Protection Techniques for Small to Medium-Sized Battery Packs

Paul Pickering

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Batteries based on lithium ion hold many advantages over other battery chemistries, such as high power density and a flat discharge curve, and are the dominant choice in everything from smartphones to electric vehicles.

Depending on the particular Li-ion chemistry used, the voltage of a single cell is between 3.3 V ($LiFePO_4$) and 3.7 V ($LiCoO_2$). A battery pack consists of several cells connected in series—a pack with two cells is a "2S"battery and outputs 7.4 V; a 3Sbattery outputs 11.1 V; and so on.

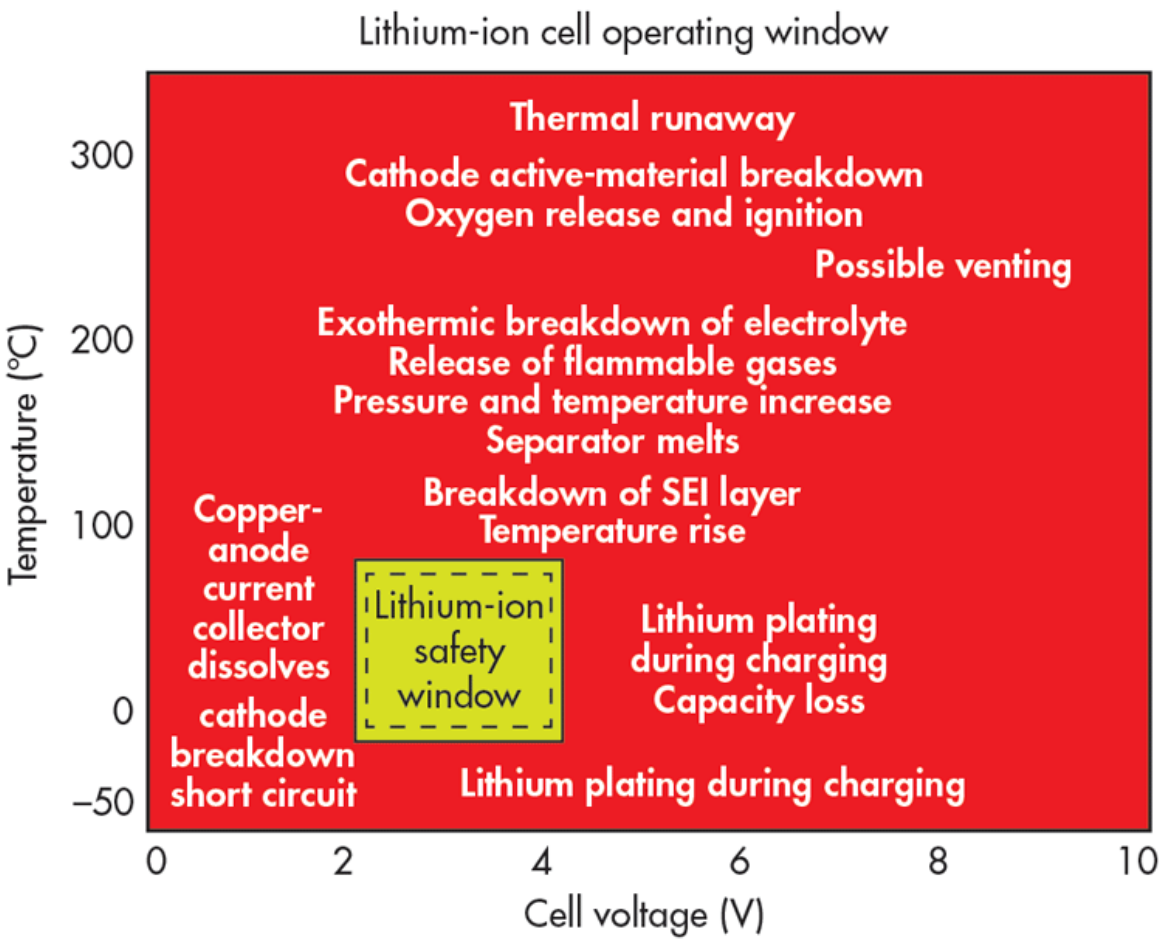
In consumer applications, a 1S battery supplies enough power for a personal electronics device such as a fitness band or smartwatch. Industrial and heavier-use consumer applications require larger sizes: 3S or 4S for small power tools or drones; 5S for professional power tools; 7S for vacuums; 10S for garden tools or larger power tools such as saws; and even 20S for heavy-duty applications like forklifts.

Protection for Li-ion Batteries

Lithium-ion batteries are saddled with one major drawback, though: They're extremely sensitive to overvoltage, high temperature, and overcurrent. Exceeding battery limits can have catastrophic consequences, as evidenced by well-publicized news items about burning hoverboards, burning cars, and even burning Boeings. Check out this news clip on one of these hoverboard mishaps:

Many airlines and delivery services ban the transportation of Li-ion batteries greater than 100-Wh capacity, equivalent to about three standard laptop batteries. *Figure 1* shows a lithium-ion cell's relatively small safe operating window and the consequences of going outside it.

To stave off disaster, Li-ion battery batteries incorporate built-in protection devices. These monitor the individual cell voltages in a multi-cell battery pack to make sure they stay within the upper and lower voltage limits. They also check for an overcurrent or short-circuit condition, typically by measuring the voltage across a series sense resistor. A sensor such as a thermistor protects against excessive temperature. If any of the limits are exceeded, the protection device disconnects the battery to avoid damage.



1. Li-ion cells must be kept within a narrow range of temperatures and voltages to avoid failure. (Source: US DOT)

Why monitor the voltage across each cell individually instead of just monitoring the voltage across the whole battery pack?

Despite the tight tolerances of modern production processes, each cell in a battery pack is slightly different. Variations between cells arise due to small differences in internal resistance, aging characteristics, self-discharge rate, overvoltage threshold, and other factors. Over time, these inter-cell variations tend to increase. In a battery pack, an undervoltage condition in one cell may cancel out an overvoltage condition in another cell with no change to the overall battery voltage. Failure may occur before the fault is recognized, so it's important to monitor each cell individually.

Incidentally, this variation between cells means that when a battery pack is charging, the process must stop when the first cell in the stack reaches its full charge, even if other cells aren't full. As differences between cells increase over time, the result is that the battery can hold less total charge, thus decreasing its useful life.

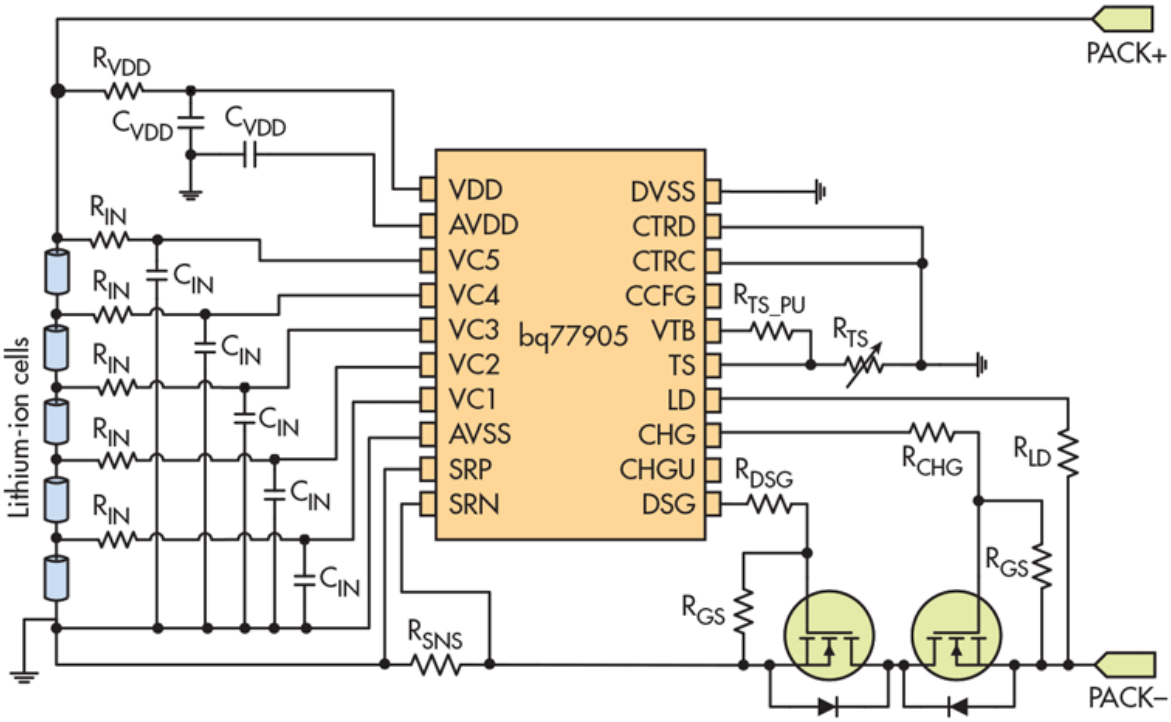
This is an inconvenience in a 5S or 10S system, but it's a major problem in an electric-vehicle (EV) battery pack that stacks 100 or more cells to generate hundreds of volts. To avoid replacing a battery due to the actions of only a couple of cells, EV battery controllers can control the charge to each cell to lessen the differences between them, a process known as load balancing.

In addition to voltage and current protection, some high-cell-count applications also require open-wire detection (OCD) to make sure that the device is always connected to each cell.

Battery Protection Using the bq7790x

possible to design rudimentary protection circuits from discrete circuits, but specialized battery-protection ɛgrated circuits are available that consume minimum power and include multiple types of protection in a single compact device.

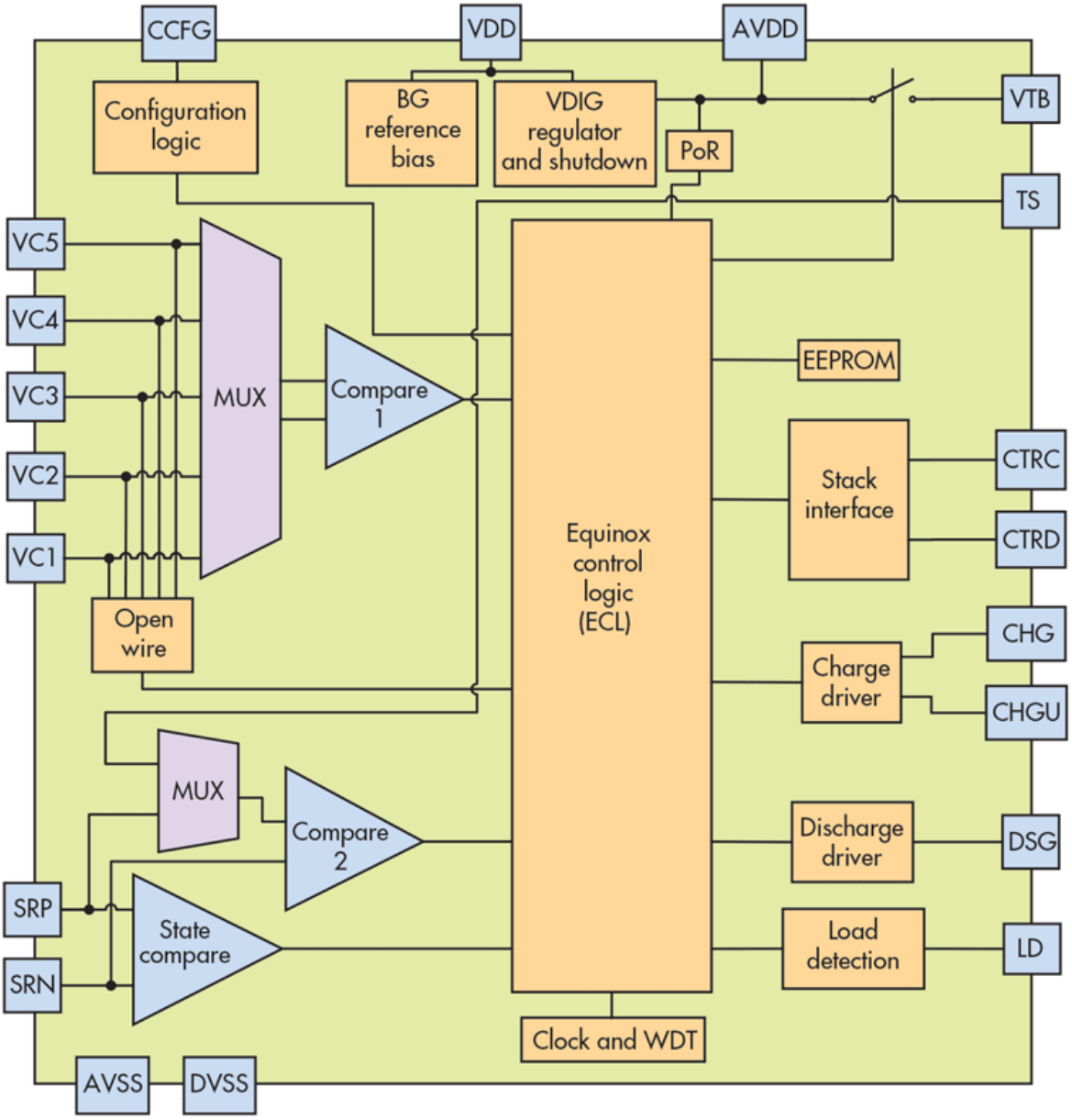
The bq77904 and bq77905 families from Texas Instruments, for example, are full-featured protectors for Li-ion or Li-polymer battery packs that provide primary protection without needing the supervision of a microcontroller. Their protection capabilities include cell overvoltage and undervoltage; battery-pack overcurrent protection; short-circuit protection; open-wire detection; and over-temperature and under-temperature protection.



2. A single bq77905 can monitor a battery pack with up to five cells; the bq77904 can accommodate up to four cells. (Source: Texas Instruments)

Figure 2 shows the bq77905 protecting a 5S battery pack. The bq77905 monitors the voltage across each cell to make sure it's within limits. The current of the battery pack is measured via a sense resistor (R_{SNS}), and a thermistor indicates the temperature. Internal circuitry detects an open-wire condition. If the bq77905 detects a fault, it disconnects the battery by means of the two series FETs in the battery-pack negative leg. Depending on the type of fault, it will turn off either the CHG FET or DSG FET, or both. Consult the datasheet for more information.

Internal Operation of bq77905



3. The bq77905 battery protector provides overvoltage, overcurrent, and over-temperature protection without microcontroller control. (Source: Texas Instruments)

Figure 3 shows the internal block diagram of the bq77905. The device supports 3S, 4S, or 5S cell configurations. The companion bq77904 supports a 3S or 4S cell configuration; the differences are discussed in the datasheet.

The bq77905 has two internal comparators that split up the detection functions according to the *table*.

DETECTION FUNCTIONS	
	Protection Checks
Comparator #1	• Overvoltage (OV) • Undervoltage (UV) • Open wire (OW)
Comparator #2	• Overcharging 1 (OCD1) • Overcharging 2 (OCD2) • Short-circuit (SCD) • Over-temperature during charging (OTC) • Over-temperature during discharging (OTD) • Under-temperature during charging (UTC) • Under-temperature during discharging (UTD)

Each of the comparators runs on a time-multiplexed schedule and cycles through its assigned protection-fault checks. For OV, UV, and OW protection faults, the bq77905 checks each cell in order, starting with cell 1. The voltage at the CCFG pin indicates how many cells are connected in series. This is necessary to avoid erroneously detecting a UV fault on an unused input pin.

The detection mechanisms vary with the fault being tested for:

• *Voltage faults (OV, UV):* The bq77905 compares the voltage of each cell to the programmed overvoltage and undervoltage values and signals of an OV or UV fault if at least one cell is above the OV limit or below the UV limit for a specified time.

• *Current faults (OCD1, OCD2):* The bq77905 measures the voltage across a sense resistor connected in series with the battery-pack negative terminal and compares it to preset values to determine overcurrent and undercurrent faults. Again, a minimum time applies.

• *Open-wire faults (OW):* To detect an open-wire (OW) fault, at least one of the cell voltages must be below the OW threshold voltage for a specified time.

• *Temperature faults (OTC, OTD, UTC, UTD):* An over-temperature fault occurs if the voltage across an external thermistor exceeds the program limit for a specified time; an under-temperature fault results from a thermistor voltage below the appropriate limit. A different set of limits applies to battery charging and discharging.

• *Short-circuit fault (SCD):* This occurs if the voltage measured across the current-sense resistor is below the specified threshold.

The protection thresholds and delays for the bq7790x are factory-programmed and parts are available in a variety of combinations. This flexibility allows the designer to create a common platform for different battery-pack designs and reduces time needed to develop new variations.

The complete part number includes two final digits that indicate its factory-programmed parameter values. *Figure 4* shows the default configuration bq7790500.

	OV			UV				OW	OCD1		OCD2		SCD	Current fault recovery		Temperature (°C)			
Part number	Threshold (mV)	Delay (s)	Hyst (mV)	Thresh (mV)	Delay (s)	Hyst (mV)	Load removal recovery (Y/N)	Current (nA)	Threshold (mV)	Delay (ms)	Threshold (mV)	Delay (ms)	Threshold (mV)	Delay (s)	Method	OTD	OTC	UTD	UTC
bq7790500	4200	0.5	100	2600	1	400	Y	100	30	1420	50	700	120	1	Load removal + delay	70	50	–20	0

4. To handle different applications, many parameters are factory-programmable—the bq7790500 is shown. The temperature trip points are target values and depend on the external components selected. (Source: Texas Instruments)

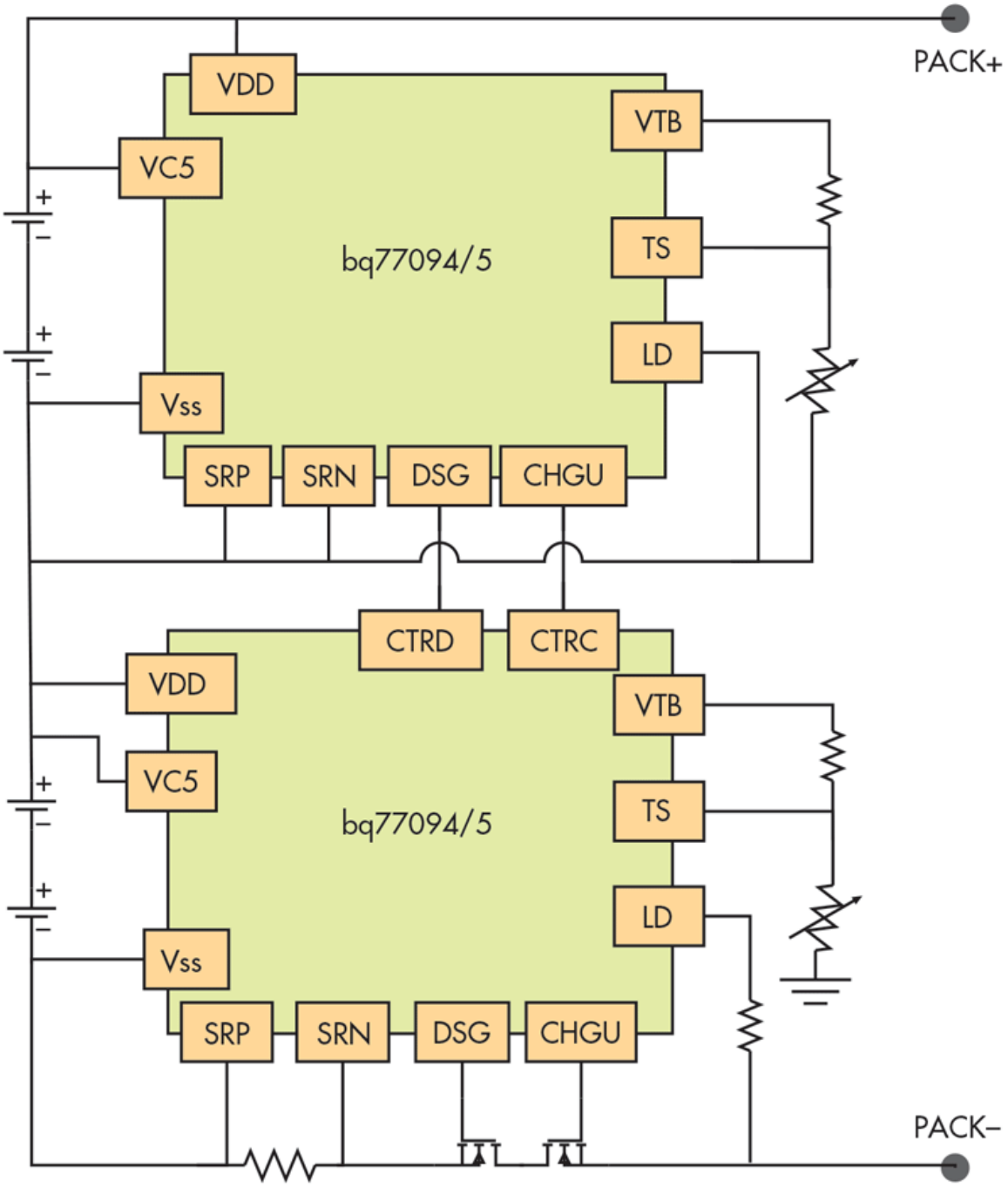
Internal Fault Checking

The bq7790x includes two internal self-checks. A scheduled built-in self-test (BIST) is run on the comparators to verify their correct operation. An error will turn off the CHG and DSG FETs, but this is not a latching fault and the device will resume normal operation when a correct BIST occurs.

During programming at the factory, a CRC is generated—and programmed into memory—that represents the configuration of the device. The device periodically checks the programmed settings against the CRC during normal operation. If three consecutive errors occur, the device will turn off both FETs to disconnect the battery, and only a power-on reset (PoR) can force a reset.

Protecting Larger Cell Stacks

If there are too many cells for a single-chip solution, *Figure 5* shows how two bq7709x devices can be daisy-chained to monitor a battery pack with up to 10 cells. Only the bottom device drives DSG and CHG FETs in a multi-stack configuration. The upper device DSG and CHGU pins are connected to the CTRD and CTRC pins of the lower device to provide the drive signal to turn off the power FETs.



5. Multiple bq7709x devices can be cascaded to monitor larger battery packs. (Source: Texas Instruments)

If spare channels are available in a stacked arrangement, the upper devices should be configured for higher cell count to provide a stronger CRTD/CRTC signal to the lowest (driving) device. A maximum of four devices can be stacked to handle a 20S battery pack.

Battery-Protection Evaluation Module (EVM)

The bq77905EVM-707 is an evaluation board for the bq77905 that includes the default bq7790500 configuration of the device. The EVM includes a thermistor and jumper pins to allow for easy simulation of over- and under-temperature conditions, plus external CHG and DSG FETs to demonstrate current control.The bq7790500 configuration is shown in Fig. 4 and in the datasheet.

Battery-Management Resources

s article has discussed primary protection for small-scale battery packs, but battery management is a multi-
ɛted topic and the requirements vary by application. Texas Instruments has a section on its website devoted to battery-management solutions, including solutions aimed at personal electronics, industrial, and automotive applications. It includes other information, specifically on battery-management training and design support. TI also offers a book on battery management from two of its battery-management experts.

For more information on any battery-protection or battery-management topic, please contact your local TI Sales Office.

Source URL: http://electronicdesign.com/power/protection-techniques-small-medium-sized-battery-packs