Lithium - ion '18650' Battery Failures

By Robert Morley MIEAust CPEng NER**,**
Consulting Electrical Engineer

Did you know that the battery pack in the Tesla Model S passenger vehicle and the Nikola One heavy duty truck are made up of individual '18650' battery cells? The Nikola One has 32,000 cells in series and parallel configuration to produce a 320kWh battery.

The 18650 battery

An individual 18650 battery cell (*Photo 1*) is 18mm in diameter and between 65mm and 67mm in length with amp-hour capacities of an individual cell pushing over 3500mAh with nominal cell voltages between 3.6 V – 3.7 V. Higher voltages are obtained by connecting cells in series and greater capacity is obtained by connecting cells in parallel. The 18650 battery is widely used in high drain consumer electronics such as torches, cordless tools and power banks. In these devices the 18650 batteries are installed in various series and parallel configuration to get the desired voltage and capacity. Whilst other battery sizes exist, the 18650 is presently the most common size; however, Tesla has announced plans to use 20700 (20mm diameter and 70mm length) size batteries.

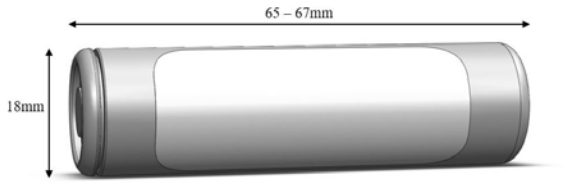

Photo 1: 18650 battery cell

Battery protections

18650 batteries require internal protection devices to avoid failures that may result in fire. Nearly all 18650 battery cells have the following internal protection devices:

- Positive Temperature Coefficient (PTC): This series element increases resistance with an increase in temperature, protecting the battery cell during a fault condition such as short-circuit. The PTC resets once the fault condition has cleared.
- Current Interrupt Device (CID): This device is a pressure valve that will protect the battery cell during fault conditions such as an overcharge, where there is an increase in internal gas pressure. The result is the internal gas will vent to atmosphere.

Additionally some 18650 battery makes have an internal protection circuit module (*Photo 2*). This method involves a small Printed Circuit Board (PCB), usually at the negative end of the battery cell, with electronics that can have protections against the following fault conditions:

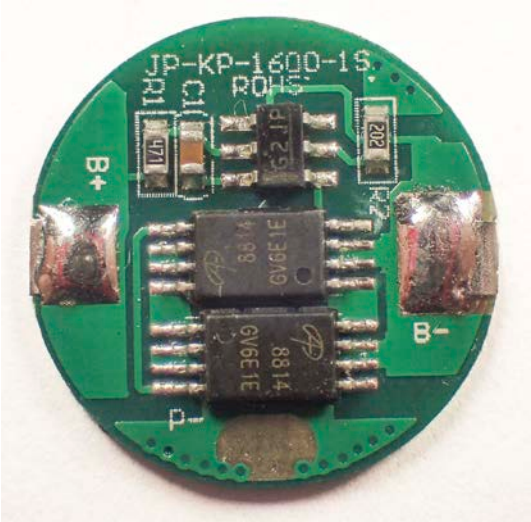

Photo 2: 18650 protection circuit module

- Overcharge (> 4.25 V*)
- Overcurrent (>8A)
- Short-circuit
- Over discharge (< 2.48 V)

* Voltage and current measurement were taken during testing of one protected 18650 cell. Values will differ between manufacturers. A protected 18650 battery with a protection circuit module can be identified by the slightly longer length (typically ~67mm). This method of protection monitors the voltage and current of each individual 18650 battery cell and temporarily disconnects the battery if a limit is exceeded.

A research study completed by the National Aeronautics and Space Administration (NASA)[1] looked into the *Safety limitations associated with commercial 18650 lithium-ion cells.* The research paper studied the limitation of both PTC and CID protections in single and various series and parallel connection arrangements of 18650 battery cells.

The NASA paper concludes the PTC and CID protections were effective for imposed single cell overcharge and external short-circuit conditions. PTC and CID protection failed to protect the cells when installed in certain series and parallel arrangements. The paper also concluded that certain series and parallel arrangements resulted in a thermal runaway condition and cell rupture. That is, under fault conditions a battery cell became hot and the elevated temperature led to further degradation and eventual failure / thermal runaway. The majority of electrical applications that use 18650 batteries have multiple battery inter connections.

Monitoring individual battery cell voltage can be an effective protection measure against overcharge or over discharge. This is known as a Battery Management System (BMS). This

[1] https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20100037250.pdf

increases manufacturing costs and complexity and therefore is not a widely adopted protection method for multiple 18650 battery configurations.

Battery failure

I recently investigated a 24V battery pack failure which involves 28 individual 18650 battery cells arranged in a 7S4P (7 in series, 4 in parallel) arrangement.

Photo 3: Failed 18650 battery cell

The 18650 batteries, shown in *Photo 3,* had both PTC and CID protection; however, did not have a PCB module. One of the 18650 battery cells was defective resulting in overcharging of the other 18650 battery cells. The overcharged 18650 battery cell eventually ruptured releasing flammable gases. The charge system did not have a BMS to monitor individual cell voltages. In this example overcharging and fire initiation would probably not have occurred if a BMS or protection circuit modules had been incorporated into the charge system. There is an international standard IEC 62133 for lithium ion / polymer batteries; however, this standard is not mandated in Australia. In Australia they are classified as level 1 (non-prescribed) electrical equipment, only requiring the supplier to provide evidence that the equipment is electrically safe.

Another problem that sometimes occurs is that an incorrect charging voltage is applied to a battery pack because there are no mandated standards for cylindrical DC charge plug voltage levels. Plugging a 12 Vdc supply into a 6 Vdc battery pack can result in an over-charging failure.

Corrective Action

Cell level protection methods such as Positive Temperature Coefficient (PTC) and Current Interrupt Device (CID) are not always effective when 18650 battery cells are installed in series and parallel configurations. A Battery Management System (BMS) should be utilised in all multiple 18650 battery configurations, allowing individual cell voltages to be measured. This approach would greatly reduce the likelihood of overcharging an individual cell and cell failure possibly resulting in fire.