Application Report
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Using the bq2954 to Charge the LiFePO$_4$ Battery

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ABSTRACT

This application report describes how to use the bq2954 charge controller device to provide a high-efficiency switching-mode charging solution for multi-cell LiFePO$_4$ battery.

1 Introduction

The bq2954 was designed to charge Li-ion and Li-polymer battery packs. Its regulation voltage set point can be easily adjusted by two external resistors, which give an opportunity to support new developed LiFePO$_4$ battery. This application report shows how to use the bq2954 to provide a high-efficiency switching-mode charging solution for the multi-cell LiFePO$_4$ battery.

The LiFePO$_4$ battery has many unique features such as very high thermal runaway temperature, very high discharge current capability and high charge current. These special features make it very attractive in many applications such as power tools. Figure 1 shows a typical open circuit voltage (OCV) curve versus depth of discharge (DOD) of ANR26650M1 LiFePO$_4$ from A123Systems. Figure 2 shows the typical discharge characteristics at 25°C[1] and it is able to support very high discharge rate. The recommended charge voltage is 3.6 V and termination current is 50 mA.

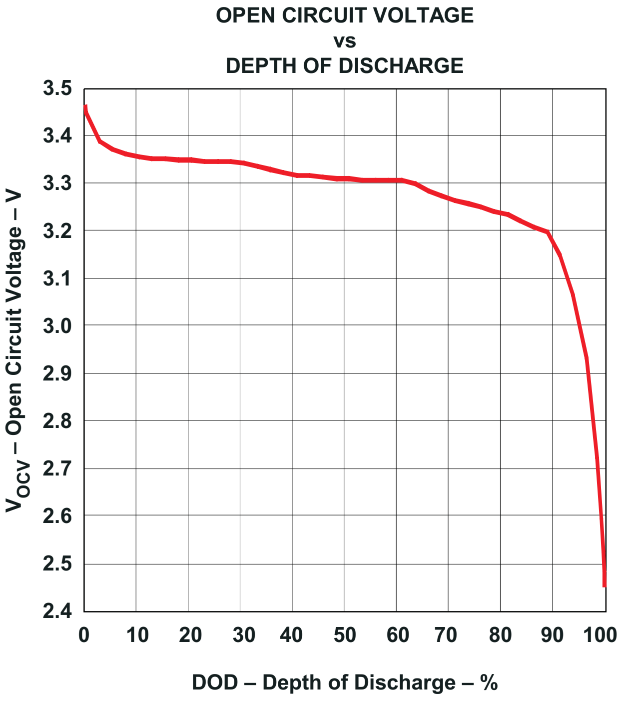

Figure 1.

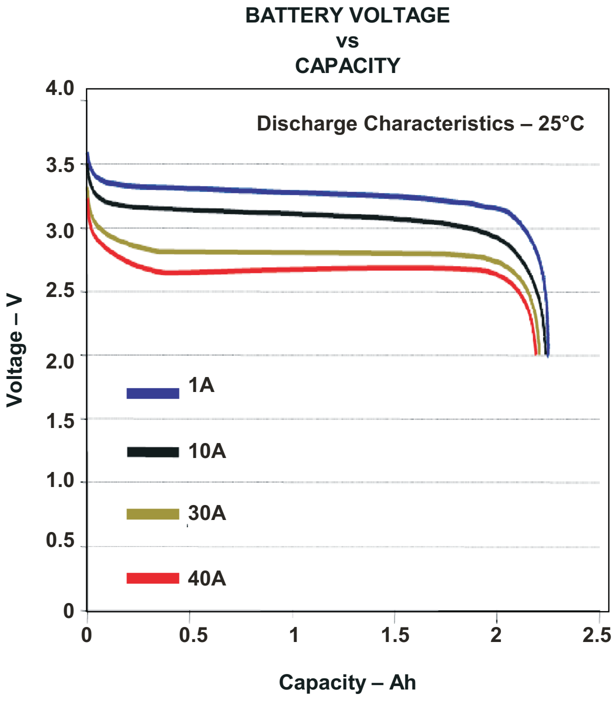

Figure 2.

This bq2954 prototype for a 6-cell application was developed to evaluate the performance for charging the $LiFePO_4$ battery and demonstrating its multi-cell application capability. The maximum charge voltage for each cell is 3.6 V, therefore 6-cells yield 21.6 V of maximum output voltage. Given the maximum 80% duty cycle limit of bq2954 and estimating 90% power conversion efficiency, the input voltage should be 30 V. To fast charge the $LiFePO_4$ battery, the prototype was designed to provide 5 A (for a 30-minute charge) charge current. The power stage design is straightforward. Figure 3 shows the schematic.

The output inductor (L1) is a key component. It's value is determined by the specified charge current ripple. 20% of ripple current is typically selected in a practical design. To reduce the size of the output inductor, a 200-kHz frequency (the maximum frequency of bq2954) is selected . Below is the design procedure.

2 Step-By-Step Design Procedure

2.1 System Design Specification

- V_{IN}= 30 V
- V_{BAT}= 21.6 V (6-cell, 3.6-V per cell)
- I_{CHARGE}= 5 A
- Inductor ripple current ΔI_L= 20% of fast charge current
- Frequency f = 200 kHz

2.2 Inductor Design

The inductance is given by Equation 1.

$$L_1 = \frac{V_{BAT} \times (V_{IN} - V_{BAT})}{V_{IN} \times f \times \Delta I_L} \tag{1}$$

The highest inductor ripple current occurs when the battery voltage equals half of the input voltage. Here V_{BAT}=15 V (6-Cell, 2.5-V per cell) generates highest inductor ripple current.

$$L_1 = \frac{15 \times (30 - 15)}{30 \times (200 \times 10^3) \times 5 \times 0.2} \tag{2}$$

L1 = 37.5 µH.

Select 33-µH standard value for output inductor.

Calculate the total ripple current with the 33-µH inductor.

$$\Delta I_L = \frac{V_{BAT} \times (V_{IN} - V_{BAT})}{V_{IN} \times f \times L_1} \tag{3}$$

$$\Delta I_L = \frac{15 \times (30 - 15)}{30 \times (200 \times 10^3) \times (33 \times 10^{-6})} \tag{4}$$

ΔI_L = 1.14 A

Calculate the maximum output current.

$$I_{LPK} = I_{OUT} + \frac{\Delta I_L}{2} \tag{5}$$

$$I_{LPK} = 5 + \frac{1.14}{2} \tag{6}$$

I_{LPK} = 5.57 A

A 33-µH, 7-A inductor SER2817H-333KL from Coilcraft is selected.

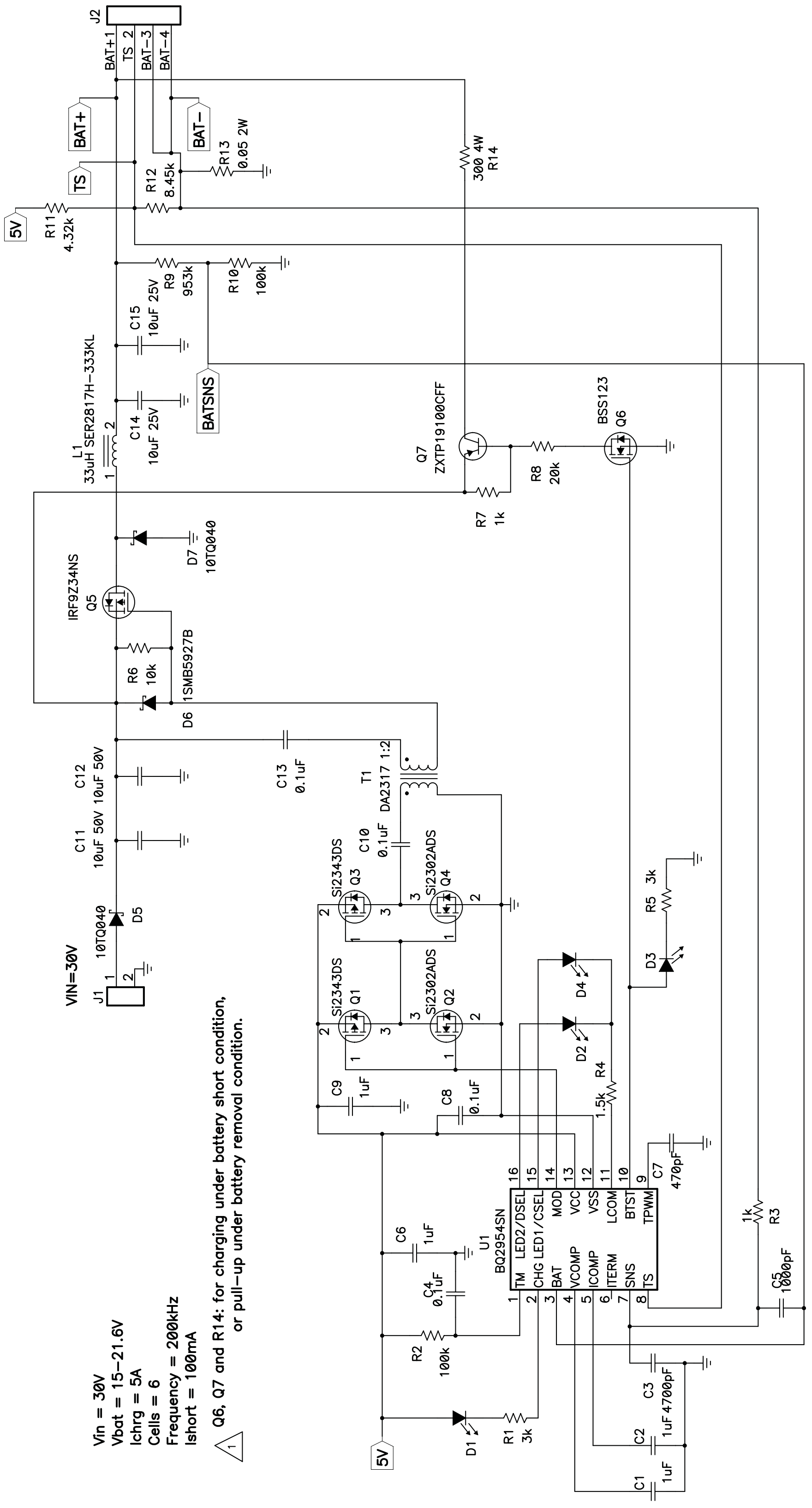

Figure 3. bq2954 Schematic For a 6-Cell, 5-A $LiFePO_4$ Battery Application

2.3 Input and Output Capacitor Design

The input capacitor voltage ripple should be small enough to maintain a DC voltage at the input stage. Assume the input current is DC and ignore output current ripple and power loss. Equation 7 calculates the input voltage ripple.

$$\Delta V_{IN} = \frac{I_{CHG} \times (V_{IN} - V_{BAT}) \times V_{BAT}}{V_{IN}^2 \times f \times C_{IN}} \tag{7}$$

The highest input ripple voltage occurs when the battery voltage equals half of the input voltage. Here V_{BAT}=15 V (6-cell, 2.5-V per cell) generates highest input ripple voltage. Select two 10-µF ceramic capacitors in parallel as the input capacitor.

$$\Delta V_{IN} = \frac{5 \times (30 - 15) \times 15}{30^2 \times (200 \times 10^3) \times (20 \times 10^{-6})} \tag{8}$$

ΔV_{IN} = 0.3125 V, which is approximately 1% of input voltage.

Also select two 10-µF ceramic capacitors in parallel as output capacitor. The output voltage ripple is given by Equation 9.

$$\Delta V_{OUT} = \frac{\Delta I_L}{8 \times f \times C_{OUT}} \tag{9}$$

$$\Delta V_{OUT} = \frac{1.14}{8 \times (200 \times 10^3) \times (20 \times 10^{-6})} \tag{10}$$

ΔV_{OUT}= 35.625 mV, which is very small compared to output voltage.

2.4 Voltage Divider Design

R9 and R10 voltage divider determine the final voltage regulation point. According to the datasheet Equation 11 is used for calculation.

$$\frac{R_9}{R_{10}} = \frac{N \times V_{CELL}}{V_{REG}} - 1 \tag{11}$$

where

- Number of cells in series N = 6
- Charging cell voltage V_{CELL}= 3.6 V
- Internal reference V_{REG} = 2.05 V

$$\frac{R_9}{R_{10}} = \frac{6 \times 3.6}{2.05} - 1 = 9.5366 \tag{12}$$

select

- R10 = 100 kΩ
- R9=953.66 kΩ
- R9=953 kΩ standard value

2.5 Current Sense Resistor

R13 is the current sensing resistor. A 5-A charge current should generate a 250-mV voltage drop according to datasheet. Therefore, a 50-mΩ, 2-W current sensing resistor is selected.

2.6 Control Circuit Design

The control circuit is similar to the datasheet typical application circuit in the evaluation module (EVM) schematic. bq2954 was configured as Mode 3 so that BTST pin can be used to drive Q6 and Q7 for pre-charge battery. The maximum pre-charge current is limited to 100 mA by R14. The ITERM pin is left floating so that the termination current is 250 mA with a 5-A fast charge current.

This controller requires a 5-V bias power supply which can be easily generatred by a wide-input-range, step-down SWIFT™ converter such as the TPS5410.

2.7 Gate Drive Circuit and Power Stage Design

Q1 to Q4 are two inverter buffers that provide correct logic and drive an isolation transformer. These four MOSFETs can be replaced by one single-channel high-speed MOSFET driver such as the TPS2829. A DA2317 1:2 turns ratio gate drive transformer from Coilcraft is used. D6 is used to clamp the gate voltage to a safe level for the 55-V top-switch P-channel MOSFET Q5. A 40-V Schottky diode (D7) is selected as the bottom switch of the buck converter. The D5 diode prevents battery leakage current when the input voltage is removed and provides short circuit protection when the voltage input is shorted to ground.

2.8 Test Results

The P-channel MOSFET gate, drain and inductor current waveforms are shown in Figure 4. Figure 5 shows the measured power stage efficiency with battery voltage. The efficiency is between 92.5% and 93.5% when the battery voltage changes from 15 V to 21.6 V with a 5.28-A fast charge current. This represents a power stage loss between 6.4 W and 7.7 W. The test shows that this design is practical. It is easy to configure this circuit for charging any number of cells with different chemistries by selecting the external resistor divider R9 and R10.

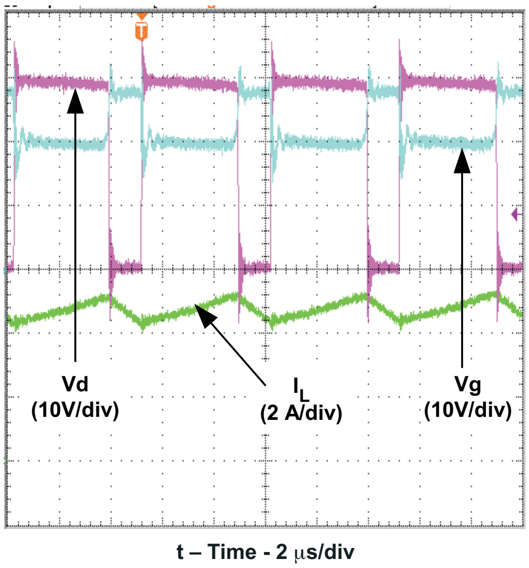

Figure 4.

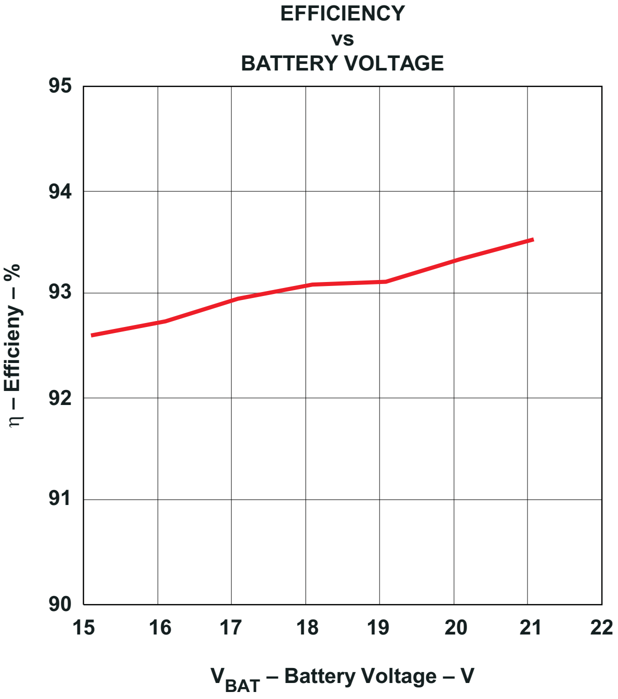

Figure 5.

2.9 References

1. ANR26650M1 LiFePO4 battery cell datasheet. (http://a123systems.textdriven.com/product/pdf/1/ANR26650M1_Datasheet_NOV_2007.pdf)
2. bq2954 datasheet (http://focus.ti.com/lit/ds/symlink/bq2954.pdf)

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