DESIGN SOLUTION 7323

HOW TO FAST-CHARGE YOUR SUPERCAPACITOR

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Abstract:

Supercapacitors (or ultracapacitors) are suited for short charge and discharge cycles. They require high currents for fast charge as well as a high voltage with a high number in series as shown in two usage cases: an automatic pallet shuttle and a fail-safe backup system. In these and many other cases, the fast charge is provided by a flexible, high-efficiency, high-voltage, and high-current charger based on a synchronous, step-down, supercapacitor charger controller.

Introduction

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. Their low impedance enables fast charge and discharge in 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 0V, 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 design solution, we will discuss two use cases: automatic pallet shuttles in storage facilities and short-duration backup systems in fail-safe valve actuators (**Figure 1**). Subsequently, we will introduce a synchronous step-down 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.

Figure 1. Warehouse automated pallet shuttle.

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 serves each of the storage channels while a motorized shuttle moves the pallets back and forth inside the channel.

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

Figure 2 illustrates the power system based on two supercapacitors in series each rated at 400F and 2.7V. The supercapacitor ensemble is on board the pallet shuttle, while the charger is already on board the transfer car. The charger draws power from V_{BUS} = 24V. During the docking time in between shuttle flights, it charges the 200F supercapacitor ensemble (C) at a voltage V = 5V, storing a charge:

$$Q = C \times V = 200 \times 5 = 1000 \text{ Coulomb}$$

With a 20A charging current, the supercapacitor will charge in time τ = 50s (Q/I). The boost converter on the pallet shuttle boosts the 5V input voltage to VM = 12V to help drive the motor with a 5A current. Neglecting the losses, the boost converter input current will be:

$$I = 12V \times \frac{5A}{5V} = 12A$$

This current will discharge the supercapacitor at the following rate:

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

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

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

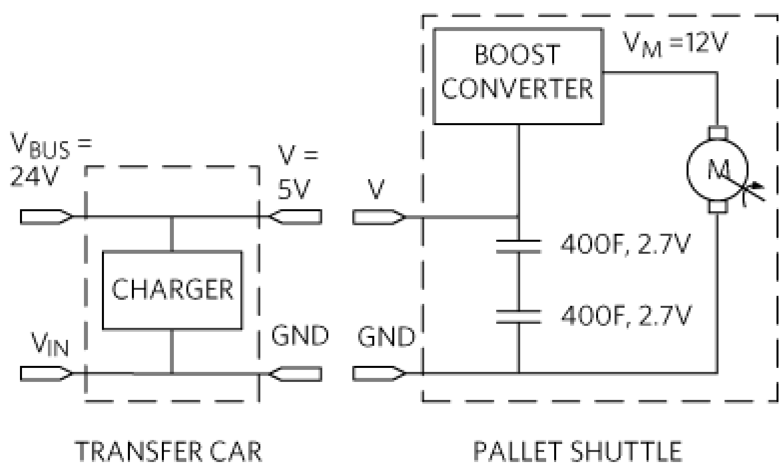

Figure 2. Supercapacitors power an automated pallet shuttle.

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

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.

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

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

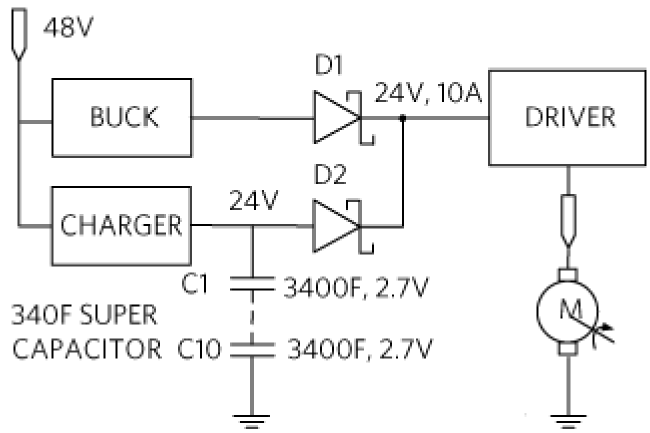

Figure 3. Supercapacitor-powered fail-safe valve actuator.

The Supercapacitor Charger Solution

As an example, the MAX17701 is a high-efficiency, high-voltage, synchronous, step-down, supercapacitor charger controller designed to operate over an input-voltage range (VDCIN) of 4.5V to 60V. The output voltage is programmable from 1.25V up to (VDCIN - 4V). The device uses an external N-MOSFET to provide input supply-side ORing function, preventing a supercapacitor discharge back to the input. **Figure 4** shows a $24V_{IN}/5V_{OUT}/20A$ application circuit for the pallet shuttle application discussed earlier in Figure 2.

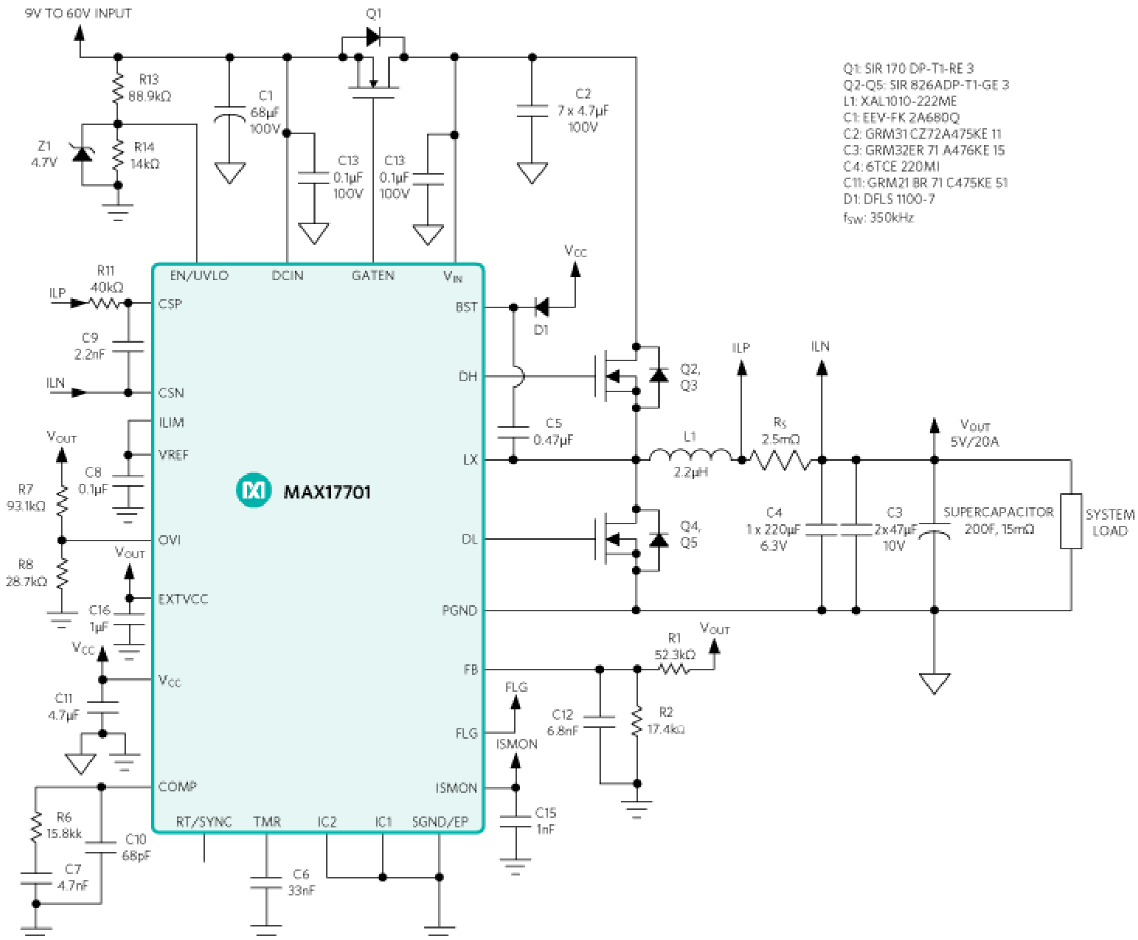

Figure 4. 5V/20A supercapacitor charger with input short-circuit protection.

Figure 5 shows the efficiency of this application circuit with 24V input and 5V output. Both 8V and 12V input voltages are also shown.

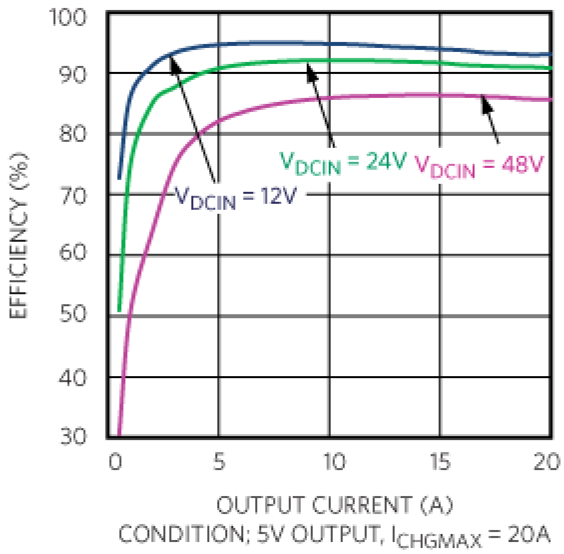

Figure 5. 5V/20A supercapacitor charger efficiency.

The charger efficiency is excellent (> 90%) with 24V input and 5V output, in the pallet shuttle use case. The efficiency is also very good with 48V (> 85%), the input voltage adopted by the second application discussed.

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

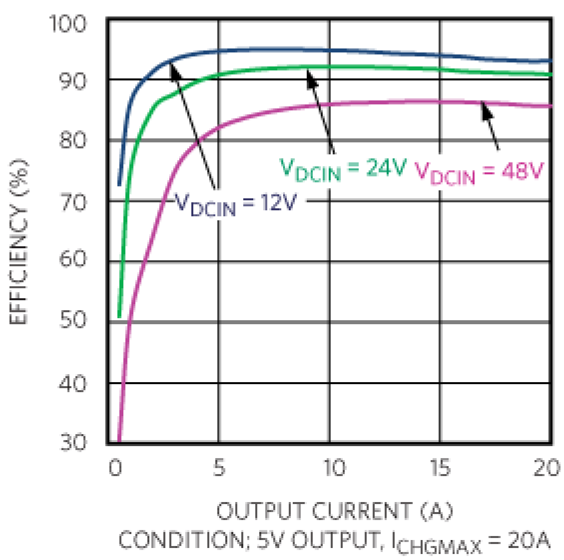

Figure 6. Charger Current and Voltage Profile.

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 4mm x 4mm TQFN package with an exposed pad.

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.

A similar version of this design solution originally appeared in How2Power on Sept. 2020.

Related Parts	
MAX17701	4.5V to 60V, Synchronous Step-Down Supercapacitor Charger Controller