Passive thermal management optimizes lithium-ion battery pack performance

Steve Wener - May 08, 2019

When properly designed and manufactured, lithium-ion battery packs are very reliable and will usually live up to the lofty expectations people have for them. However, when exposed to certain events or conditions, lithium-ion battery packs can experience performance degradation or even failure.

Electrical or mechanical abuse, cell manufacturing defects, and unfavorable thermal conditions can cause problems for lithium-ion packs. Of these, unfavorable thermal conditions may be the most common reason for sub-par battery pack performance. This article explains how passive thermal management in Li-ion battery packs promotes optimal pack performance. It also describes some practical and effective passive thermal management techniques.

While some Li-ion battery packs use only a single Li-ion cell, many involve multiple cells connected in series and parallel configurations to increase the pack's voltage and capacity. Li-ion battery packs also require a safety circuit, which can be anything from a basic, off-the-shelf safety circuit to a sophisticated battery management system (BMS). Simple Li-ion battery packs consist of a couple of cells, a basic safety circuit, nickel tabs, electrical insulation, and wires within a PVC heat-shrink sleeve (Figure 1).

Figure 1 Simple Li-ion battery pack with heat-shrink cover
Many of today’s Li-ion battery packs, however, are complex electro-mechanical systems housed in durable enclosures designed to be used in life-saving medical devices, and critical military and aerospace applications. These battery packs are expensive and expected to meet demanding consumer performance and capacity expectations (Figure 2).

![Complex Li-ion battery pack](image)

**Figure 2** Complex Li-ion battery pack (machined aluminum enclosure not shown)

Most Li-ion battery packs perform well. Occasionally, however, some packs exhibit inadequate charge acceptance and rapid capacity fade. A common reason for poor Li-ion battery pack performance is the existence of unfavorable thermal conditions within the pack. Excessive heat, either combined with or independent of an inhomogeneous thermal profile across the cells within a pack affects performance significantly. Elevated temperatures accelerate the normal chemical processes taking place in the cells, leading to cell aging and loss of capacity [1]. Testing has shown cells cycled at 45°C experience a more significant decrease in capacity than cells cycled at 25°C over the same period [2].

Furthermore, simulations show that a temperature difference between parallel-connected cells greatly aggravates the imbalance discharge phenomenon between the cells. This chain of events accelerates the losses of the battery pack capacity [3]. For Li-ion battery packs, the industry accepted design constraint for temperature variation between cells in a pack is 5°C [3]. Li-ion cells can be charged and discharged over a broad temperature range. Most of today’s ordinary Li-ion cells can be charged from 0°C to 45°C and discharged from −20°C to 60°C [4]. Among Li-ion cell manufacturers, the generally accepted optimal operating temperature range for Li-ion cells is between 20°C and 40°C.

Li-ion cells heat up when subjected to high charge and discharge currents. To keep cells within a battery pack operating in their optimal temperature range and maintain a homogeneous thermal profile across the cells, battery pack engineers should incorporate some form of thermal management into their designs. The two types of thermal management applied to battery packs are “active” thermal management and “passive” thermal management. Active thermal management includes cooling from forced air, forced liquid, or both. Active thermal management systems require fans or blowers for forced air cooling and pumps for forced liquid cooling. Active thermal management is often used for Li-ion battery packs in all-electric and hybrid-electric vehicles.
However, active thermal management technologies can be complex and costly.

Passive thermal management is a cooling technology that absorbs heat solely via thermodynamics; i.e., convection, conduction, and radiation [6]. Passive cooling techniques are typically less complex and less expensive than active cooling approaches and are more suited for many smaller and mid-sized battery packs. One common approach to passive thermal management in Li-ion battery packs is to apply a heat sink. Heat sinks are typically made from aluminum, copper, or some other material with a high level of thermal conductivity. Through conduction, the heat from the Li-ion cells transfers to the heat sink and then to an enclosure’s walls. The heat then dissipates into the surrounding environment. It’s good practice to apply a compliant thermal interface material between the heat sink and the cells to promote efficient heat transfer (Figure 3).

![Figure 3](image)

Figure 3 A Li-ion battery pack with an aluminum heat sink is shown in blue and a thermally conductive, dielectric pad between cells and heat sink is shown in red.

Another effective passive thermal management technique is to employ phase change material (PCM) in the battery pack design. PCMs absorb heat while changing from a solid to a liquid state, once their phase transition temperature is reached. Manufacturers of PCM thermal management products
produce a variety of materials that are impregnated with PCMs. These materials maintain their original solid shape while the PCM within changes phase and absorbs heat (figures 4-7).

**Figure 4** 18650 Li-ion cell next to PCM sleeve

**Figure 5** 18650 Li-ion cell inserted into PCM sleeve
Heat spreaders contribute to balancing the thermal profile within Li-ion battery packs. Heat spreaders used in conjunction with heat sinks efficiently transfer heat away from the cells. Heat spreaders can be graphite sheets coated with thin dielectric films or thermally conductive metal foils. Since they are flexible, heat spreaders can weave between cells before terminating at heat sinks (Figure 8).
The fourth example of a practical approach to passive thermal management in battery packs is to encapsulate the Li-ion cells and other electronics within the enclosure in a thermally conductive, electrically insulating potting compound. The heat from the cells is dissipated within the enclosure and conducted to the heat sink or enclosure walls. It is important to note that when encapsulating Li-ion cells, the area around the cell vents must be kept clear of potting compound (Figure 9).
While this article touches on four methods used for passive thermal management in Li-ion battery packs, there are other methods. The reader is encouraged to do additional research and choose the approach that is right for their specific application. Additionally, the methods described here are not mutually exclusive and can be used in combination with one another.

Steve Wener is senior principal engineer at Inventus Power.

References

1. Tom O’Hara and Dr. Maria Wesseimark, Battery Technologies: A General Overview and Focus on Lithium-Ion, Intertek
2. Diagnostic Examination of Generation 2 Lithium-Ion Cells Assessment of Performance Degradation Mechanisms, Argonne National Laboratory (July 2005)
4. Dr. Robin Sarah Tichy, Battery Power Products and Technology (May/June 2007)
5. BU-410: Charging at High and Low Temperatures, Battery University (Sept 2017)

Related articles:

- Introduction to lithium-ion rechargeable battery design
- Keeping it safe: The lithium-ion battery
• Virtual prototyping: a powerful tool for thermal management
• Special report: Beyond the exploding battery