*Application Note*

# *Charging $LiFePO_4$ Battery And Supercapacitor Using BQ25756*

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**ABSTRACT**

This application note provides how to configure BQ25756 buck-boost charge controller for charging $LiFePO_4$ batteries and supercapacitors.

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## Trademarks

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# 1 Introduction

Lithium Iron Phosphate ($LiFePO_4$) batteries offer good thermal stability and low risk of thermal runaway. $LiFePO_4$ batteries also offer longer cycle life and high discharge current. Charging $LiFePO_4$ batteries is similar process as Li-Ion batteries. However, there are few important voltage thresholds to be considered. Apart from the batteries, supercapacitors are a popular choice for backup power. Picking the correct charging device can maximize the charge life of both $LiFePO_4$ batteries and supercapacitors. The BQ25756 buck-boost charge controller can be programmed to support both $LiFePO_4$ batteries and supercapacitors.

# 2 $LiFePO_4$ Charging Profile

$LiFePO_4$ battery has some unique features compared to a Li-ion battery such as high thermal runaway temperatures, very high discharge current capability and high charge current. $LiFePO_4$ batteries follow a similar charging profile to the Li-ion batteries. The device charges the battery in four phases.

**Phase 1** – Trickle charge: When the battery heavily depleted, the battery voltage is very low and below the threshold $V_{BAT\_SHORT}$. The device employs low charge current called trickled charge to bring the battery voltage up above $V_{BAT\_SHORT}$.

**Phase 2** – Pre-charge: When the battery voltage is above $V_{BAT\_SHORT}$ but below $V_{BATLOWV}$, the device charges the battery with pre-charge current in to bring the battery voltage above $V_{BATLOWV}$. The pre-charge current is usually 20% of the fast charge current. For $LiFePO_4$ battery, $V_{BATLOWV}$ is 55% of the fully charged voltage. For example, a one cell battery has charge voltage of 3.6 V and $V_{BATLOWV}$ = 1.98 V.

**Phase 3** – Constant current: When the battery voltage is above $V_{BATLOWV}$, the device charges the battery with a full fast charge current. This phase continues until the battery voltage reaches the charge regulation voltage. A one cell $LiFePO_4$ battery typically has a regulation voltage 3.5 V to 3.65 V.

**Phase 4** – Constant voltage: When the battery voltage reaches the regulation voltage, the charge current is tapered down and the battery voltage is held constant at the regulation voltage. When the battery voltage is above a recharge threshold and the current is below termination current, the device terminates charging. The recharge threshold $V_{RECHG}$ = 93% of the battery regulation voltage and termination current is typically 10% of the fast charge current.

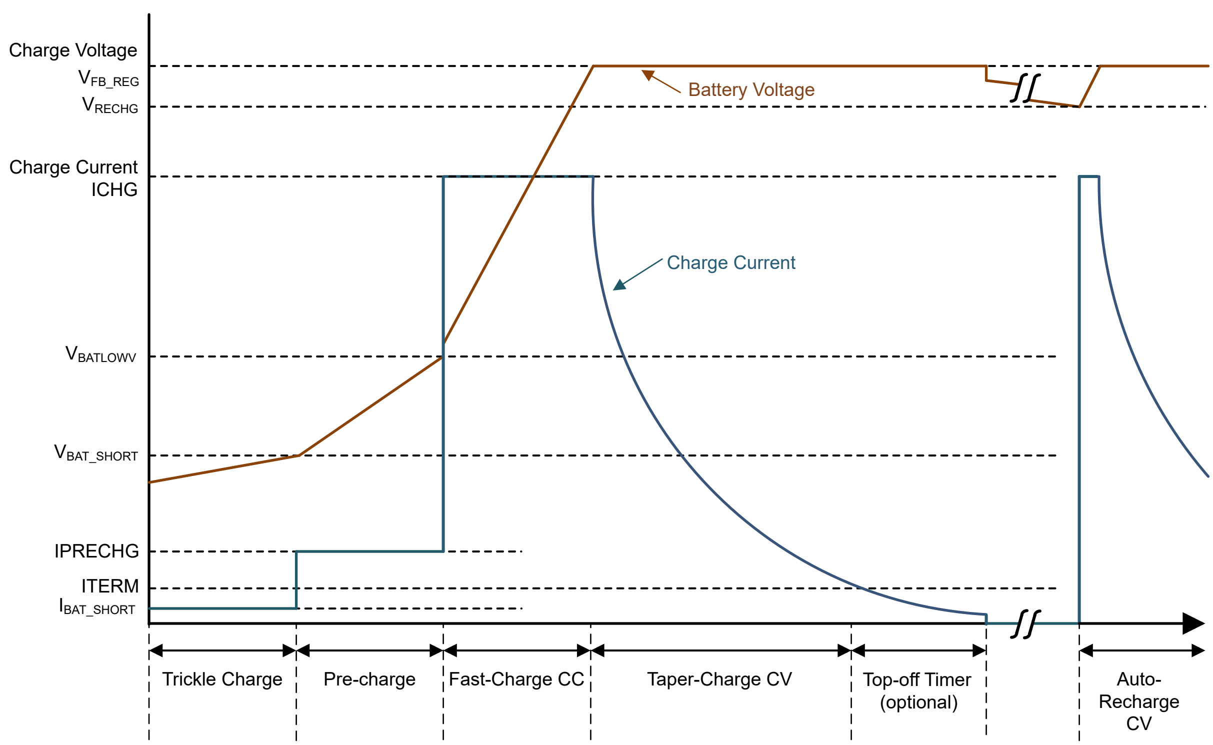


**Figure 2-1. Typical $LiFePO_4$ Charging Profile**

# 3 BQ25756 Settings For $LiFePO_4$

## 3.1 Set Charging Voltages

### 3.1.1 Regulation Voltage

Battery regulation voltage is programmed using a resistor divider to the FB pin. The default internal voltage reference is $V_{FB}$=1.536 V, and can be changed using the VFB_REG register bits. The top of the resistor divider is selected to be 249 kΩ. The bottom resistor is calculated as

$$R_{BOT} = R_{TOP} \times \frac{V_{FB}}{V_{BATREG} - V_{FB}} + R_{FBG} \tag{1}$$

where $V_{FB}$=1.536 V, $R_{TOP}$=249 kΩ and $R_{FBG}$=33 Ω which is the internal FBG pull down resistor. For a 4 S battery, the desired battery regulation voltage $V_{BATREG}$=4×3.6 V=14.4 V. With these values the bottom resistor is calculated to be $R_{BOT}$ = 29.76 kΩ.

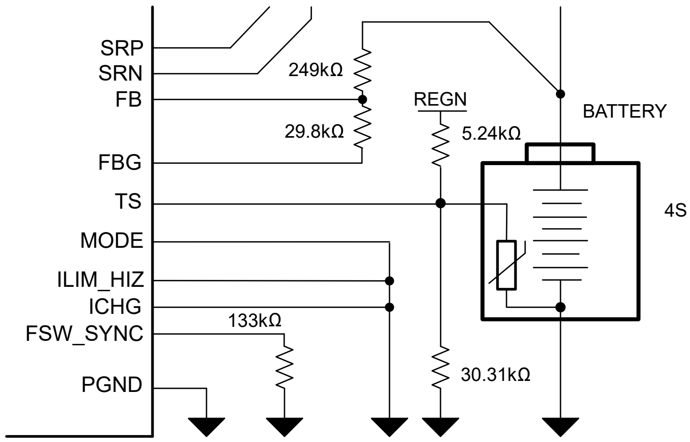


**Figure 3-1. Regulation Voltage Setting Using a Resistive Divider to pin FB**

If we choose the nearest 0.1% resistor, for example, $R_{BOT}$ = 30.1 kΩ, then effective $V_{BATREG}$ is 14.25 V. We can fine tune $V_{BATREG}$ by adjusting the internal reference $V_{FB}$ via VFB_REG in register REG0x00. In this case, the value can be set to 1.552 V which makes battery regulation voltage $V_{BATREG}$ very close to 14.4 V.

### 3.1.2 Recharge Voltage

This can be set using VRECHG field in register REG0x17. For $LiFePO_4$ battery, recommended VRECHG = 0x0 which sets the battery low voltage to be 93%×VFB_REG. As an example, for a 4 S battery, regulation voltage is 14.4 V and VRECHG = 13.4 V.

### 3.1.3 Battery Low Voltage

This can be set using VBAT_LOWV field in register REG0x14. For $LiFePO_4$ battery, recommended VBAT_LOWV = 0x1 which sets the battery low voltage to be 55%×VFB_REG. As an example, for a 4 S battery, regulation voltage is 14.4 V and VBAT_LOWV = 7.92 V.

## 3.2 Set Charging Current

$LiFePO_4$ batteries can charge using the same fast charge current settings as the Li-ion batteries. No specific settings for LiFePO4 are required. The user can control the fast charge, pre-charge and termination current limit.

### 3.2.1 Charging Current

There are two ways to set the charging current limit. One way is to use the hardware control with ICHG pin pull down resistor. The other way is to use ICHG_REG register bits. If both are enabled, the lowest limit of these two applies.

#### 3.2.1.1 ICHG Pin Pull Down Resistor

To control maximum charge current using ICHG pin only, the ICHG_REG register bits are set to the maximum value. By default, ICHG_REG is set to maximum value allowing ICHG pin to set the charge current. A pull-down resistor $R_{ICHG}$ is connected to ICHG and PGND which is calculated using the following relationship.

$$R_{ICHG} = \frac{K_{ICHG}}{I_{ICHG\_MAX}} \quad (2)$$

Where $K_{ICHG}$=50 A-kΩ. The requirement is required to use a 5 mΩ $R_{BAT\_SNS}$ sense resistor.

#### 3.2.1.2 ICHG_REG Register Bits

To control maximum charge current using register only, ICHG pin is shorted to PGND and disable the ICHG pin function by setting the EN_ICHG_PIN=0 in REG0x18. Then charge current limit can be set in register REG0x02. The charge current limit range is from 400 mA to 20 A with 50 mA/step.

### 3.2.2 Pre-Charge Current

By default, the pre-charge current is set to 20%×ICHG when ICHG pin sets the charge current limit. If REG0x10 is used to set a pre-charge current then, the lower of 20%×ICHG or the register value is used.

### 3.2.3 Termination Current

By default, the termination current is set to 10%×ICHG when ICHG pin sets the charge current limit. If REG0x12 is used to set a pre-charge current then, the lower of 10%×ICHG or the register value is used.

## 3.3 TS Pin Setting

$LiFePO_4$ batteries have a better chemistry stability than Li-ion batteries. This allows them less prone to thermal runaway. $LiFePO_4$ batteries generally perform well in higher ambient temperature. However, charging the battery with JEITA compliance rules provides additional layer of security. Although, there are no specific JEITA guidelines for $LiFePO_4$ in particular, a good practice is to use thresholds for Li-ion batteries if the user wants to use JEITA. Depending on whether the user wants to use JEITA or NTC monitoring, there can be three scenarios.

### 3.3.1 JEITA Enabled

Assuming a 103AT NTC thermistor on the battery pack, a resistor divider from REGN connected to TS pin and to the battery pack thermistor sets the T1 and T5 temperature window beyond which charging is disabled. As shown in the figure blow, in T1<TS<T2 charge current is reduced and in T3<TS<T5 battery regulation voltage is reduced. The blue trace is the default behavior and the red traces shows programmable range which can be set in REG0x1B.

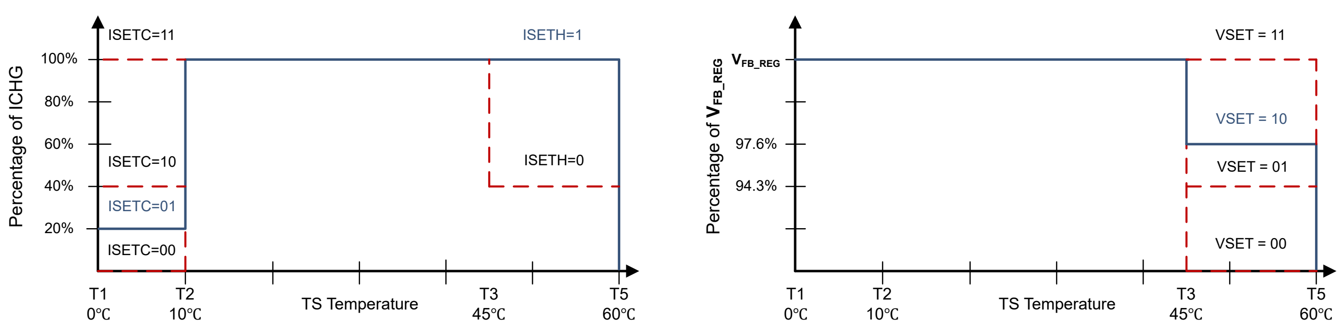


**Figure 3-2. TS charging values**

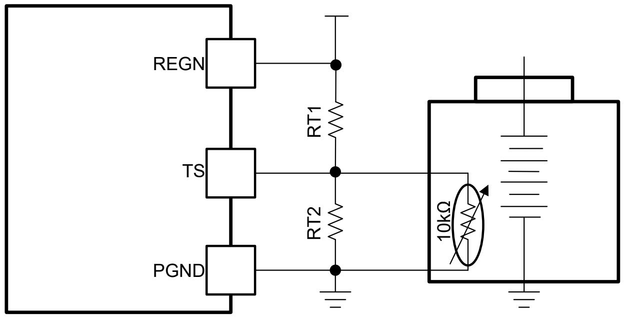


**Figure 3-3. Resistive divider to TS pin**

### 3.3.2 JEITA Disabled

JEITA profile can be disabled by clearing EN_JEITA register bit in REG0x1C. However, the charger still disable charging outside the T1<TS<T5 window. The process just disables the special charge profile for T1 to T2 and T3 to T5 regions.

### 3.3.3 NTC Monitoring Disabled

The JEITA and NTC monitoring can be completely disabled by clearing EN_TS register bit in register REG0x1C. In this case TS pin voltage is ignored and TS pin can be either be floated or connected to PGND.

## 4 Supercapacitor Charging Profile

Most super capacitors can be discharged down to 0 V and recharged to the maximum voltage with the manufacturer recommended charge current. For a super capacitor, trickle charge and pre-charge phase is not required. As a result, the supercapacitor can charge in two phases.

**Phase 1 – Constant current:**

Charging starts with the full fast charge current and the capacitor voltage increases to the regulation voltage setting.

**Phase 2 – Constant voltage:**

Once the capacitor voltage reaches the regulation voltage, the charge current is tapered down to zero and the capacitor voltage is held at the regulation voltage.

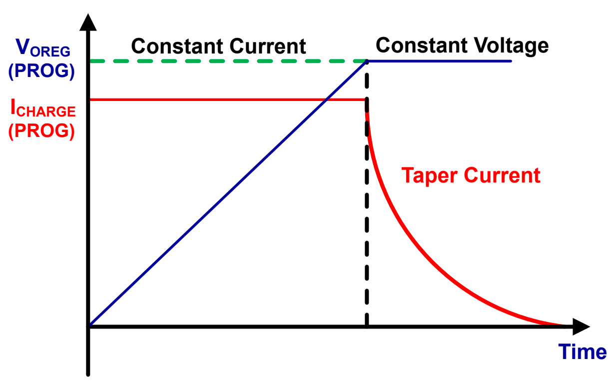


**Figure 4-1. Supercapacitor Charging Profile**

# 5 SBQ25756 Settings For Supercapacitor

## 5.1 Charge Current Setting

Supercapacitors does not require trickle charge or pre-charge when their voltage is low. Supercapacitors can be charged with fast charge current even when the voltage is zero. The termination current setting is also not required. For setting EN_PRECHHARGE bit to 0 disables both trickle charge and pre-charge. The charge timer can be disabled as well. To use optimum charge current, the settings in Table 5-1 can be used.

**Table 5-1. Supercapacitor Charge Current Settings**

| Settings | Value | Register |
|---|---|---|
| EN_PRECHG | 0 | REG0x14 |
| EN_TERM | 0 | REG0x14 |
| EN_CHG_TMR | 0 | REG0x15 |

The desired fast charge current can be set using the method described in Section 3.2.1.

## 5.2 Charge Voltage Setting

For supercapacitors, only the battery regulation voltage $V_{FB}$ needs to be set. As an example, if we want to charge a 1.67 F capacitor to 14.5 V then the FB pin bottom resistor is calculated as $R_{BOT}$ = 29.54 kΩ using the equation described in Section 3.1.1. If we select a 0.1% resistor of value 30.1 kΩ then effective $V_{BATREG}$ is 14.25 V. We can fine tune $V_{BATREG}$ closer to 14.5 V by adjusting the internal reference $V_{FB}$ via VFB_REG in register REG0x00 and setting the value to 1.562 V.

## 5.3 TS Pin Setting

Optional TS pin can be used to sense the supercapacitor temperature from an NTC thermistor placed on the supercapacitor and disable charging if the supercapacitor temperature is outside a set window. The following figure shows a 103AT NTC thermistor connection configuration. The temperature window setting process is described in Section 3.3.

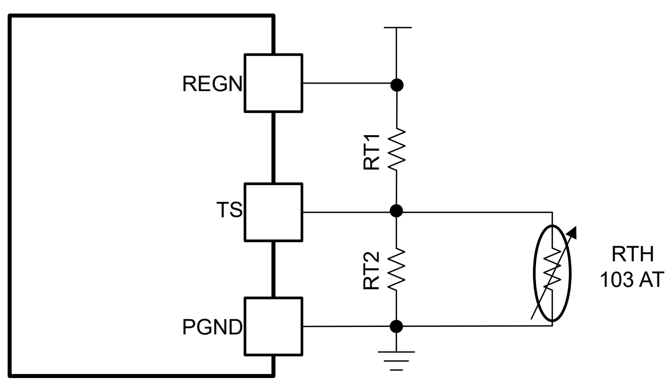


**Figure 5-1. TS Resistor Network for Supercapacitor**

# 6 Test Results From EVM

## 6.1 Charging $LiFePO_4$ Battery

On the EVM original $R_{BOT}$ of 13.7 kΩ is replaced with 30.1 kΩ which translates to $V_{BATREG}$ being 14.25 V. This means we can charge 14.25 V/3.6 V or about 4-cell battery. To set $V_{BATREG}$ more accurately which is 4x3.6 V=14.4 V, VFB_REG register is set to 1.552 V using bqStudio. The charging current is set to 2 A, pre-charge current is set to 500 mA and trickle charge current is set to 250 mA. VBAT_LOWV is set to 55% × VFB_REG and VRECHG is set to 93% × VFB_REG. The input voltage to the charger is at 31 V. With a heavily depleted battery, the charger starts charging with a trickle charge when charging is enabled by setting EN_CHG. When the battery voltage reaches pre-charge threshold, the charger employs pre-charge current. When the battery voltage is close to 7.9 V, the battery charges with full fast charge current. When the battery reaches 14.4 V the charge current is tapered down to termination current and the charging cycle is complete. Charge status register is shown as ‘charge done’. During the charging the STAT1 pin is ON and STAT2 pin is OFF indicating charge in progress. When charging is done STAT1 pin is OFF and STAT2 pin is ON.

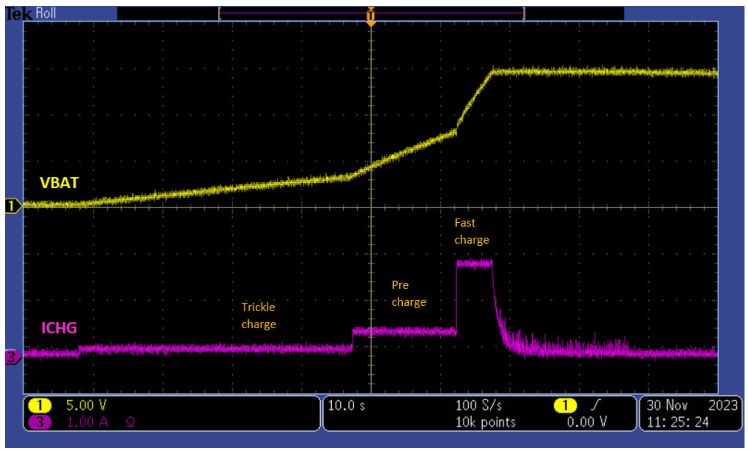


**Figure 6-1. $LiFePO_4$ Battery Charging Cycle on an EVM**

## 6.2 Charging Supercapacitor

For charging supercapacitor on the EVM, EN_PRECHG, EN_TERM and EN_CHG_TMR is disabled using bqStudio. VFB_REG is set to 1.562 V to achieve charge voltage of 14.5 V. Charging current is set to 2 A. Input voltage is at 31 V. A 1.67 F discharged capacitor is attached for charging. When EN_CHG is enabled, the charger charges the capacitor with full fast charge current. When the capacitor reaches 14.5 V, charge current is tapered down. The charge status register is shown as ‘taper charge’. At this stage STAT1 pin is ON and STAT2 pin is OFF. Because the termination has been turned off, the charger status stays at the taper charge phase indefinitely to keep the supercapacitor charged at 14.5 V.

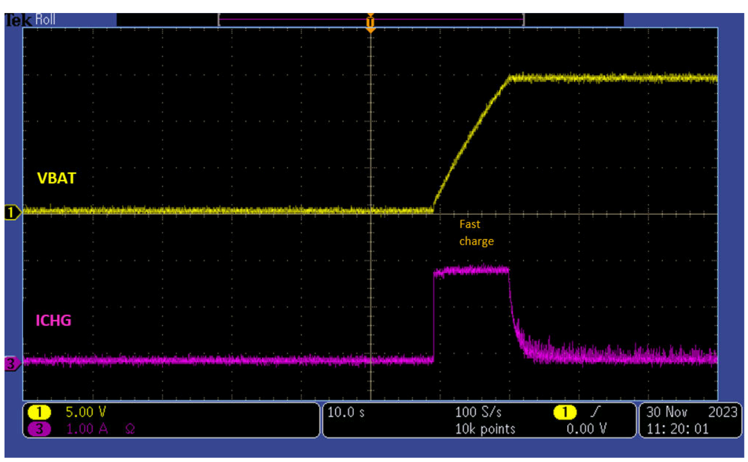


**Figure 6-2. Supercapacitor Charging Cycle on the EVM**

## 7 Summary

This application note provides detailed description of how to configure the BQ25756 buck-boost charge controller for charging $LiFePO_4$ batteries and supercapacitors. Test results from the EVM is also presented.

## 8 References

1. Texas Instruments, *BQ25756: Standalone/I2C Controlled, 1- to 14-Cell Bidirectional Buck-Boost Battery Charge Controller*, data sheet.
2. Texas Instruments, *LiFePO4 Design Considerations*, application note.

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