gunderson holds a bachelor’s degree in electrical engineering, and his interests include composing and performing music and playing with his grandchildren.

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