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A Flexible Design For Fast Charging Supercapacitors In Industrial Applications

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Supercapacitors (or ultracapacitors) are finding increasing usage in a variety of applications thanks to their unique advantages over batteries. Supercapacitors function on electrostatic principles with no chemical reactions, averting 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.

Meanwhile, the supercapacitors' low impedance enables fast charge and discharge on the order of seconds. This, in conjunction with their moderate ability to hold charge over long periods of time, makes supercapacitors ideal for applications that require 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.

The supercapacitors' short charge and discharge cycles require chargers that can handle high current. The chargers must work smoothly in constant current (CC) mode during a charge, which often starts 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.

In this article, we will discuss two use cases for supercapacitors: automatic pallet shuttles in storage facilities and short-duration backup systems in fail-safe valve actuators. Subsequently, we will introduce a synchronous stepdown supercapacitor charger that, thanks to its high output current and wide input and output voltage range of operation, can handle a large number of industrial and consumer applications.

First Case Study: Automatic Pallet Shuttle

A modern storage facility consists of one or more racking units with a high number of channels on various levels to store thousands of pallets. A transfer car carries pallets to and from each of the storage channels, while a motorized shuttle moves the pallets back and forth inside the channel (Fig. 1).

Fig. 1. Centered on the rails is a typical motorized pallet shuttle. (Transfer car is not pictured.)

An automatic pallet shuttle is an ideal application to use ultracapacitors as its main source of electrical power. The autonomous shuttle flight within the channel lasts only a few seconds, requiring a limited amount of energy per-flight, with power supplied by supercapacitors within the pallet shuttle. The supercapacitors quickly recharge within seconds while the shuttle is connected to the transfer car. The shuttles are always available and can operate continuously, 24 hours a day, assuring high durability without any maintenance.

Fig. 2 illustrates a power system based on two supercapacitors in series each rated at 400 F and 2.7 V. The supercapacitor ensemble is on board the pallet shuttle, while the charger is on the transfer car. The charger draws power from V_{BUS} = 24 V.

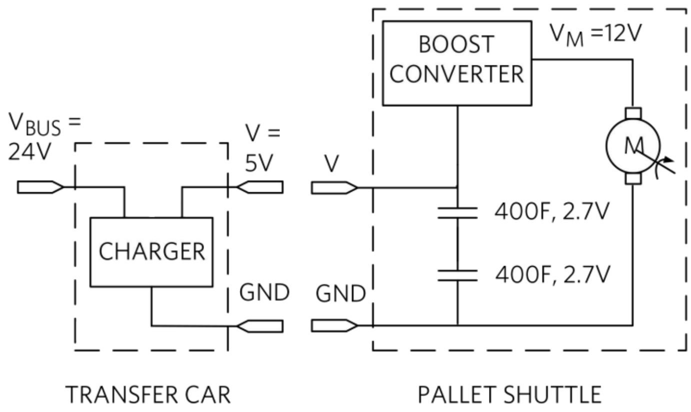

Fig. 2. Supercapacitors power an automated pallet shuttle.

During the docking time in between shuttle flights, it charges the 200-F supercapacitor ensemble (C) at a voltage V = 5 V, storing a charge:

$$Q = C \times V = 200 \times 5 = 1000 \ Coulombs$$

With a 20-A charging current, the supercapacitors will charge in time τ = 50 s (Q/I).

The boost converter on the pallet shuttle boosts the 5-V input voltage to V_M = 12 V to drive the motor with a 5-A current. Neglecting the losses, the boost converter input current will be:

$$I = 12\,V\,x\,\frac{5\,A}{5\,V} = 12\,A$$

This current will discharge the supercapacitor at the following rate:

$$r = \frac{\mathrm{I}}{\mathrm{C}} = \frac{12}{200} = 0.06\,V/s$$

Assuming that the boost converter input UVLO is 3 V, the capacitor discharge range is ΔV = 2 V. Accordingly, the boost converter will drive the motor for a time:

$$t = \frac{\Delta \mathrm{V}}{r} = \frac{2}{0.06} = 33\,s$$

With a full charge/discharge (τ + t) cycle of 83 s, a single pallet shuttle could theoretically support a movement of 43 pallets per hour.

Second Case Study: Fail-Safe Valve Actuator Backup

In industrial oil- and gas-flow control applications, a power failure has the potential to leave actuators stuck in the operating position, leading to unsafe conditions, accidents, or equipment damage. The fail-safe valve actuator backup systems automatically return the valve to a safe emergency position if the power supply is interrupted.

In traditional solutions, the return to a safe position is performed by a mechanical spring. With supercapacitors, if there is a power failure, the actuator can be moved to a specifically chosen emergency position with the energy stored in the supercapacitor. Supercapacitors require less space and, without moving parts, ensure that the energy storage has a long service life and is low maintenance.

Fig. 3 illustrates the power system based on ten supercapacitors in series each rated at 3400 F and 2.7 V. During normal operation, a 48-V bus is stepped down to 24 V to power the actuator driver while also charging the 340-F supercapacitor ensemble (C).

In the event of a power failure, the 340-F supercapacitor string powers the 10-A load (I). With a discharge rate of 0.03 V/s (I/C) and a discharge range, ΔV = 10 V, the actuator can be driven for 330 s, a sufficient time to move it to the specified emergency position.

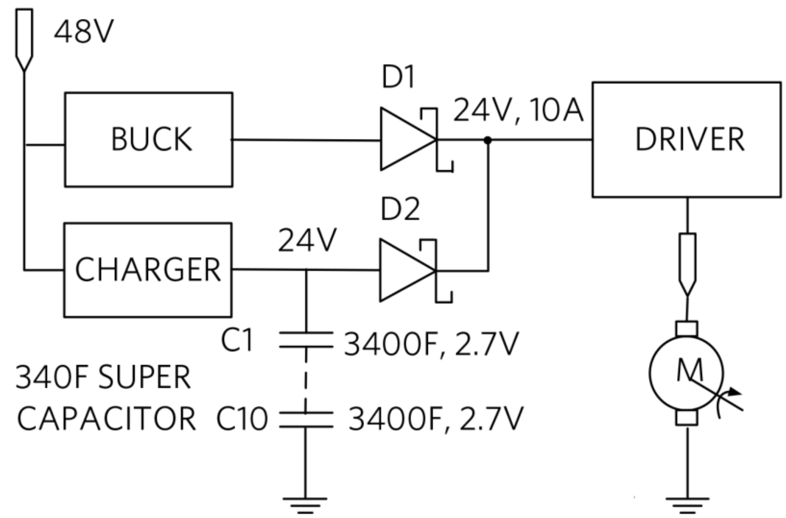

Fig. 3. Supercapacitor-powered fail-safe valve actuator.

A Supercapacitor Charger Solution

As an example of a device that implements a supercapacitor charger, the MAX17701 (see the reference) is a high-efficiency, high-voltage, synchronous, stepdown, supercapacitor charger controller designed to operate over an input-voltage range (VDCIN) of 4.5 V to 60 V. The output voltage is programmable from 1.25 V up to (VDCIN – 4 V). The device uses an external n-channel MOSFET to provide an input supply-side ORing function, preventing a supercapacitor discharge back to the input. Fig. 4 shows a 24-V input, 5-V 20-A output circuit for the pallet shuttle application discussed earlier and illustrated in Fig. 2.

Fig. 5 shows the efficiency of this application circuit with 24-V input and 5-V output. Efficiency curves for 48-V and 12-V input voltages are also shown. The charger efficiency is excellent (>90%) with 24-V input and 5-V output, in the pallet shuttle use case. The efficiency is also very good with 48-V (>85%), the input voltage adopted by the second application discussed.

The IC charges the supercapacitor with a ±5% accurate constant current (CC mode in Fig. 6). After the supercapacitor is charged, the device regulates the no-load output voltage with ±1% accuracy (CV mode).

The IC provides a safety timer (TMR) feature to set the maximum-allowed constant current (CC) mode charging time. It operates over a -40°C to +125°C industrial temperature range and is available in a 24-pin 4-mm x 4-mm TQFN package with an exposed pad.

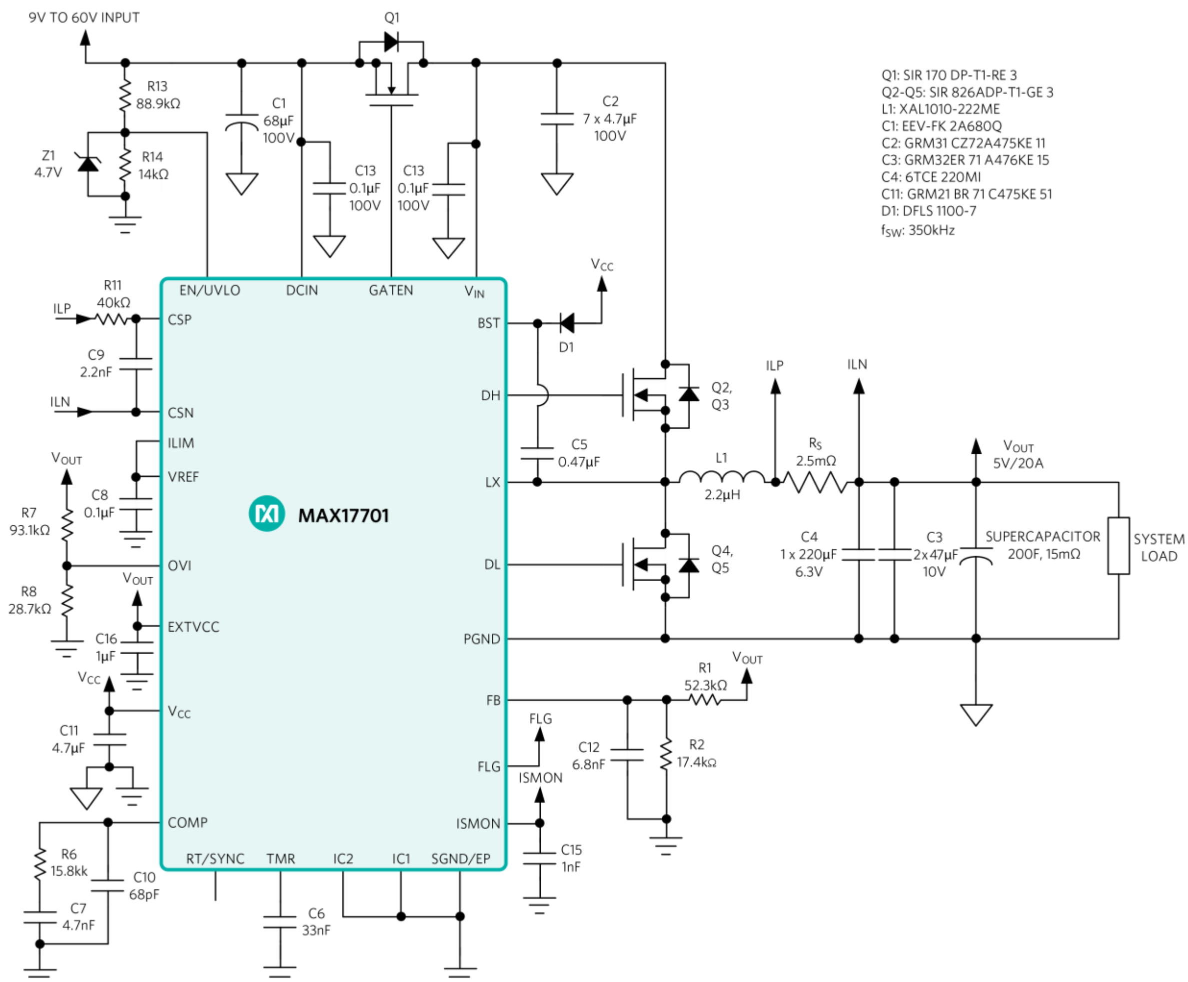

Fig. 4. A 5-V 20-A supercapacitor charger based on the MAX17701 controller includes input short-circuit protection.

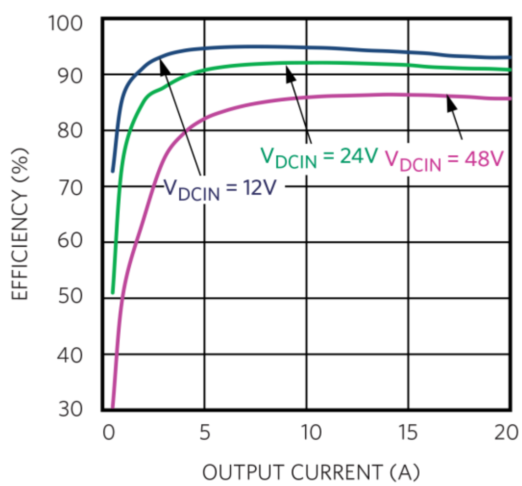

Fig. 5. Efficiency of the 5-V, 20-A supercapacitor charger depicted in Fig. 4.

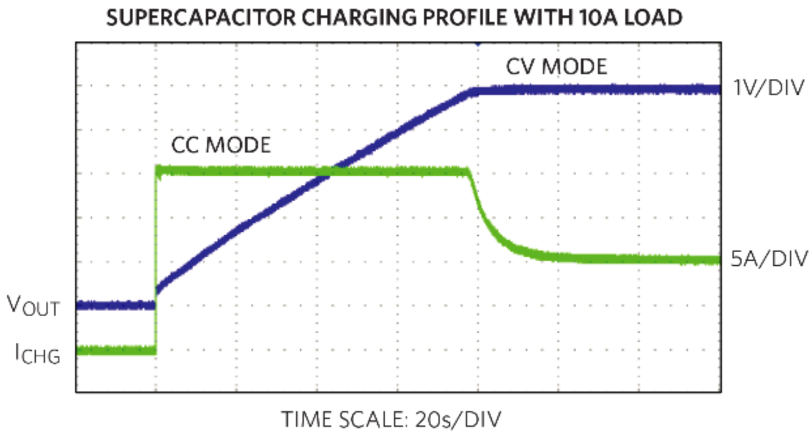

Fig. 6. Charger current and voltage profile.

Conclusion

The unique features of supercapacitors make them ideal for short charge and discharge cycles as illustrated in the two case studies we discussed—the automatic pallet shuttle in a modern storage facility and the fail-safe valve actuator backup system. Short cycles require high charge and discharge currents, while the utilization of supercapacitors in series leads to a high range of possible input and output charger voltages, depending on the number of capacitors. Accordingly, we proposed a flexible charger architecture with high current, and high input/output voltages that can handle a large variety of applications.

Reference

MAX17701 product page.

About The Authors

Nazzareno (Reno) Rossetti is an analog and power management expert at Maxim Integrated. He is a published author with several patents in this field. Reno holds a doctorate in electrical engineering from Politecnico di Torino, Italy.

John Woodward is an executive business manager for power management products at Maxim Integrated. He has 18 years of industry experience, with ten years working on the engineering side in applications/test and eight years on the marketing/business side, helping drive product management.

For further reading on supercapacitor charger designs, see the How2Power Design Guide, and do a keyword search on "supercapacitor". Also search for "ultracapacitor".

