Application Report
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Battery Charger Overload Protection in Boost Mode Operation

Gabriel Xu, Eric Zhao

ABSTRACT

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1 Introduction

Many personal portable devices that are battery-powered are used to power external accessories. At the time of this writing, smartphones or tablets are the most popular applications used to power up external keyboards or USB storage devices with USB on-the-go (OTG) functionality. Another very similar application is the power bank. A power bank battery is charged when the wall power is available, after which it is used to charge external accessories when required. The most common topology of a battery charger is the step-down buck converter during the charging stage. When a battery is discharging to power up the external accessories, power flow is reversed and the converter operates as a boost converter. Depending on the power flows, operating the converter in either buck or boost mode reduces the total solution size and cost. The overload protection scheme is crucial to ensure that the battery charger and battery operate safely. This application note discusses the overload protection schemes of a battery charger operating in OTG boost mode. In addition to the cycle-by-cycle current limit, the average output current protections are implemented in battery chargers. Three different boost mode overload protections are analyzed based on the average output current and the implementation. This application note also discusses and compares the advantages of each scheme.

2 Average and Cycle-by-Cycle Overcurrent Protection

Most chargers from Texas Instruments such as the bq2560x, bq2419x, and bq2589x provide different levels of overcurrent protection depending on either the average current or switching cycle-by-cycle current (see Figure 1) The charger senses the current flowing through the Q1 field-effect transistor (FET), which is the average current of the boost output. Alternatively, the cycle-by-cycle current limit is implemented by sensing the current flowing through the Q3 FET.

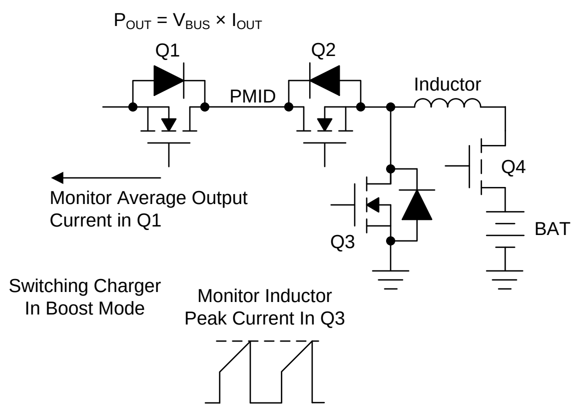

Figure 1. Switch Charger Operating in Boost Mode

3 OTG Mode Overload Protection Based on Average Current

OTG boost output overloading can potentially cause both the external accessary and the charger to overheat; therefore, different layers of overload protection schemes are implemented in a battery charger. The overload detection is generally based on the average current and the most common schemes are: LDO mode, hiccup mode, and constant current-mode protection.

3.1 LDO Mode

In low-dropout regulator (LDO) mode, the Q1 FET operates in the saturation region and functions like a variable resistor. When the average output current hits the preset threshold, the overload condition is detected. The control loop limits the output current in the preset value I_{LDO} by changing the Q1 conduction resistance (see Figure 2).

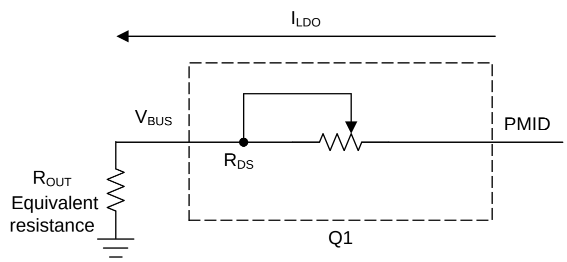

Figure 2. Q1 FET Equivalent Circuit in LDO Mode

The overload output power and Q1 FET losses can be calculated in Equation 1 and Equation 2 as:

$$P_{OVERLOAD} = V_{BUS} \times I_{LDO} = I_{LDO}^2 \times R_{OUT} \tag{1}$$

$$P_{Loss\_Q1} = \left(V_{PMID} - R_{OUT}\right) \times I_{LDO} \tag{2}$$

Equation 1 indicates that the LDO mode can significantly limit the output power with a simple implementation to prevent the device from thermal damage, even with an output short circuit. The major drawback is that the voltage drop in Q1 FET is high in a severe overload condition and leads to a Q1 FET high-power dissipation. This high-power dissipation has a risk of thermal damage and battery energy loss. The time in which Q1 is operated in LDO mode must be controlled to prevent thermal damage of the Q1 FET. Figure 3 shows the overload protection waveform of the bq24157 LDO mode. The charger operates in LDO mode for 32 ms until the input current hits the 1-A threshold, after which the converter shuts down.

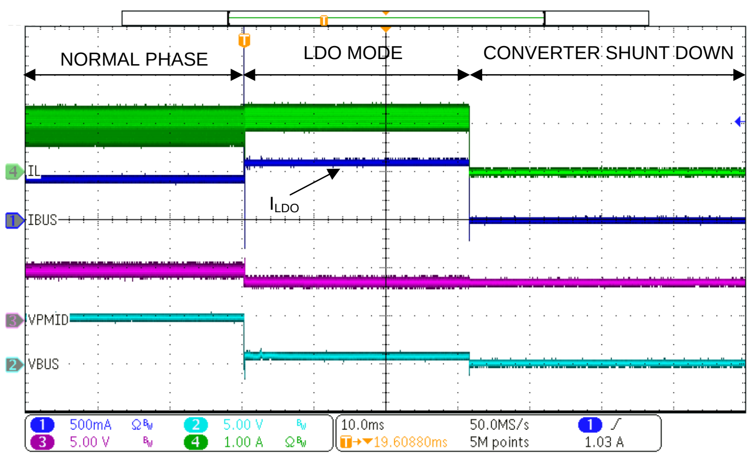

Figure 3. bq24157 LDO Mode Protection

3.2 Hiccup Mode

To reduce the power dissipation of the Q1 FET, the hiccup mode turns off the Q1 FET when the overload condition has been detected. The Q1 FET remains turned off for a certain period of time before it turns on again. If the overload condition still exists after Q1 FET has been turned on, the Q1 FET repeats this process repeatedly. Figure 4 and Figure 5 show the hiccup overload protection waveform. The overload output power can be calculated in Equation 3 as:

$$P_{OVERLOAD} = \frac{\left(t_{Q1\_ON} \times \left(\frac{V_{BUS}^2}{R_{OUT}}\right)\right)}{\left(t_{Q1\_ON} + t_{Q1\_OFF}\right)} \tag{3}$$

The t_{Q1_ON} must be kept much shorter than t_{Q1_OFF} to limit the overload output power. Take bq24296 as an example: t_{Q1_ON} = 260 µs, t_{Q1_OFF} = 32 ms, and the input current overload threshold is 1.5-A (default).

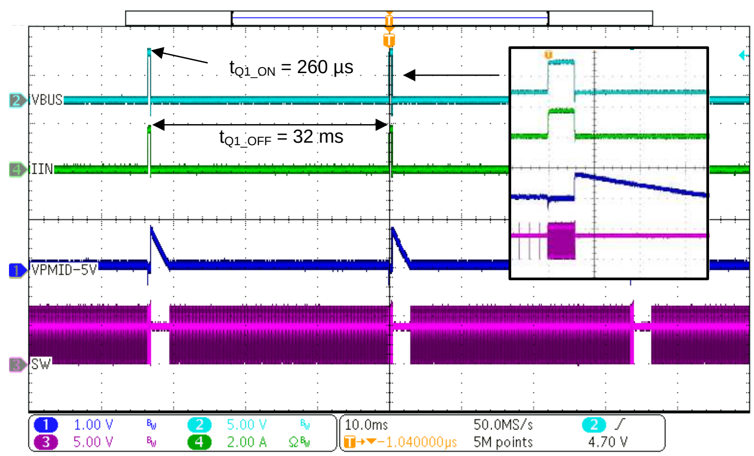

Figure 4. Hiccup Mode Overload Protection of bq24296

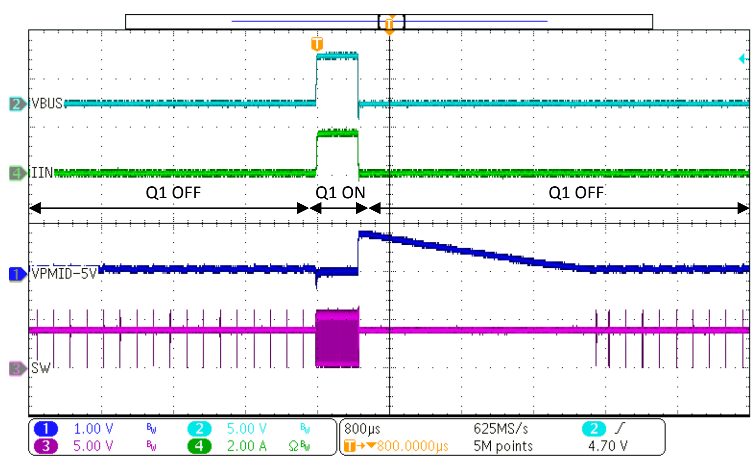

Figure 5. Hiccup Mode Overload Protection of bq24296 (Zoomed In)

The hiccup mode can limit the overload output power with less loss in the Q1 FET and provide self-recovery function.

3.3 Constant Current (CC) Mode

Figure 6 shows the CC mode operating with the V-I characteristic. When the overload condition has been detected, the converter output characteristic shifts from the equivalent voltage source to the equivalent current source and keeps the output current constant (CC mode). In the meantime, the Q1 FET completely turns on consistently during the CC mode. Therefore, the voltage drop in the Q1 FET is low regardless of the overload level and does not cause extra loss in the Q1 FET. In CC mode, when the output voltage decreases to hit the battery voltage, the converter can no longer maintain operation in boost mode, so it shuts down. Figure 7 shows the bq2560x CC and CV mode overload protection waveform.

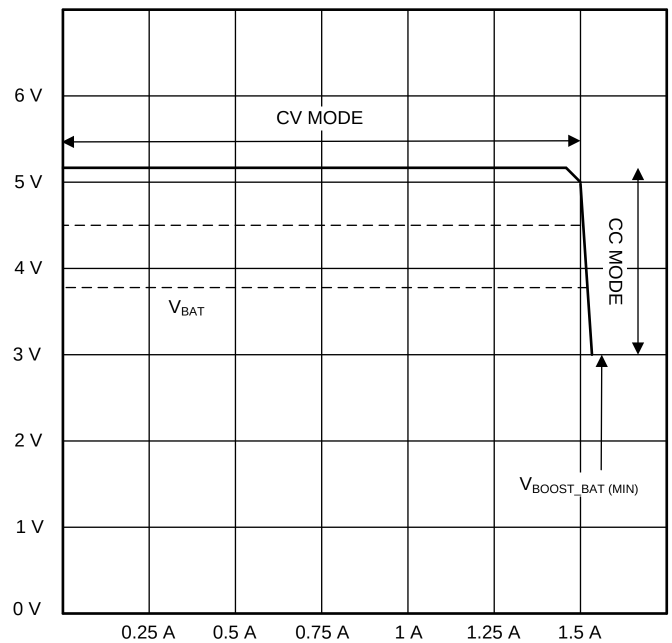

Figure 6. V-I Operating Characteristic of CC and CV Mode Overload Protection

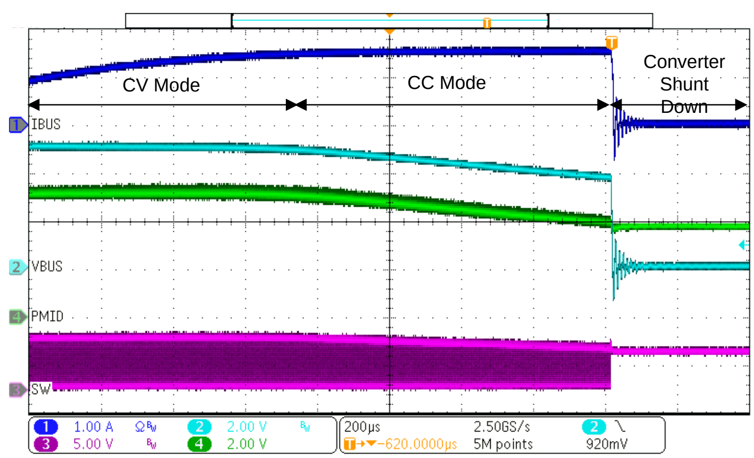

Figure 7. CC and CV Mode Overload Protection of bq2560x

The CC mode overload output power can be calculated in Equation 4 as:

$$P_{OVERLOAD} = I_{CC}^2 \times R_{OUT} \tag{4}$$

4 Persistent Overload Reaction

For a persistent overcurrent condition, all three protection schemes turn off the converter to eventually achieve protection. The procedures and result are different. In general, the better solution is to inform the external device that the power supply is in an overloaded condition and then make it reduce the charging power rather than to turn off the converter directly. The device is typically being charged and does not recognize the exact output capability of the power supply. To prevent overload and break down the power supply, the VDPM) of the charger reduces the charging power when the input voltage drops to a certain threshold. See *Dynamic power management for faster, more efficient battery charging* (SLYT546) for more details.

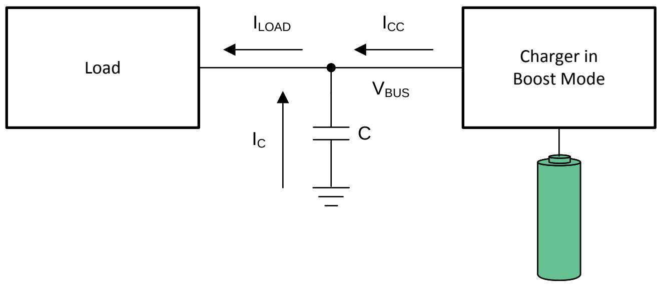

Figure 8. Equivalent Output Circuit in CC Mode

The time converter that operates in CC mode, t_{cc}, is determined by I_{LOAD} (see Figure 8); therefore, for severe overloaded conditions, such as output short-circuit conditions, the converter is very quickly turned OFF. For a slightly overloaded condition, the output voltage dropping is slower and leaves enough time for the VDPM to function. Increased capacitance of the bus cap can provide more VDPM response time margin to handle more severe overload conditions with higher battery voltage. Figure 9 shows the response of the bq25601 active VDPM function in CC mode.

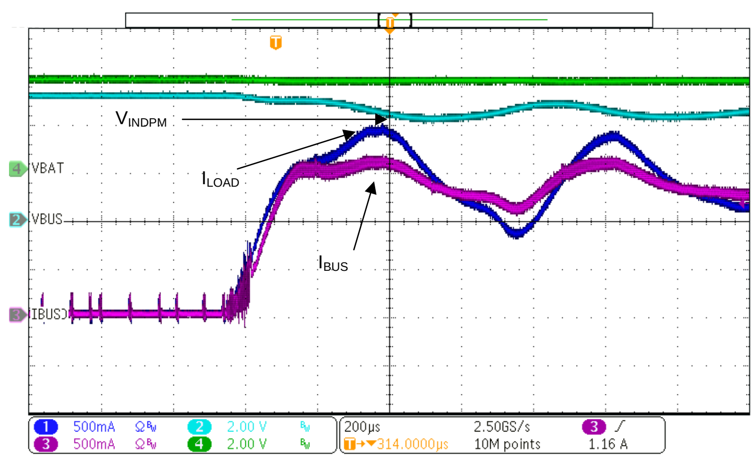

Figure 9. Active VDPM Function in CC Mode

5 Summary

Each three kinds of overload protection can limit the output power efficiently, even in a short-circuit condition. As Table 1 shows, the LDO mode is a simple and low-cost solution; however, LDO mode can result in high losses and power dissipation in the Q1 FET before the converter shuts down. The Q1 FET loss in hiccup mode is smaller than in LDO mode and provides a self-recovery function. CC mode does not cause extra power loss in the Q1 FET and can enable VDPM functionality.

Table 1. Comparison of Three Different Overload Protection Features

FEATURE	LDO MODE	HICCUP MODE	CC/CV MODE
Limit overload power	✓	✓	✓
Without extra Q1 FET loss	X	✓	✓

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265