Fuel-gauging considerations in battery backup storage systems

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Analog Field Applications

Accurate fuel gauging in battery backup systems requires special considerations. Using Texas Instruments (TI) battery fuel gauges with Impedance Track™ technology offers the distinct advantage of not requiring a full discharge of the pack for learning as the cells age. This article discusses different implementations and techniques for completing a proper learning cycle in backup applications. Additionally, a case study of an aged battery pack's changes in capacity and impedance is reviewed.

TI's Impedance Track algorithm uses voltage, current, and impedance measurements of the cells to accurately calculate a battery pack's remaining capacity and run time. Proper selection of a cell's specific chemistry is required for the most accurate gauging. As of this writing, there are six distinct classes of chemistries, with several options within each class.

In determining a battery backup system's cell aging over time, the major concerns are (1) the maximum chemical capacity (Q_{max}) of the cell, specified in milliampere-hours (mAh), and (2) the actual measured impedance of the cells (R_a table values), which will determine true run time based on loading and temperature.

Most notably, high temperatures will adversely impact Q_{max} and the internal cell impedances. Charging and storing the cells at a lower voltage (between 3.9 and 4.1 V for standard 4.2-V cells) will increase their lifetime at the expense of shorter run times.

Older gas-gauging technologies require a complete discharge of the cells to update capacity information. Impedance Track technology eliminates this full-discharge requirement and instead uses two relaxed-voltage measurement points to update Q_{max}. In the default firmware, these voltage measurements are typically performed before and after the battery state of charge (SOC) has changed by about 40%. With modified firmware from TI, this SOC range can be decreased to as low as 10% for a "shallow" discharge. Decreasing the SOC range for the Q_{max} update will affect gauging accuracy; the more SOC range used, the better.

The two relaxed-voltage measurements need to be taken in a qualified voltage range based on the cell chemistry. For more information, please review Reference 1. To see an Excel® file with disqualified Q_{max}-update voltage ranges based on cell chemistry, go to http://www.ti.com/lit/zip/slua372 and click Open to view the WinZip® directory online (or click Save to download the WinZip file for offline use). Then open the file:

chemistry_specific_Qmax_disqv_voltages_table.xls

Table 1 shows an excerpt from this file. As the table shows, if the chemical ID is 0100, then Q_{max}-update voltage measurements are not allowed between 3737 and 3800 mV due to the flatness of the voltage profile at this SOC. This disqualified voltage range is based on measuring the cell's relaxed voltage after a rest period of at least an hour. Impedance measurements and updates will happen during discharge with a load of greater than C/10. (A "C rate" is based on the cell's capacity. If a 3s2p pack has a design capacity of 4400 mAh, then the C/10 discharge rate is 440 mA. In this case, a safe discharge rate would be 500 mA.)

To store varying resistances at different SOC values, 15 grid points are used. Once one grid point has been recalculated, all subsequent grid points may be modified accordingly. A discharge needs to exceed 500 seconds to avoid transient effects and distortion of resistance values.

How to initiate a Q_{max} learning cycle

TI provides evaluation software that shows the status and allows controlling parameters of an Impedance Track gas gauge (see Related Web Sites). After confirming that the battery voltage is outside the disqualified range, a RESET command can be sent to the gauge that will set the R_DIS bit and clear the VOK bit. When a proper OCV measurement has been completed by the gauge, the R_DIS bit will be cleared. Now battery charging or discharging can be started which will set the VOK bit in a few seconds. With the firmware set for a shallow SOC change of 10%, allow the charge/discharge to change the SOC by at least 15%. After stopping the charge/discharge cycle, allow the cells to relax (up to 5 hours in a deeply depleted state) outside the disqualified voltage range. The VOK bit should clear, which is the indication that a second valid OCV measurement has been taken and a Q_{max} update has been completed successfully.

Table 1. Disqualified Q_{max}-update voltage ranges based on cell chemistry

Description	Chemical ID	Vqdis_min	Vqdis_max	SOC_min, %	SOC_max, %
LiCoO2/graphitized carbon (default)	0100	3737	3800	26	54
Mixed Co/Ni/Mn cathode	0101	3749	3796	28	51
Mixed Co/Mn cathode	0102	3672	3696	6	14
LiCoO2/carbon 2	0103	3737	3800	26	54
Mixed Co/Mn cathode 2	0104	4031	4062	77	88

The following two examples describe different system implementations for battery backup systems.

Example 1: Passive discharge of cells

In this configuration, the active current of the gas-gauge chipset (~375 µA) can be used to discharge the batteries over an extended period of time. Depending on the capacity of the pack, this could be several months. Keeping the gauge continuously in active mode is programmable by setting the SLEEP bit in the "Operation Cfg A" register to 0. Another option is to assert the /PRES GPI with the non-removable bit (NR = 0) set in the "Operation Cfg B" dataflash register.

With firmware modified for a shallow discharge such as 20% for a Q_{max} update, the pack can be allowed to discharge down to 75% of its capacity over time and can then be charged back up to full capacity. The Q_{max} parameter will be updated accordingly. Note that only the Q_{max} values, not the cell impedances (R_a table values), will be updated during this type of cycling. It is assumed that a rest period of several hours is allowed at the end of charge for the second relaxed-voltage measurement.

Example 2: Active discharge of cells

In this configuration, a discharge resistor in the system can be used to actively discharge the cells. This could be controlled by a host processor inside the battery packs or externally in the system. As discussed earlier, a discharge current of greater than C/10 for 500 seconds is required for impedance grid-point updates.

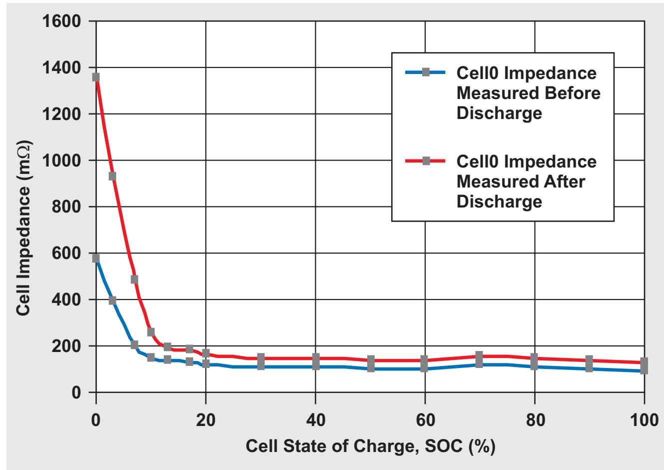
Even though the 10% minimum discharge requirement applies for a Q_{max} update, ideally the pack should be discharged through two impedance grid-point updates. These occur during discharge at SOC intervals of approximately 11% (i.e., at 89%, 78%, 63%, 52%, etc.). In this case, discharge from 100% to 75% capacity would be sufficient. If the battery is being stored with the SOC at 80% for longevity reasons, two impedance grid-point updates would happen within a 25% discharge.

A proper Q_{max} update will happen only after two consecutive relaxed-voltage measurements separated by a charge or discharge are taken (assuming that both measurements are outside the disqualified voltage range of the specific chemical ID). Therefore, after the pack is actively discharged to 75% of its capacity, a rest period of several hours is required, depending on the SOC. (Based on cell chemistry, up to 3.5 hours is required for a semicharged state, and up to 5 hours for a fully discharged state.)

Case study

The effects of long-term storage were studied by using a Microsun Technologies 3s4p 8.8-Ah battery pack that had LGDS218650 cells with the bq20z80 chipset produced in June of 2006. The pack was stored at about 45% capacity at room temperature for two years without being cycled. The parameters of interest were changes to Q_{max} and to the cell impedances, as well as the accuracy of remaining-capacity and time-to-empty calculations. The estimated self-discharge of these cells is less than 4% per year.

Figure 1. Changes in cell impedance over time



A constant resistive load of 3 Ω was used for discharging the packs (equating to a discharge rate of approximately 3.5 A). Changes in Q_{max} and in the impedance values are respectively shown in Table 2 (on the next page) and Figure 1. On average, Q_{max} decreased by 3% and the impedances of the cells increased by 35%. Even with these changes in the cells, the accuracy of the initial discharge cycle following the two-year rest period was greater than 99%; specifically, a capacity of 67 mAh was reported when the terminate voltage was reached (67 mAh/8819 Q_{max} = 0.00761, or an error of 0.761%).

Conclusion

TI's battery fuel gauges with Impedance Track technology provide an extremely accurate estimation of remaining battery capacity. Understanding how the technology works is especially important in designing storage and backup systems with long periods of rest. Examples were presented of using passive and active discharge of the pack to update Q_{max} and cell impedance values. Additionally, discharge results from an aged battery pack were shared to illustrate the concepts and overall accuracy of this technology.

Reference

For more information related to this article, you can download an Acrobat® Reader® file at www.ti.com/lit/*litnumber* and replace "*litnumber*" with the **TI Lit. #** listed below.

Document Title **TI Lit. #**

1. Yevgen Barsukov, "Support of Multiple Li-Ion Chemistries With Impedance Track™ Gas Gauges," Application Report. slua372

Related Web sites

power.ti.com
www.ti.com/sc/device/bq20z95
To download bq evaluation software:
www.ti.com/litv/zip/sluc107b

Table 2. Q_{max} and cell impedance values before and after discharge of a sample pack

	Cell Impedance Measurements Before Discharge	Cell Impedance Measurements After Discharge	Q_{max} (mAh) Before	Q_{max} (mAh) After
CELL0	xCell0 R_a 0 = 93	Cell0 R_a 0 = 124	9096	8819
	xCell0 R_a 1 = 102	Cell0 R_a 1 = 136		
	xCell0 R_a 2 = 112	Cell0 R_a 2 = 149		
	xCell0 R_a 3 = 117	Cell0 R_a 3 = 156		
	xCell0 R_a 4 = 103	Cell0 R_a 4 = 137		
	xCell0 R_a 5 = 102	Cell0 R_a 5 = 136		
	xCell0 R_a 6 = 112	Cell0 R_a 6 = 149		
	xCell0 R_a 7 = 112	Cell0 R_a 7 = 148		
	xCell0 R_a 8 = 117	Cell0 R_a 8 = 165		
	xCell0 R_a 9 = 128	Cell0 R_a 9 = 179		
	xCell0 R_a 10 = 138	Cell0 R_a 10 = 195		
	xCell0 R_a 11 = 146	Cell0 R_a 11 = 259		
	xCell0 R_a 12 = 204	Cell0 R_a 12 = 479		
	xCell0 R_a 13 = 393	Cell0 R_a 13 = 927		
	xCell0 R_a 14 = 573	Cell0 R_a 14 = 1355		
CELL1	xCell1 R_a 0 = 71	Cell1 R_a 0 = 98	9102	8833
	xCell1 R_a 1 = 79	Cell1 R_a 1 = 109		
	xCell1 R_a 2 = 88	Cell1 R_a 2 = 122		
	xCell1 R_a 3 = 95	Cell1 R_a 3 = 131		
	xCell1 R_a 4 = 79	Cell1 R_a 4 = 109		
	xCell1 R_a 5 = 80	Cell1 R_a 5 = 111		
	xCell1 R_a 6 = 89	Cell1 R_a 6 = 123		
	xCell1 R_a 7 = 87	Cell1 R_a 7 = 125		
	xCell1 R_a 8 = 90	Cell1 R_a 8 = 139		
	xCell1 R_a 9 = 98	Cell1 R_a 9 = 147		
	xCell1 R_a 10 = 108	Cell1 R_a 10 = 164		
	xCell1 R_a 11 = 114	Cell1 R_a 11 = 223		
	xCell1 R_a 12 = 159	Cell1 R_a 12 = 453		
	xCell1 R_a 13 = 338	Cell1 R_a 13 = 960		
	xCell1 R_a 14 = 491	Cell1 R_a 14 = 1397		
CELL2	xCell2 R_a 0 = 56	xCell2 R_a 0 = 83	9096	8823
	xCell2 R_a 1 = 63	xCell2 R_a 1 = 93		
	xCell2 R_a 2 = 71	xCell2 R_a 2 = 105		
	xCell2 R_a 3 = 79	xCell2 R_a 3 = 117		
	xCell2 R_a 4 = 65	xCell2 R_a 4 = 96		
	xCell2 R_a 5 = 62	xCell2 R_a 5 = 92		
	xCell2 R_a 6 = 73	xCell2 R_a 6 = 108		
	xCell2 R_a 7 = 69	xCell2 R_a 7 = 108		
	xCell2 R_a 8 = 73	xCell2 R_a 8 = 118		
	xCell2 R_a 9 = 82	xCell2 R_a 9 = 127		
	xCell2 R_a 10 = 89	xCell2 R_a 10 = 145		
	xCell2 R_a 11 = 93	xCell2 R_a 11 = 211		
	xCell2 R_a 12 = 134	xCell2 R_a 12 = 304		
	xCell2 R_a 13 = 323	xCell2 R_a 13 = 734		
	xCell2 R_a 14 = 475	xCell2 R_a 14 = 1079		

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