SAM DAVIS, Editor in Chief

Power-Tracking Battery-Charger IC Supports Solar-Power Systems

Individual solar-panel systems produce dc power for remote applications while also storing energy in a rechargeable battery supported by a battery-charger IC.

In non-utility grid applications solar panels produce dc power for emergency roadside telephones, navigation buoys, and other remote loads. Virtually all 12-V-system solar panels comprise a series of photovoltaic cells that have a maximum output power of less than 25 W. In producing this power the solar-panel system uses a battery to provide power when the panel is "dark." The rechargeable battery can supply power for long periods of time, requiring a charger that can properly operate a solar panel.

Meeting this need is Linear Technology's LT3652 monolithic buck-charger IC, which operates with a single solar panel. The IC uses average-current-mode control-loop architecture to provide constant current/constant voltage (CC/CV) charge characteristics with a programmable charge current. The charger can be programmed to produce a 14.4-V float voltage. Housed in a 3- x 3-mm DFN-12 package, the IC can charge a variety of battery configurations, including up to three Li-Ion/Polymer cells in series, up to four Lithium Iron Phosphate ($LiFePO_4$) cells in series, and sealed lead-acid batteries up to 14.4 V.

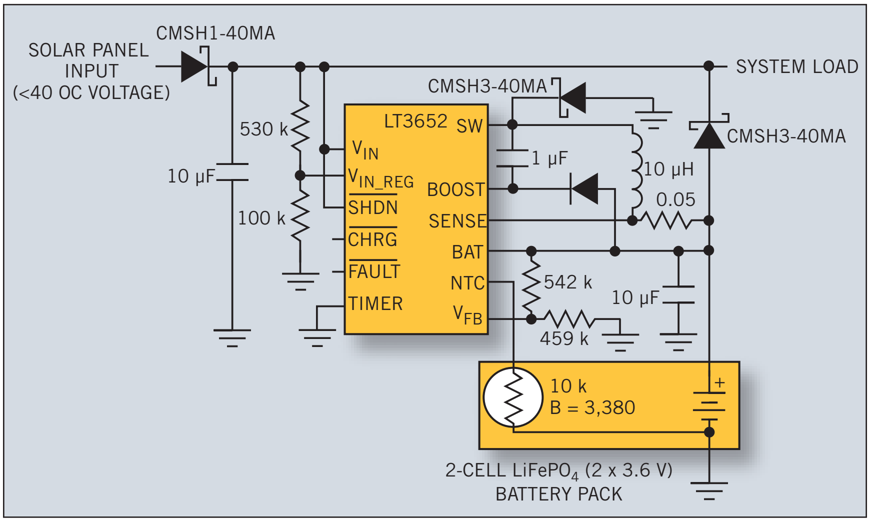

Fig. 1. A 2-A solar-panel power manager with a 7.2-V $LiFePO_4$ battery and 17-V peak-power tracking. If the panel voltage drops to zero, the battery supplies power to the load. The 10-µF input capacitor absorbs input switching ripple current, so it must have an adequate ripple current rating.

Depending on panel characteristics, the LT3652 can produce peak power in excess of 95%, with panel output voltages from 12.5 V to 18.5 V. Its input-voltage-regulation loop controls the solar-panel output voltage to produce peak output power while charging the associated battery, delivering nearly the same efficiency as more complex and expensive Maximum Peak Power Tracking (MPPT) techniques.

Fig. 1 shows a typical solar panel-charger application circuit with a 7.2-V $LiFePO_4$ battery pack. Connecting a resistor divider from V_{IN} (pin 1) to V_{IN_REG} (pin 2) programs the minimum operational input voltage, which in turn programs the peak power voltage for the solar panel. The LT3652 controls the maximum charge current required to maintain the programmed operational V_{IN} voltage by maintaining the voltage on V_{IN_REG} at or above 2.7 V. If V_{IN_REG} goes below 2.7 V it reduces the maximum charge current and maintains the panel at the output voltage corresponding to its peak output power point. *Fig. 2* plots the LT3652's maximum charger-output current vs. input voltage from a solar panel.

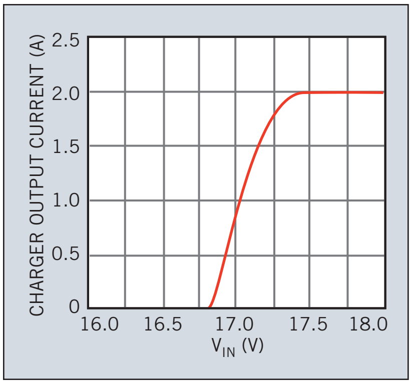

Fig. 2. Input voltage regulation described by the maximum charger output current vs. the input voltage, V_{IN}.

The LT3652 accepts inputs from 4.95 V to 32 V, with a 40-V maximum rating. Its input-voltage-regulation loop also allows optimized charging from poorly regulated sourc-

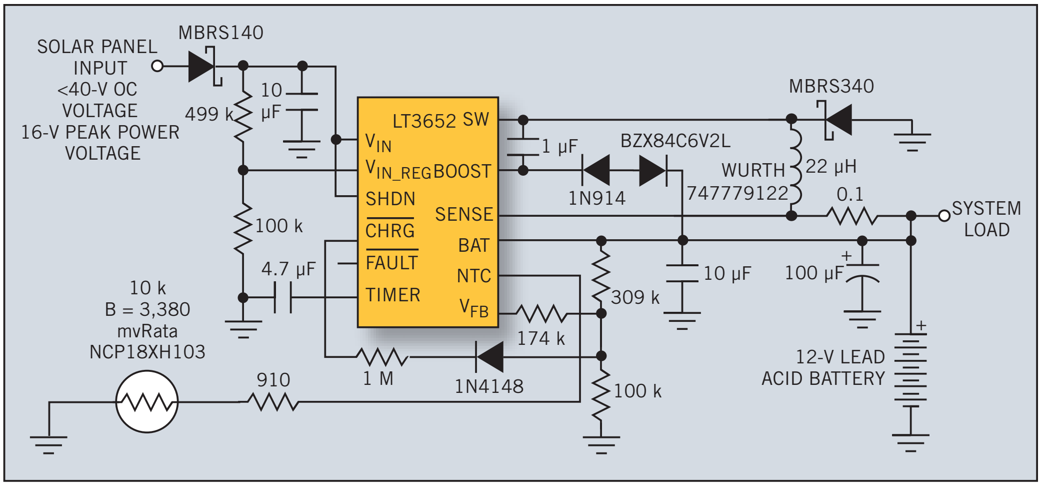

Fig. 3. 1-A solar panel powered three-stage 12-V lead-acid fast/float charger.

es where the input can collapse in overcurrent conditions. An integrated 2-A switch driven by a bootstrapped supply maximizes efficiency during charging.

The LT3652 can be configured to charge at average currents to 2 A. The user sets the max charge current by choosing an inductor sense resistor, so that the max average current through the sense resistor creates a 100-mV drop. The sense resistor in *Fig. 1* is 0.05 Ω. Besides having the appropriate inductance, the selected inductor must have a saturation current equal to or exceeding maximum peak current.

CHARGING THE BATTERY

The charge and discharge capacity of a battery is in terms of "C," given as ampere-hours (Ah). The actual battery capacity depends on the C-rate and temperature. Most batteries are rated at 1 C. A discharge of 1 C draws a current equal to the rated capacity. For example, a battery rated at 1,000 mAh provides 1,000 mA for one hour if discharged at a 1-C rate.

The LT3652 charger IC uses a charge-current-based C/10 termination scheme to end a charge cycle when the battery charge current falls to one-tenth of its programmed maximum charge current. It also contains an internal charge-cycle control timer for timer-based termination. When using the internal timer, the IC combines C/10 detection with a programmable time constraint, during which the charging cycle can continue beyond the C/10 level to top-off a battery.

A capacitor connected from Timer pin 6 to ground sets the end-of-charge (EOC) time. A 0.68-µF capacitor generates a three-hour timer EOC and a precondition limit time of 22.5 min. When using the timer-based scheme, the IC also supports bad battery detection, which triggers a system fault if a battery stays in precondition mode for more than one-eighth of the total charge-cycle time.

If a timer-based termination is not desired, you can disable the timer function by connecting the TIMER pin to ground (*Fig. 1*). With the timer function disabled, charging terminates when the charge current drops below a C/10 threshold.

After terminating the charge, the LT3652 automatically enters a low-current standby mode where supply bias currents drop to 85µA. The IC continues to monitor the battery voltage while in standby, and if that voltage falls 2.5% from the full-charge float voltage, the LT3652 engages an automatic charge-cycle restart. The IC also automatically restarts a new charge cycle after a bad battery fault once the failed battery is removed and replaced with another battery.

The IC contains provisions for a battery-temperature monitoring circuit using a thermistor during the charging cycle. If the battery temperature moves outside the safe charging range (0° to 40°C), the IC suspends charging and signals a fault condition until the temperature returns to the safe range.

A shutdown mode can disable all charging functions. This precision threshold allows the use of the SHDN pin 3 to incorporate UVLO (undervoltage lockout) functions. Pulling the SHDN pin below 0.4 V causes the IC to enter a low-current shutdown mode where V_{IN} current reduces to 15 µA. Typical SHDN input bias current is 10 nA. When not charging, the IC draws less than 1 µA from the battery.

The open-collector CHRG pin 4 and the FAULT pin 5 usually use a resistor pulled up to a reference voltage. These status pins can be pulled up to voltages as high as V_{IN} when disabled, and can sink currents up to 10 mA when enabled.

During a battery charging cycle, if the required charge current is greater than 1/10 of the programmed max current (C/10), CHRG pin 4 is pulled low. A temperature fault also causes this pin to be pulled low. After C/10 charge termination, or if the internal timer is used for termination and charge current is less than C/10, the pin stays at high-impedance.

FAULT pin 5 indicates fault conditions during a battery charging cycle. A temperature fault causes this pin to be pulled low. If the internal timer is used for termination, a bad battery fault also causes this pin to be pulled low. If no fault conditions exist, this pin remains high-impedance.

SEALED LEAD-ACID BATTERY APPLICATION

Fig. 3 shows a sealed lead-acid battery using the LT3652. This 1-A circuit fast-charges with CC/CV characteristics up to 14.4 V. If the charge current falls to 0.1 A, the charger switches to 13.5-V float-charge mode.

The charger re-initiates the 14.4-V fast-charge mode if the battery voltage falls below 13.2 V and trickle charges at 0.15 A if the battery voltage is below 10 V. A resistor divider between BAT pin 9 and V_{FB} pin 7 programs the output battery float voltage.