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Honey, Where Is My Power Cord?

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Introduction

A more common modern-day question would probably be "Honey, where is my battery charger?" The reduction in cost and improvement in battery performance, especially Li-Ion based, at the turn of the century has fueled a steady growth of battery-powered energy storage and portable equipment. Also, supercapacitors (aka ultracapacitors) are increasingly finding usage in a variety of applications due to their unique characteristics. The lead-acid battery, a 150-year-old technology, is still popularly used in cars, wheelchairs, scooters, golf carts, and uninterruptable power supply (UPS) systems. These energy storage devices must be recharged once their energy has been depleted. The worldwide charging IC shipment was 1.16 billion units in 2019 and is expected to grow to 1.72 billion units in 2024 with a healthy 8.6% annual growth rate. The respective revenue was $518.1 billion and $735.4 billion with a 7.3% CAGR. Figure 1 shows this trend, according to OMDIA's "Power IC Market Tracker - 2019."[1]

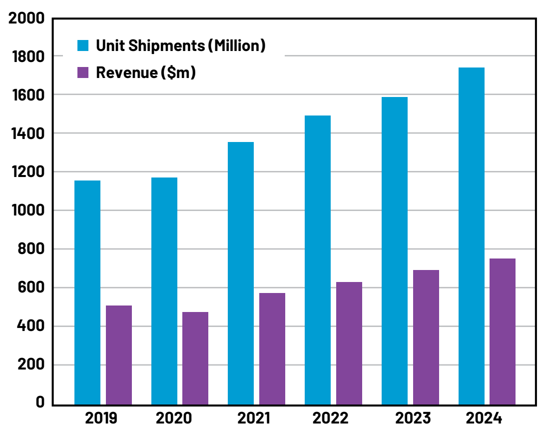

Figure 1. The world market for charging ICs.

The demand for more power, along with longer range or run time, dictates an increase in the voltages used in energy storage devices. For example, Li-Ion battery stacks have gone from one or two cells to multiple (up to 12) cells used in robots, drones, power tools, and a host of other things. A 12-cell Li-Ion battery stack provides 50.4 V maximum voltage. A 12-cell battery would last 12 times longer than a 1-cell battery at the same current rating. Alternatively, 12 batteries can be connected in parallel for higher power, but this method would increase the current 12×. Higher current causes more conduction losses, so paralleling batteries is not preferred.

Industrial systems such as emergency lighting with battery backup, UPS backup power, and HVAC use a 24 V_{DC} power source—that is, a 24 V battery is used to back up these systems. The 24 V_{DC} power source, however, can rise to 60 V peak voltage during transient conditions, according to IEC 61131-2 and IEC 60664-1 standards.

In either situation, the equipment requires charger solutions that can accommodate higher battery voltage and withstand higher input voltage during transient events.

Charger Basics

There are many charger topologies. The linear charger drops the voltage difference between the power source and the battery through a power switch. This type of charger is the least efficient, since it dissipates a lot of power across the power switch when the voltage difference between the power source and the battery is large. The boost charger boosts the voltage from the power source to the battery voltage. This topology requires the power source voltage to be lower than the battery voltage. The buck charger steps down the voltage from the power source and requires the power source voltage to be higher than the battery voltage. The buck-boost charger can charge the battery with a power source voltage that is either higher or lower voltage than the battery voltage. This topology requires four power switches (compared to two for the buck) and generally is not as efficient.

The synchronous rectification buck charger is the most efficient and is the focus of this article. Figure 2 shows a generic synchronous rectification buck charger circuit. Most buck chargers today operate at a relatively low voltage. Many are rated at only 28 V input with some at 40 V. Allowing ±10% input voltage regulation and a 2 V drop across the buck charger, a 28 V-rated charger can only practically charge a 5S Li-Ion battery stack (maximum). We will examine a new family of 60 V input charger ICs that allow higher voltage charging—up to 52 V battery voltage (or a 12-cell Li-Ion stack)—and that can withstand a 65 V input voltage transient.

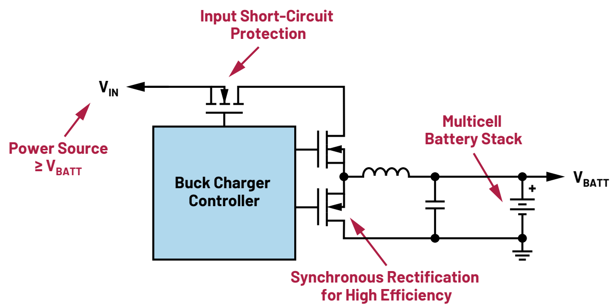

Figure 2. Generic synchronous rectification buck charger.

The standby current on a charger should be low to save energy. Energy Star® assigns five stars to mobile phone chargers and other small chargers that draw 30 mW or less on standby. One star goes to chargers with 300 mW or more, and there are other ratings for everything else in between. Energy Star aims to reduce current consumption of personal chargers that are mostly left plugged in when not in use. There are over 1 billion such chargers connected to the grid globally at any given time.

Even though the lead-acid battery, Li-Ion-based battery, and supercapacitor are all energy storage devices, they have very distinct charging/discharging characteristics. We will examine these characteristics and discuss a charging solution for each of them. A good battery charger provides battery performance and durability, especially when charging under adverse conditions.

Lead-Acid Battery Charger

Lead-acid is the oldest rechargeable battery in existence and was invented by the French physician Gaston Planté in 1859.[2] One hundred and fifty years later, it is still popularly used in cars, wheelchairs, scooters, electric bikes, golf carts, and UPS systems.

The lead-acid battery must be charged slowly. Typical charge time is 8 to 16 hours. The battery must always be stored in a charged state, and a periodic fully saturated charge is essential to prevent sulfation. It is common practice to charge lead-acid batteries to 70% in about 8 hours, and another 8 hours to do the all-important absorption charge. A partial charge is fine provided the lead-acid occasionally receives a fully saturated charge to prevent sulfation. Leaving the battery on float charge for a prolonged time does not cause damage.

Finding the ideal charge voltage limit is critical. A high voltage (above 2.45 V/cell) produces good battery performance but shortens service life due to grid corrosion on the positive plate. A low voltage limit is subject to sulfation on the negative plate. Temperature also affects the cell voltage with a typical –5 mV/°C (0.028 V per cell for every 10°F).[3] A good charger must compensate for this temperature coefficient to avoid overcharge of the battery when hot or undercharge when cold.

As an example, the MAX17702 (see Figure 3) is a complete lead-acid battery charger controller designed to operate over an input voltage range of 4.5 V to 60 V. The device offers a high efficiency (over 97%), high voltage, synchronous buck solution to charge 12 V/24 V/48 V lead-acid battery stacks. Figures 4a and 4b show its charging cycle and charging efficiency.

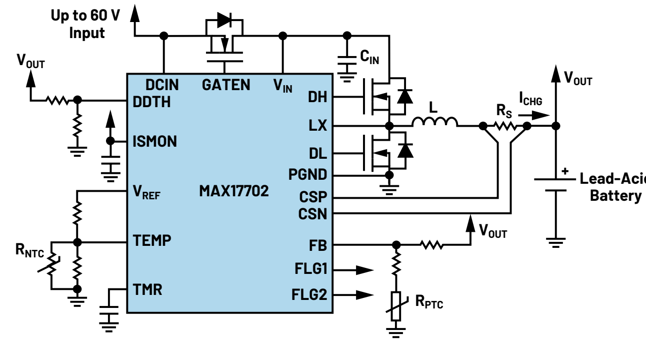

Figure 3. High voltage lead-acid battery charger controller.

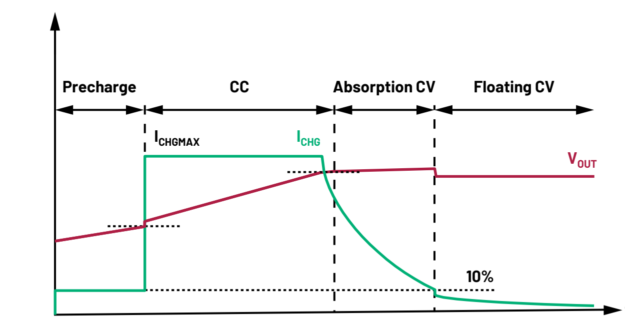

Figure 4a. MAX17702 lead-acid charging cycle.

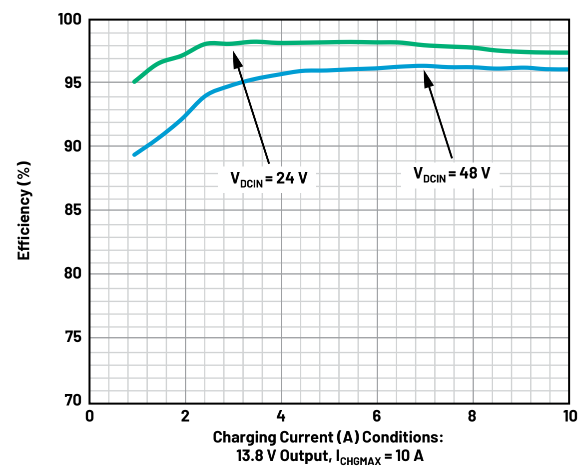

Figure 4b. MAX17702 charging efficiency.

The lead-acid battery has low energy densities, making it unsuitable for portable devices. This is where a lithium-based battery comes into play.

Li-Ion Battery Charger

Li-Ion is the universally accepted battery for portable applications, heavy industries, electric powertrains, and satellites due to its light weight and high energy density.

Li-Ion is a low maintenance battery. The battery has no memory and does not need exercising (deliberate full discharge) to keep it in good shape. But it needs protection circuits, both built-in inside the battery pack as well as in the charger to prevent short circuit, overcharge, thermal runaway, and overdischarge. If a Li-Ion battery has dwelled below 1.5 V/cell for a week or longer, dendrites may have developed that could compromise safety.

To prevent overdischarge, the built-in battery protection circuit puts the battery into a sleep condition. This happens when storing the battery in a discharged state in which self-discharge brings the voltage to the cutoff point. A regular charger treats such a battery as unserviceable, and the pack is often discarded. An advanced Li-Ion charger includes a wake-up feature, or "precharge," to allow recharging if a Li-Ion battery has fallen asleep due to overdischarge. In precharge mode, the charger applies a small charge current to safely raise the voltage to between 2.2 V/cell and 2.9 V/cell to activate the protection circuit, at which point a normal charge commences.

During normal charge, the Li-Ion charger operates on constant current constant voltage (CCCV). The charge current is constant, and the voltage is capped when it reaches a set limit. Reaching the voltage limit, the battery saturates; the current drops until the battery can no longer accept further charge and charging terminates. Each battery has its own low current threshold.

Li-Ion batteries should always stay cool on charge. Li-Ion cannot absorb overcharge. Thus, it is very important to monitor the battery temperature and its charging voltage to assure battery health and safety. A good charger must include these features.

Figure 5 shows an example of an advanced Li-Ion battery charger. The MAX17703 is a high efficiency, high voltage, synchronous, step-down charger controller designed to operate over a wide input voltage range of 4.5 V to 60 V. The device offers a complete charging solution for up to 12 Li-Ion cell stacks.

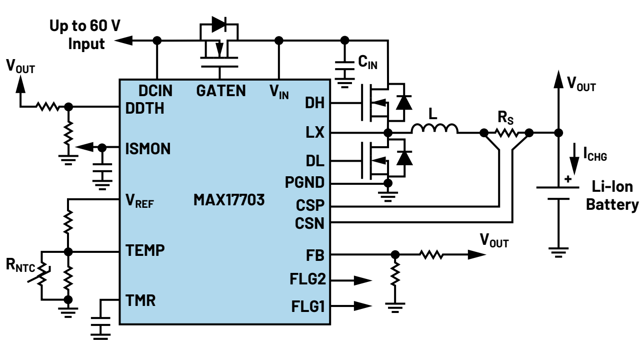

Figure 5. Advanced, high voltage Li-Ion battery charger circuit.

The device offers accurate CCCV charging current/voltage at ±4% and ±1%, respectively. The charger enters a top-up-charge state when the charging current reduces to the taper-current threshold and then exits charging after a taper-timer period elapse. The charger initiates a recharge cycle when the output voltage falls below the recharge threshold voltage. This is a nice feature to keep the battery fully charged, if left in the charging cradle for a long period, without using too much power and to comply with Energy Star requirements. The device can detect and precondition deeply discharged batteries, waking them up with the precharge feature. For added protection, the device senses the battery temperature and allows charging only when within the temperature range. There is also an input short-circuit protection feature, which prevents discharging of the battery when the input is accidentally short circuited. Figure 6 illustrates the MAX17703's charging cycle.

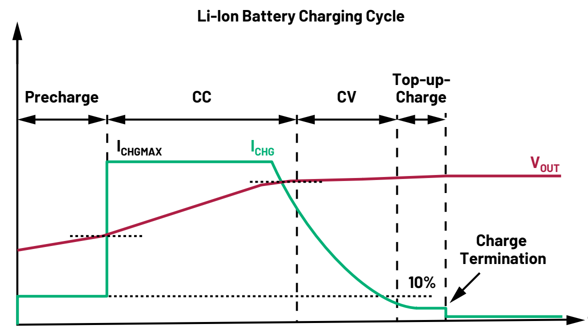

Figure 6. MAX17703 Li-Ion battery charging cycle.

Supercapacitor Charger

Supercapacitors are increasingly finding usage in a variety of applications, thanks to their unique advantages over batteries. Supercapacitors function on electrostatic principles with no chemical reactions, avoiding the lifetime issues associated with chemical storage of batteries. Their high durability allows for millions of charge/discharge cycles with lifetimes up to 20 years, one order of magnitude above batteries. Their low impedance enables fast charge and discharge in a matter of seconds. This, in conjunction with their moderate ability to hold charge over long periods of time, makes supercapacitors ideal for applications requiring short charge and discharge cycles. They are also used in parallel with batteries, in applications where instantaneous peaks of power delivery are necessary during load transitions.

Supercapacitor short-charge and discharge cycles require chargers to handle high currents and work smoothly in constant current (CC) mode during a charge, which may start at 0 V, and in constant voltage (CV) mode once the final output value is achieved. In high voltage applications, many supercapacitors are connected in series, requiring chargers to manage high input and output voltage.

The MAX17701 (see Figure 7) is a high efficiency, high voltage, synchronous, step-down supercapacitor charger controller designed for high current charging and operates over an input voltage range (V_{DCIN}) of 4.5 V to 60 V. The output voltage is programmable from 1.25 V up to (V_{DCIN} – 4 V). The device uses an external N-MOSFET to provide an input supply-side OR'ing function, preventing supercapacitor discharge back to the input. Figure 8 illustrates the simplistic, but high current charging profile.

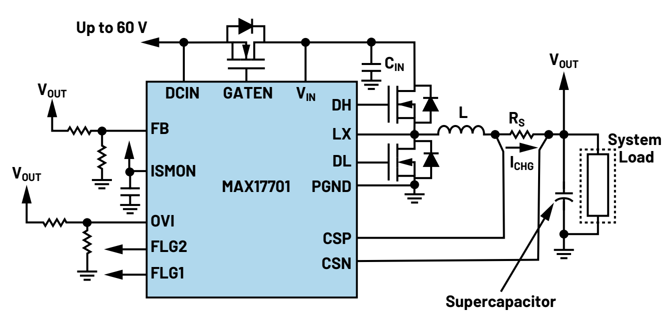

Figure 7. Supercapacitor high voltage, high current charger.

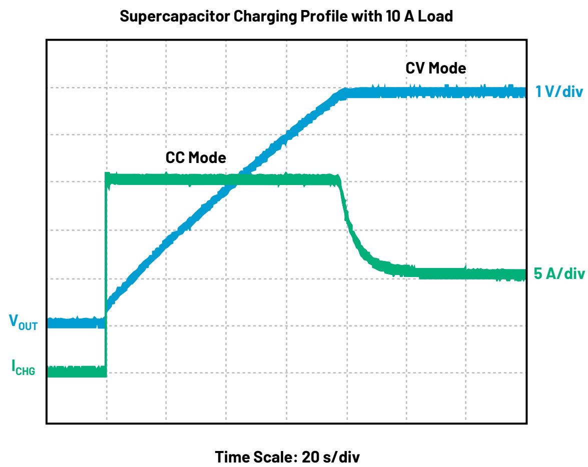

Figure 8. MAX17701 supercapacitor charging profile.

Conclusion

The use of battery-powered energy storage and portable equipment has grown steadily. The demand for more power, along with longer range or run time, dictates an increase in the voltages used in their battery stacks. Applications in industrial systems using a 24 V_{DC} power supply can see 60 V peak voltage during transient conditions. Legacy charger solutions are mostly limited to 28 V input. Newer charger solutions from Analog Devices enable higher battery stack voltage and higher charging efficiency, thanks to the high voltage, synchronous buck charging topology.

Lead-acid batteries, lithium-based batteries, and supercapacitors are all energy storage devices that have very distinct charging/discharging characteristics and require a dedicated charger for an optimum charging solution. An advanced battery charger also provides adequate protection to give battery performance and durability, especially when charging under adverse conditions. These are also addressed in newer charger solutions.

References

[1]Kevin Anderson. "Power IC Market Tracker - 2019." OMDIA, September 2020.

[2]"Advancements in Lead Acid." Battery University, July 2016.

[3]US 31DC XC2 - Data Sheet. U.S. Battery, 2019.

About the Author

Anthony T. Huynh (aka Thong Anthony Huynh) was a principal member of technical staff (MTS), applications engineering, at Maxim Integrated (now part of Analog Devices). He has more than 20 years of experience designing and defining isolated and nonisolated switching power supplies and power management products. At ADI, he has defined more than 100 power management products including DC-to-DC converters, hot swap controllers, Power over Ethernet, and various system-protection ICs adopted by the world's leading manufacturers.

Anthony holds four U.S. patents in power electronics and has written several public articles and application notes in this area. He has a B.S. in electrical engineering from Oregon State University and has completed all coursework for an M.S. in electrical engineering at Portland State University, where he also taught a power electronics class as an adjunct instructor.