Application Report
SLVA437A–September 2010–Revised October 2011

Using the bq24650 to Charge a Sealed, Lead-Acid Battery

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ABSTRACT

This application report shows how to modify the bq24650 to charge a sealed, lead-acid battery from a solar panel. The circuit uses constant current (CC) charging to reach the bulk battery voltage and then switches to constant voltage (CV) charging until the termination current is reached. The modifications necessary to change the regulated voltage, recharge voltage and regulated current are discussed. The datasheet explains how to configure the MPPSET components, the switching converter active and passive components and other components for the specific application.

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1 Pulse Current Charging

With some simple modifications, the bq24650 charger, designed specifically for charging Li-ion batteries, can charge lead-acid batteries.

Figure 1 shows the pulse current charging algorithm that is used to charge the sealed lead-acid battery.

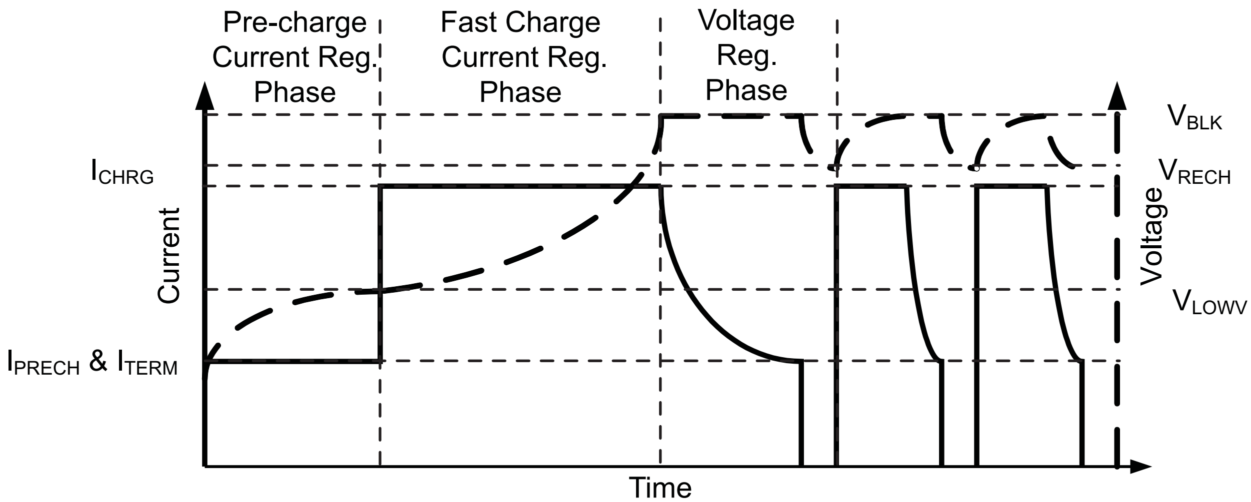

Figure 1. Algorithm for Pulse Current Charging

V_{BLK} is the bulk battery voltage and is the maximum voltage at which the charger regulates. The remaining terms are explained in the bq24650 data sheet (SLVSA75).

Figure 2 shows the schematic used to implement the algorithm in Figure 1. Five additional components are needed in addition to the typical evaluation module (EVM) circuit. These components, along with the components whose values changed from the EVM circuit, are shown in bold in Figure 2.

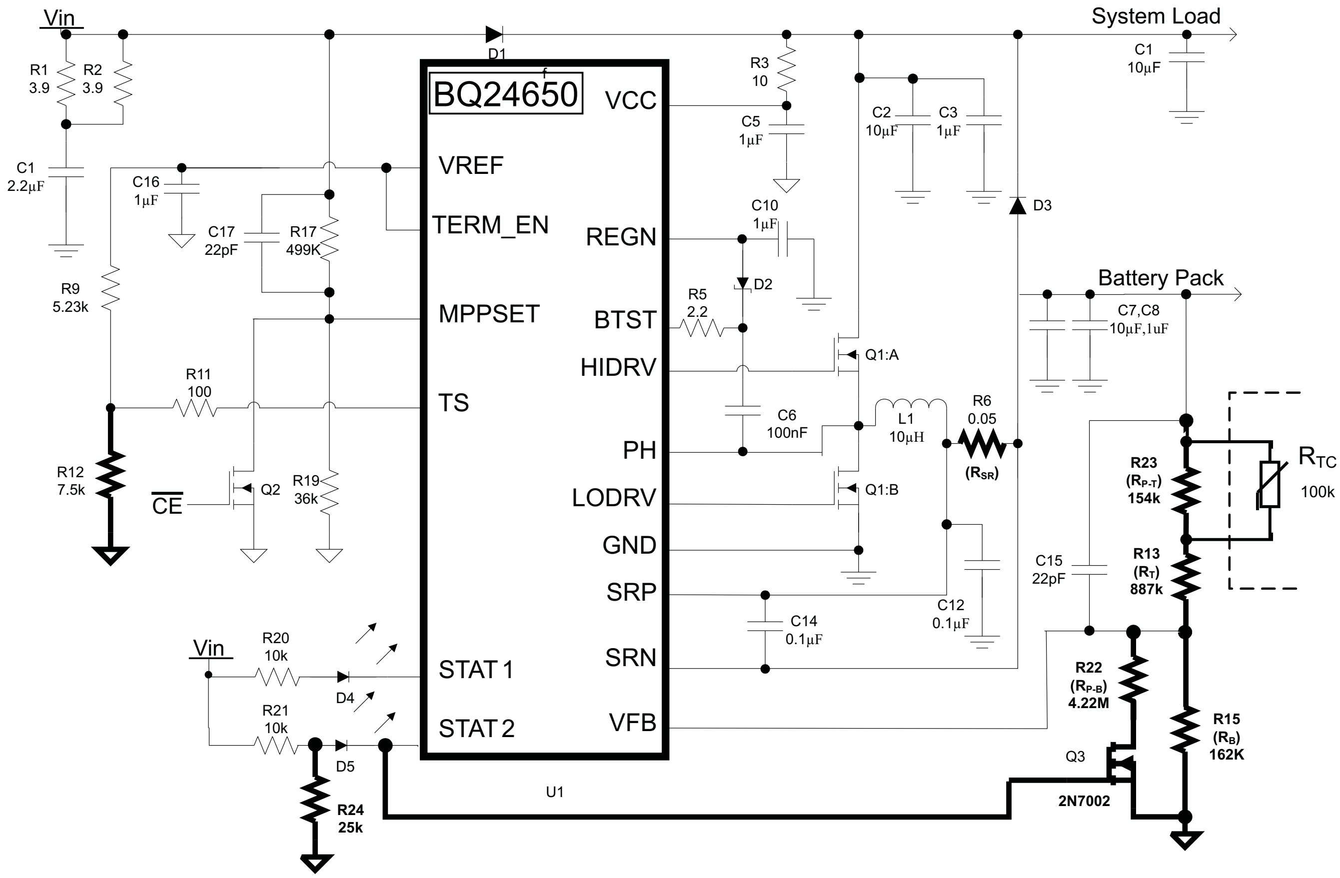

Figure 2. Schematic for Pulse Charging

The charger begins in CC mode and then switches to CV mode. The circuit uses the STAT2 pin, which is pulled high while the battery is charging, to turn on Q3 and increase the charger's CV regulation point to the battery's bulk voltage until the charger senses that the current has tapered off. Normally STAT2 is pulled up to V_{IN}, but to protect the gate of FET Q3, resistor R23 divides down the voltage at STAT2. Once the charging current falls below the termination current threshold, STAT2 goes to low impedance. This causes Q3 to turn off, thus lowering the recharge threshold voltage, V_{RECH}, to the battery's float voltage. When V_{BAT} drops to V_{RECH}, the charger returns to CC charging and sends a pulse of current to recharge the battery to the bulk voltage and the cycle repeats. Equation 1 gives the V_{BULK} regulation voltage:

$$V_{BULK} = V_{REF} \times \left(1 + \frac{R_T + R_{P-T} \| R_{TC}}{R_B \| R_{P-B}}\right) \tag{1}$$

Equation 2 gives the V_{RECH} threshold voltage.

$$\left(V_{REF} - 50mV\right) = V_{RECH} \times \left(\frac{R_B}{R_B + R_T + R_{TC} \| R_{P-T}}\right) \tag{2}$$

Because lead-acid batteries do not typically have built-in thermistors, the charger's over/under temperature regulation features are not used. By changing EVM resistor R12 to 7.5 kΩ, the TS input senses a fixed voltage that is within the normal operating range and does not change any of the regulation parameters with temperature.

2 Circuit to Implement Temperature Compensation

The life span of a lead-acid battery is longer if the charging voltage is adjusted with temperature. For applications where the temperature changes only slightly around 25°C, using a linear negative temperature charging coefficient of approximately –2.5 mV/C per cell is adequate. However, the recommended charging profile over a wider temperature range is not linear. Although not required, for applications where the battery is exposed to a range of ambient temperatures, the regulated bulk and recharge voltages must be adjusted with temperature to maximize battery life. The pink curve in Figure 3 shows the recommended bulk voltage charging profile over temperature, using a 6-cell, lead-acid battery with a bulk voltage of 2.6 V/cell at 25°C. The blue curve is the V_{BULK} regulation value, including the thermistor's resistance variation with temperature, as designed in the following example.

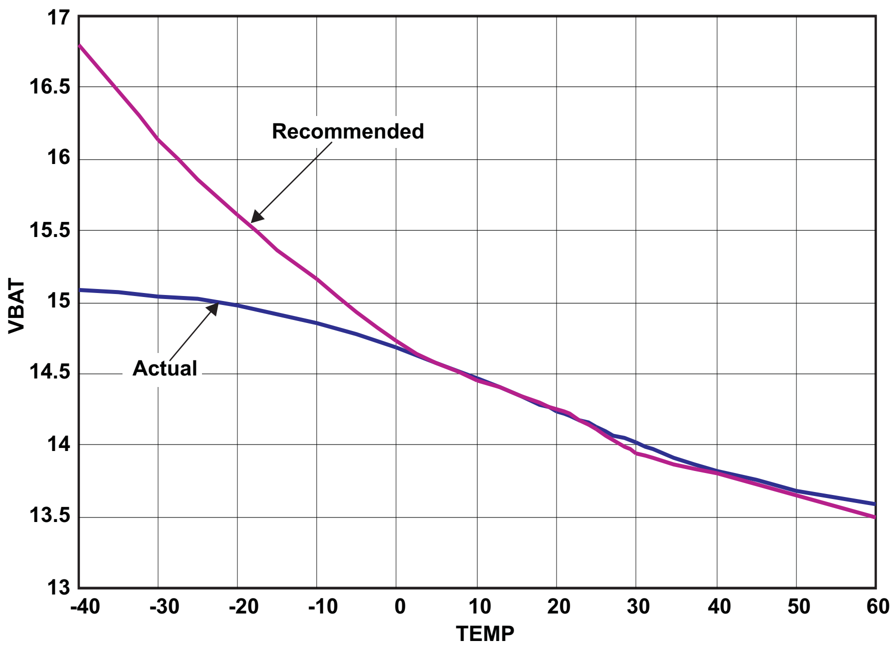

Figure 3. Battery Voltage vs Temperature for a 6-cell, Sealed, Lead-Acid Battery

From Figure 2 and Equation 1, the additional, series feedback resistor ($R_{P\text{-}T}$) in parallel with thermistor R_{TC}, placed close to the battery, alters the charger's bulk regulation and recharge (i.e., float) threshold voltages as the temperature changes. Sizing the resistors to achieve the appropriate negative temperature coefficient and regulation point is a trial and error process. One method for finding the best-fit resistor values is as follows:

1. From the selected thermistor's data sheet, select at least three temperature (e.g., maximum, nominal, and minimum) and corresponding resistance values to compute/plot in a spreadsheet.
2. Initially choose ($R_B||R_{P\text{-}B}$) and $R_{P\text{-}T}$ equal to 1-2 times the thermistor's 25°C value, weighting closer to 2 times as the temperature range goes below zero. Use Equation 3 to estimate R_T to give the appropriate bulk battery voltage at nominal temperature.

$$R_T = \left(\frac{V_{BULK@T(NOM)}}{V_{REF}} - 1\right) \times R_B||R_{P\text{-}B} - \frac{R_{P-T} \times R_{TC@T(NOM)}}{R_{P-T} + R_{TC@T(NOM)}} \tag{3}$$

3. Adjust $R_{P\text{-}T}$ up or down to change the slope of the regulated voltage curve. Increasing $R_{P\text{-}T}$ significantly increases the regulated voltage at low temperatures.
4. Adjust R_T up or down to shift the entire curve up or down.

Note that the resistors can only be configured to provide regulation and recharge voltages that match the desired values over a limited temperature range.

3 Design Example

The following design example illustrates how to modify the bq24650EVM so that it can recharge a lead-acid battery. For the 6-cell, 2.4-Ahr sealed lead-acid battery used in this example, the bulk (maximum) battery voltage at 25°C is 14.85 V, and the float voltage, used as the recharge voltage, is 14.1 V. The ambient temperature range is 0°C to 55°C.

Step 1. Compute the sense resistor, R_{SR}, to provide the maximum charge current (I_{CHARGE}), which also sets the precharge and termination current to one-tenth of the maximum charge current. It is generally recommended to charge lead-acid cells between 0.1-0.3 times the batteries maximum current rating during CC charging. For this example, I_{CHARGE} = 2.4 A x 0.3 = 0.72 A rounded up to 0.8 A

$$R_{SR} = \frac{40\text{ mV}}{I_{CHARGE}} = \frac{40\text{ mV}}{800\text{ mA}} = 0.05\ \Omega \tag{4}$$

The inductor, L1 and FETS Q1A and Q1B must be sized per the data sheet to accommodate this current.

Step 2. Select temperature compensation resistors. With a 100-kΩ thermistor having $R_{TC\text{ at }25C}$ = 100 kΩ, selecting $R_B||R_{P\text{-}B}$ = 156 kΩ and $R_{P\text{-}T}$ = 154 kΩ and use Equation 1 to estimate the top feedback resistor, R_T.

$$R_T = \left(\frac{V_{BULK@T(NOM)}}{V_{REF}} - 1\right) \times (R_B||R_{P-B}) - \frac{R_{P-T} \times R_{TC@T(NOM)}}{R_{P-T} + R_{TC@T(NOM)}} = \left(\frac{14.85V}{2.1V} - 1\right) \times 156k\Omega - \frac{154k\Omega \times 100k\Omega}{154k\Omega + 100k\Omega} = 947k\Omega \tag{5}$$

Lowering R_T to 887-kΩ standard value gives the best fit as shown by the gold curve in Figure 3.

Step 3. Compute the value for R_B, the bottom feedback resistor that sets V_{RECH}, the recharge voltage threshold. In this example, V_{RECH} at 25°C is 14.1 V.

$$R_B = \frac{R_{P-T} \| R_{TC} + R_T}{\frac{V_{RECH}}{V_{REF} - 50mV} - 1} = \frac{100k\Omega || 154k\Omega + 887k\Omega}{\frac{14.1V}{2.05V} - 1} = 161k\Omega \rightarrow 162k\Omega \text{ standard value} \tag{6}$$

Note that the temperature compensation circuit shifts V_{RECH} in the same manner that it shifts V_{BULK}.

Step 4. Compute the value for $R_{P\text{-}B}$, the switched-in resistor that sets $R_B||R_{P\text{-}B}$ = 156 kΩ.

$$R_B = R_{P-B} = \frac{(R_B||R_{P-B}) \times R_B}{R_B - R_B||R_{P-B}} = \frac{156k\Omega \times 162k\Omega}{162k\Omega - 156k\Omega} = 4.21M\Omega \rightarrow 4.22M\Omega \text{ standard value} \tag{7}$$

Step 5. NMOS FET Q3 in series with the resistor $R_{P\text{-}B}$ can be any low-cost FET. However, few FETs have wider than a ±20-V maximum V_{GS} rating. The 2N7002, with ±20-V maximum V_{GS} rating, was selected. Therefore, a resistor divider, formed by STAT2's pullup resistor, R21, and an additional resistor, R23, to ground is needed to protect the FET from overvoltage if V_{IN} exceeds 20 V. Resistor R23 must be large enough to protect the FET but not too large that it lowers the FET's gate voltage below at least 2 V above its 2.5-V maximum threshold voltage. Equation 8 computes R23 assuming the maximum input voltage is 22 V.

$$R23 > \frac{V_{GS(MAX)} - R21}{V_{IN(MAX)} - V_{GS(MAX)}} = \frac{20\text{ V} \times 10k\Omega}{22\text{ V} - 20\text{ V}} = 10\text{ k}\Omega \tag{8}$$

R23 was selected to be 25 kΩ.

4 Test Results

Table 1 shows measured results from using a source meter to simulate the battery compared to minimum and maximum expected results, including resistor and voltage tolerances. Figure 4 shows a scope shot of the circuit as the battery charger moves from precharge mode to CC mode to CV mode and then toward termination.

Table 1. Measured Results using a Source Meter to Simulate a Lead-Acid Battery

	0°C			25°C			55°C		
	Computed Minimum (V)	Measured (V)	Computed Maximum (V)	Computed Minimum (V)	Measured (V)	Computed Maximum (V)	Computed Minimum (V)	Measured (V)	Computed Maximum (V)
V_{LOWV}	11.2	*11.4*	11.8	10.7	*10.9*	11.2	10.3	*10.6*	10.8
V_{BULK}	15.2	*15.5*	15.9	14.5	*14.8*	15.2	14.0	*14.4*	14.6
V_{RECH}	14.7	*14.6*	15.1	14.1	*14.1*	14.5	13.5	*13.5*	13.9

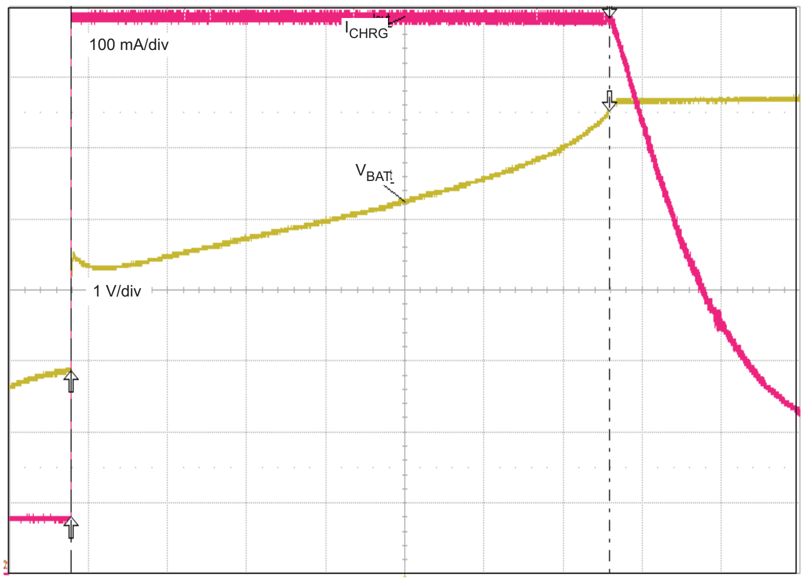

Figure 4. Measured Results With Circuit Charging a 6-Cell, 2.4-Ahr Battery

5 Circuit to Disable Precharge

For an explanation of a circuit to disable Precharge, see the application report *Reducing Precharge Phase Region for bq24650* (SLVA473).

6 Conclusion

The bq24650 battery charger can be modified to charge a lead-acid battery simply by changing the charger's regulation and recharge voltage set points. The circuit modifications also cause the charger's set points to vary with temperature by placing a thermistor and parallel resistor in series with the top, external feedback resistor. In addition, the modifications cause the charger to "exercise" the battery with pulsing currents during the constant voltage phase of the charge profile. For most lead acid batteries, this charging profile prolongs battery life. However, the user should follow their battery manufacturer's recommended charging profile in order to maximize battery life.

7 References

1. *bq24650, Synchronous Switch-Mode Battery Charge Controller for Solar Power With Maximum Power Point Tracking* data sheet (SLUSA75)

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