Design Example to Charge Three Super Capacitors in Series with Health Monitoring Using bq24610 and bq33100

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ABSTRACT

This application report introduces a charging solution for three super capacitors in series including its health monitoring functions to have longer hold-up time in enterprise SSD applications. This is a special requirement for enterprise SSD, and the impact of this requirement is that energy for longer than 1sec hold-up time must be stored in the system. This requirement ensures enterprise SSD to get enough time to backup after a loss of 12 V system power rail. Also, the efficiency is one of key factors for this system, and this report shows how well the initial design tests met the goals using the both bq24610 and bq33100.

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1 Introduction

Most enterprise SSDs including server and datacenter SSDs rely on power failure function that monitors the system power rail (12 V) from the host and generates an early warning signal to SSD controller if the system voltage drops below a predetermined threshold. And, a hold-up circuit is implemented to protect against loss of data upon power failures. The hold-up time is the amount of time that the system can continue to run without resetting or rebooting during a power interruption, and a high capacity super capacitor or a bank of discrete capacitors can be used for the proper hold-up time function.

Figure 1 shows the simplified application circuit of the bq24640, and the bq24640 charges super capacitors in both constant current and constant voltage mode. The device can charge supercapacitors from 0 V with high current charging set up to 10A on the ISET pin, and this approach is well used because of its simple structure and simple control.
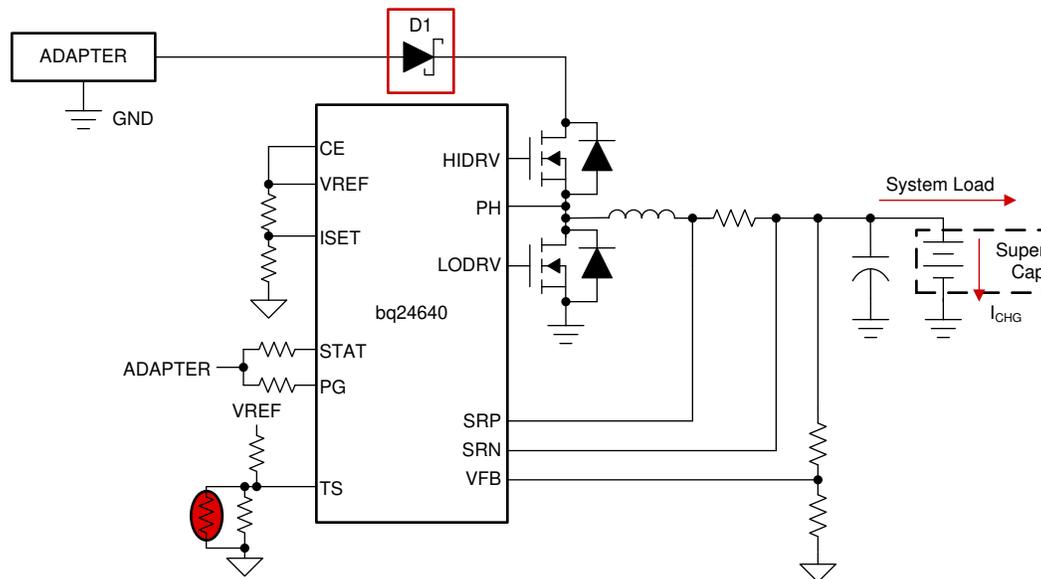

Figure 1. Simplified Application Circuit of the bq24640

However, D1 is used to protect the reverse current from the super capacitor to adaptor. The problem of this approach is a forward voltage drop of D1 at normal operating conditions, and the converter efficiency is significantly reduced by D1. To understand the power loss of D1, the input current (I_{in}) of 12 V rail is calculated as follows (considering I_{CHG}=2A, System Load=3A, V_{CHG}=7.2V and η (efficiency)=95%):

$$I_{in} = \frac{7.2\ V \times (2A + 3A)}{12\ V \times 0.95} = 3.16\ A$$

(1)

We can get the power loss of D1 (P_{lossD1}).

$$P_{loss.D1} = V_F \times I_{in} = 1.26\ W$$

(2)

Where: V_F=0.4V (the forward voltage drop of D1)

2 Design Considerations for Higher Efficiency

Figure 2 shows the simplified application circuit using bq24610. This approach controls external switches (M1 and M2) to prevent battery discharge back to the input, connect the adaptor to the system, and connect the super capacitors to the system using another external switch (M3) for better system efficiency.

Three 15 Farad super capacitors are used for the backup storage, and the bq24610 has the proper functions to control M1, M2, and M3 charging the super capacitors up to the predefined voltage. The reason for having 3 super capacitors in series is to have higher charging voltage for longer hold-up time. Pre-charge current ($i_{pre-charge}$) and fast-charge ($i_{fast-charge}$) current are set by 1.2A and 2A respectively targeting 7.2 V charging voltage (V_{CHG}). The both pre-charge time ($\Delta t_{pre-charge}$) and fast-charge time ($\Delta t_{fast-charge}$) can be calculated as follows:
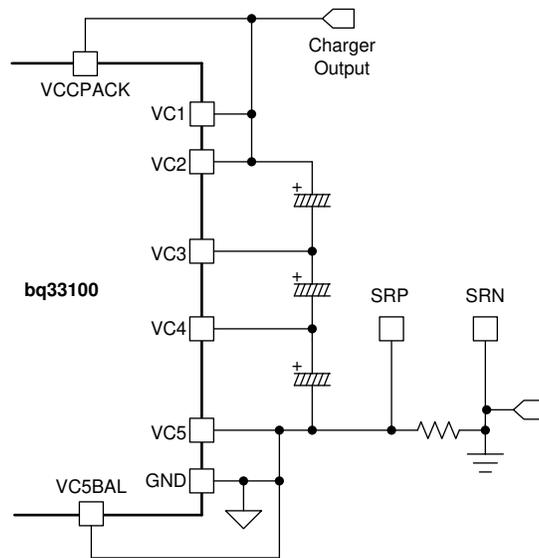
$$\Delta t_{pre-charge} = \frac{C_{out}}{3} \times \frac{V_{LOWV}}{i_{pre-charge}} = 22.38 \text{ sec}$$

(3)

where: V_{LOWV} (Pre-charge to fast-charge transition threshold voltage) is 5.371 V in this setting, $C_{out} = 15$ Farad.

$$\Delta t_{fast-charge} = \frac{C_{out}}{3} \times \frac{V_{out} - V_{LOWV}}{i_{fast-charge}} = 4.72 \text{ sec}$$

(4)

The total charging time will be:

$$\Delta t_{total-charge} = \Delta t_{pre-charge} + \Delta t_{fast-charge} = 27.1 \text{ sec}$$

(5)

Figure 2. Simplified Schematic for Better Efficiency Using bq24610

The bq33100 super capacitor manager is a fully integrated solution, and Figure 3 shows the connection method for three series super capacitors with individual super capacitor monitoring, charge control and protection. As for the individual super capacitor balancing, it is accomplished by connecting an external parallel bypass load to each super capacitor, and enabling the bypass load depending on each individual super capacitor voltage level. The bypass load is typically formed by a P-ch MOSFET and a resistor in series across each super capacitor as it is shown in bq33100 Super Capacitor Pack Manager EVM User's Guide.

VC5 should be connected to IC ground with SRP. The delta-sigma ADC measures the system current of the super capacitors by measuring the voltage drop across a small-value sense resistor between the SRP and SRN pins, and SRN should be connected to VSS (System GND).

Figure 3. Connection Method for 3 Series Super Capacitors

The bq33100 supports two main charge control methods, discrete control and smart control. In a discrete charge control implementation, the CHGLVL0 and CHGLVL1 pins can be used to adjust the super capacitor charging voltage as shown in Figure 4.
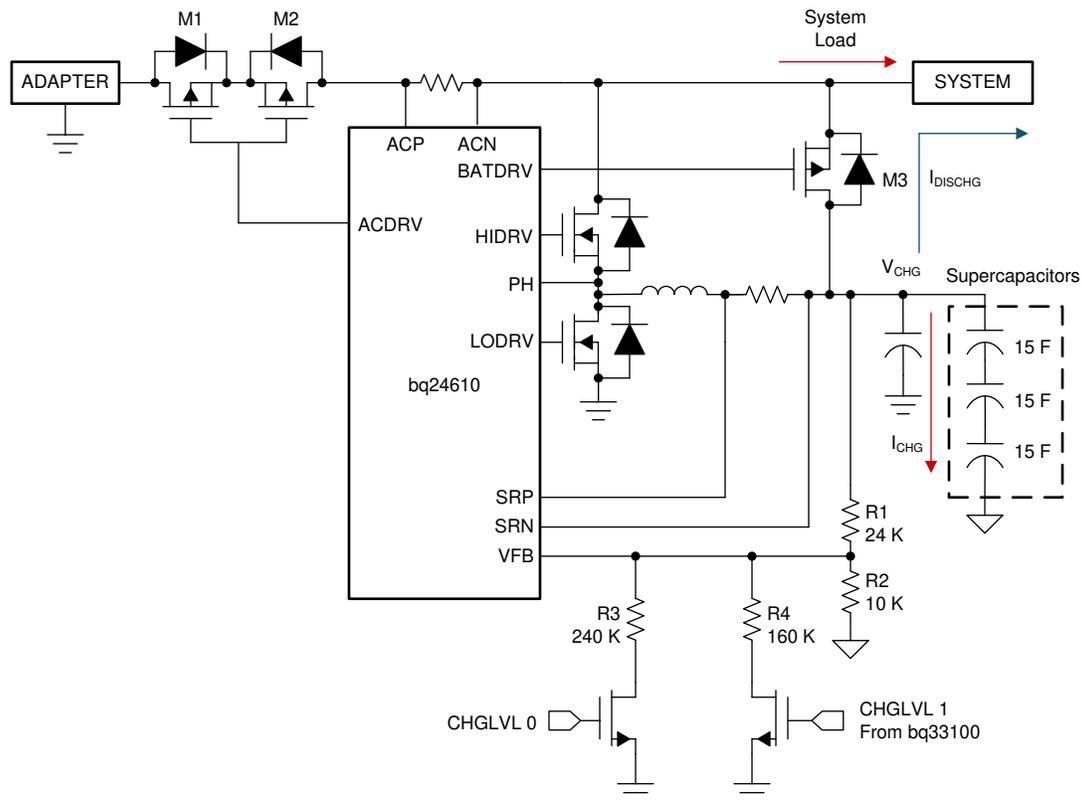

Figure 4. Discrete Charge Control Implementation

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There are four levels of charging voltages that can be chosen, V Chg Nominal, V Chg A, V Chg B, V Chg Max to offset the deteriorating super capacitor ESR and capacitance due to aging. The CHGLVL0 and CHGLVL1 pin states are defined by the V Chg X parameters as shown in Table 1, and the charging voltages are set with a resistor divider by R1, R2, R3, and R4. Start with 10 kΩ for R2 and calculate R7 to get V Chg Nominal (V_{CHG} = 7.14V). It is recommended to use 1% tolerance or better divider resistors. To improve efficiency at light loads consider using larger value resistors. However, if the values are too high, the converter is more susceptible to noise and voltage errors from the VFB input current are noticeable.

Table 1. Four Levels of Charging Voltages Setting

CHARGING VOLTAGE	CHGLVL1 (PIN12)	CHGLVL0(PIN11)	V_{CHG}
V Chg Nominal	0	0	7.14 V
V Chg A	0	1	7.35 V
V Chg B	1	0	7.46 V
V Chg Max	1	1	7.67 V

A useful application example using both bq24610 and bq33100 to charge 3 super capacitors in series is shown in Figure 5. The bq33100 GND should be connected to VC5, VC5BAL, SRP pins, and SRN pin should be connected to the system ground (VSS) for this configuration.
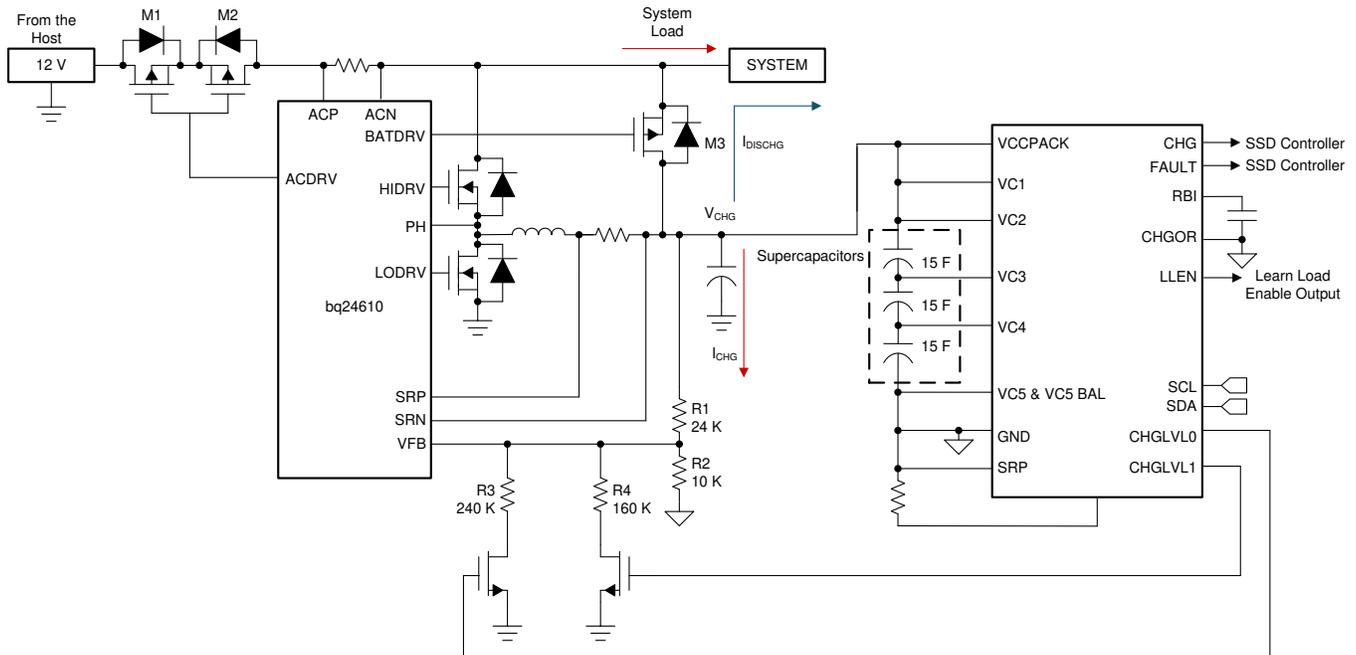
Figure 5. Application Example Using Both bq24610 and bq33100

The bq24610 automatically detects the presence and the absence of a super capacitor. When the super capacitor is detected, charging begins in one of three phases (depending upon super capacitor voltage): pre-charge, constant current (fast-charge current regulation) and constant voltage (fast-charge voltage regulation). The bq24610 will terminate charging when the termination current threshold has been reached and will begin a recharge cycle when the super voltage has dropped below the internal recharge threshold.

3   Experimental Results

To verify the operation and performance of the proposed application method, the super capacitor voltage is measured during the periods of charging and discharging. Figure 6 shows the pre-charge and the fast-charge phases, and the total charging time is about 27 seconds as it is calculated in Equation 5.
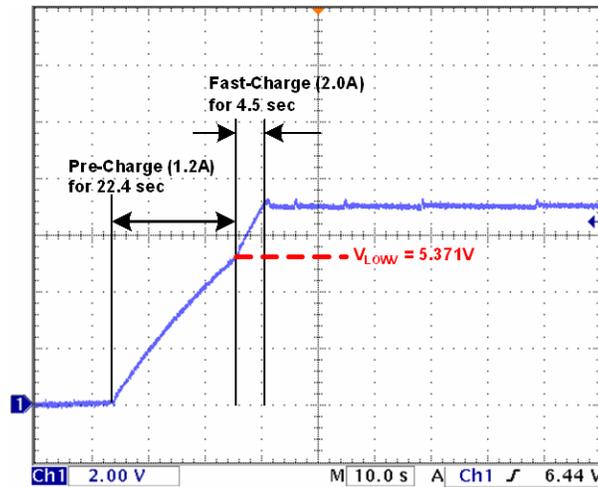
Figure 6. Pre-Charge and Fast-Charge Phases

Figure 7 shows the discharge waveform from full charge voltage to 4 V with 2A system load condition after a loss of 12 V system rail, and the hold-up time is about 7 seconds.
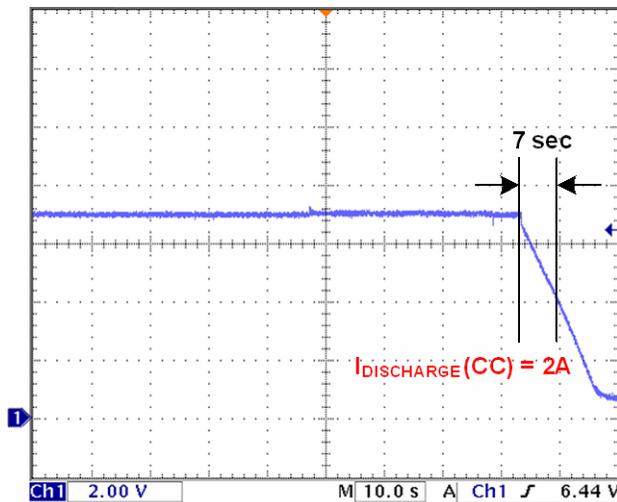

Figure 7. Discharge Waveform for Hold-up Time

The CC0, CC1, and CC2 bits in Operation Cfg register must be programmed to match the corresponding configuration, and Figure 8 shows its value for the setting using 3 super capacitors in series with the bq Evaluation Software.
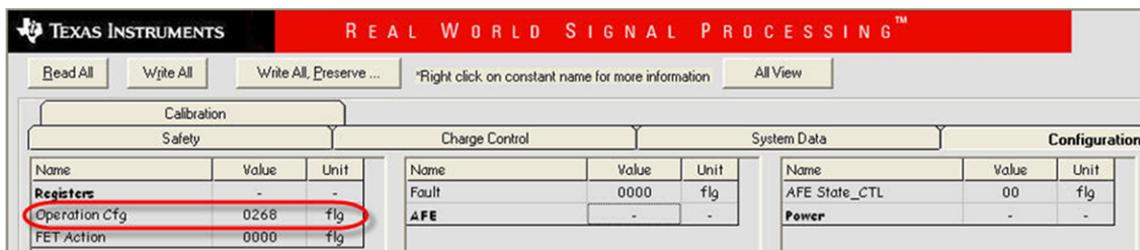

Figure 8. Data Flash Screen, Configuration Class

The bq Evaluation Software provides a calibration function as shown in Figure 9. Ensure that the settings are correctly changed to match the capacitor stack, and the correct settings are essential to get the best performance. For the calibration, select the type of calibration to be performed, and enter the measured values for the types selected.
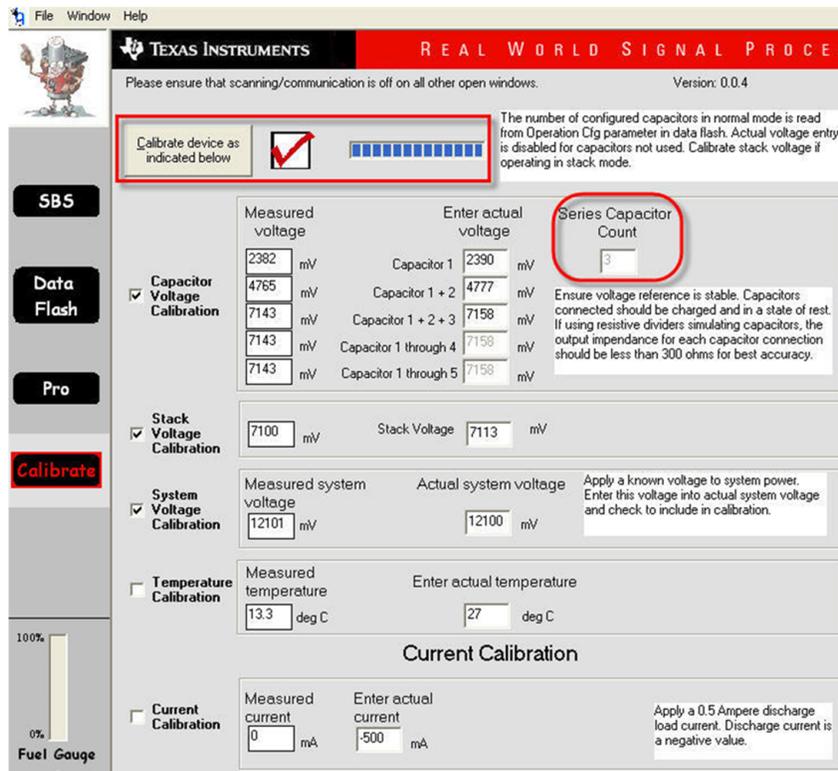
Figure 9. Calibration Screen

4   Summary

A design example using bq24610 and bq33100 to charge 3 super capacitors in series is described in this application report. Though the bq24610 is a highly integrated Li-ion or Li-polymer switch-mode battery charge controller, it can be used for charging multiple super capacitors in series to have longer hold-up time in enterprise SSD applications. The bq33100 provides a rich array of features for super capacitor applications maximizing functionality and safety. As it has been confirmed with the actual application case (VI_N=12 V, V_{CHG}=7.2 V, 3 super capacitors in series), the solution operates properly, and it is suitable for higher efficiency using the external MOSFETs (M1, M2, M3) instead of D1.

5   References

- Texas Instruments, bq24640 High-Efficiency Synchronous Switched-Mode Super Capacitor Charger Data Sheet
- Texas Instruments, bq2461x Stand-Alone Synchronous Switched-Mode Li-Ion or Li-Polymer Battery Charger With System Power Selector and Low Iq Data Sheet
- Texas Instruments, bq33100 Super Capacitor Manager Data Sheet
- Texas Instruments, bq24610, EVM (HPA422(Multi-Cell Synchronous Switch-Mode Charger, User Guide
- Texas Instruments, bq33100, Super Capacitor Pack Manager EVM, User Guide

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