Megger.

Lithium-Ion battery maintenance

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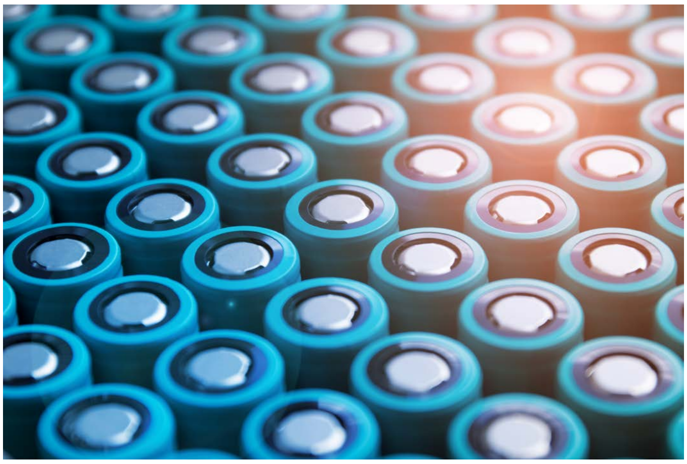
Lithium-ion (or Li-ion) batteries are a family of batteries that consist of different types of chemistries, each with their own unique characteristics and configurations.



General types:

As there are both lithium batteries and lithium-ion batteries, it may be easy to assume that they are the same, but these battery types are, in fact, fundamentally different.

Lithium batteries are primary batteries, meaning they are not rechargeable. Because lithium batteries use metallic lithium as the anode, these types of batteries are also referred to as lithium-metal batteries.

Lithium-ion batteries, on the other hand, are secondary batteries or rechargeable batteries. Lithium-ion batteries are constructed with rechargeable cells that can be built in several different configurations.

Cylindrical: This type of lithium-ion battery is constructed using multiple individual cylindrical cells. These can be connected in different series – parallel configurations. This allows the battery to meet different voltage and capacity requirements. Cylindrical cells can be produced easily and quickly, often resulting in a lower cost per kWh. These types of battery packs tend to be larger and heavier than other configurations, such as prismatic. However, due to their larger mass, they carry the benefit of radiating heat and controlling temperature more easily.

Prismatic: Prismatic cells are made up of many flat, positive and negative electrodes layered together. The main advantage of this lithium-ion type battery is its thin profile, light weight, and effective use of space. These batteries are typically used in mobile phones. Prismatic cells can be designed to be larger than cylindrical cells and hence contain more energy per cell. Because prismatic cells can be larger than cylindrical cells, fewer cells can be used to achieve the same amount of energy, meaning fewer electrical connections and fewer opportunities for manufacturing defects. Also, since prismatic cells can be larger than cylindrical cells, they can store more energy. However, cylindrical cells will tend to be able to supply more power.

In general, cylindrical cells are better for high-performance applications because they can dissipate heat better, whereas prismatic cells are better for optimized energy efficiency.

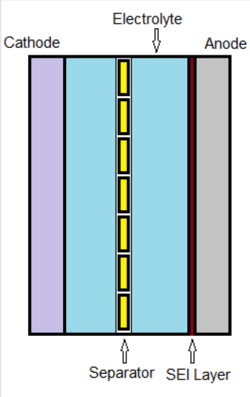
Lithium-ion battery chemistries:

The characteristics of different chemistry lithium-ion batteries are distinct due to the unique materials used in each composition.

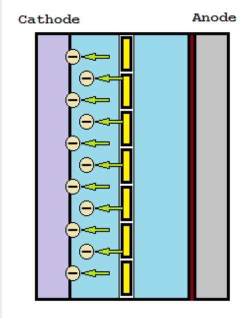
The following table allows a basic comparison of battery attributes for different chemistries.

Attribute	lithium nickel-manganese-cobalt oxide (NMC)	lithium nickel-cobalt-aluminium oxide (NCA)]	lithium manganese oxide (LMO)	lithium iron phosphate (LFP)
Calendar life (20 °C – 25 °C)	3	4	2	3
Calendar life (> 40 °C)	3	4	1	2
Low temperature capacity availability	3	3	3	2
Safety	2	2	3	4
Energy density	4	4	3	3
Power density	4	4	4	4

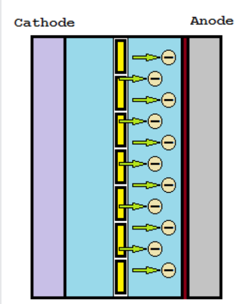
Although the Li-ion battery can come in a wide range of chemistries, they all tend to operate in the same general manner. They consist of a negative electrode (anode). This is typically a layered carbon. They also contain a positive electrode (cathode). This is typically a metal oxide or metal phosphate. The anode and cathode will be contained within an electrolyte that is comprised of a lithium salt in an organic solvent.



During discharge, lithium ions flow from the carbon layers in the anode to the oxide layers in the cathode.



During charging, the process reverses. The lithium ions flow from the cathode to the anode. This process is known as intercalation.



Lithium-ion battery aging and failures:

Aging of lithium-based batteries is due to both calendar aging and battery cycling. The overall rate of aging will be a combination of both the battery cycling and the calendar aging.

As lithium-ion batteries age, there will be a reduction of available capacity (fading) and an increase in internal battery impedance. For many Li-ion technologies, the aging will proceed at a relatively linear rate up to a certain point, typically 60 or 70 of rated capacity. At this point the rate of aging will accelerate.

Calendar aging

Calendar aging is influenced by the type of positive electrode material, temperature, and operating voltage.

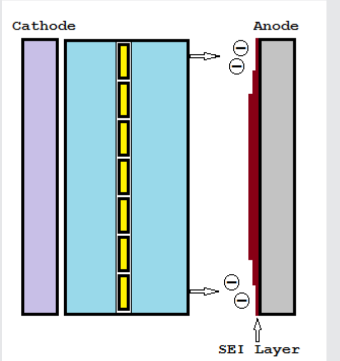
In general, an increase in temperature of 10 ◦C will reduce the life of the battery by half. The voltage level affects the thermodynamic stability of the positive material. Calendar aging occurs during both battery storage and battery service.

Cyclic aging

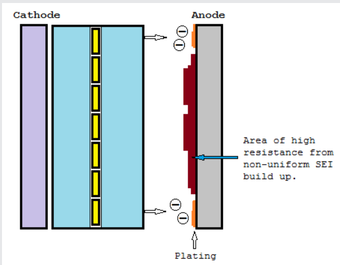
Cyclic aging affects both the positive and negative electrodes. The rate of this aging process is dependent not only on the frequency of the cycling, but also the depth of the cycling and the rate of charge.

Some materials will experience stress during very deep discharges, with a corresponding increase in internal resistance. How the rate of charge impacts aging is better understood through a brief review of the physical processes taking place during the charging period.

On the anode, there is a limit to the rate at which lithium ions can be accepted during charging. Lithium ions must pass through the Solid Electrolyte Interface (SEI) during charging. The faster the rate of charging, the more lithium ions will be deposited on the outside of the SEI. These will react to form lithium carbonate. This causes a loss of capacity and an increase in the thickness of the SEI layer, which leads to a higher internal resistance.



The maximum rate of intercalation of lithium ions into the anode decreases as the temperature decreases. This means that charge rates must be decreased to avoid excessive SEI build up. This can lead to lithium plating that can lead to a thermal runway condition.



For most lithium-ion chemistries, therefore, the maximum rate of charge will be lower than the maximum rate of discharge.

Failure modes:

Beyond the normal aging modes, there are various failure modes associated with lithium-ion batteries. Lithium-ion battery packs generally have a built-in battery management system (BMS). This will monitor parameters such as voltage, temperature, rate of discharge, and rate of recharge. The BMS electronics are intended to maintain battery safety. This will reduce the likelihood of a catastrophic failure. However, cells can still fail within the pack.

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Short circuits

Short circuits can occur within an individual cell or within the battery. Shorts within the battery can result from abuse, component failure or manufacturing defects. Shorts in the cell can also be caused by dendrite formations that occur due to excessive charge rates. These short circuits create heat which can lead to thermal runaway.

Overdischarge

Overdischarge of a lithium-ion battery occurs when a cell voltage falls below a critical minimum. At this point, material from the anode will dissolve into the electrolyte. When recharged, the material comes out of solution to form micro-shorts. The battery management system (BMS) typically includes a device that will open when a minimum battery voltage is reached. However, if the battery is not recharged for an extended period, it is possible that ongoing self-discharge could lead to an overdischarge condition. Prolonged storage can lead to overdischarge.

Overcharge

Charging rates should be controlled by the BMS. However, control failures or improper system setup can result in excessive charge rates. Excessive charge rates will increase the battery aging, or depending on the rate of charge, it can cause lithium plating on the anode, causing short circuits.

Thermal runaway

Heat from an external source or from short circuits can cause the SEI to become unstable and to react uncontrollably with the electrolyte. This will lead to a thermal runaway. The temperature at which a thermal runaway will take place is design dependent. It is generally in excess of 100 °C. Batteries that have higher safety marks typically will require higher temperatures to elicit a thermal runaway.

Electronic failures

Lithium-ion batteries are normally equipped with battery management systems (BMS). Electronic failures should be expected. Failures of the BMS will generally result in a battery string being taken off-line. So, in critical applications, parallel strings are recommended.

Safety:

When working with lithium-Ion batteries, proper PPE should be worn based on electrical hazards such as voltage and arc flash.

The electrolyte used in lithium-ion batteries is flammable and will ignite if it gets hot enough. Different chemistries have different ignition temperatures.

If one cell within a lithium-ion battery pack goes into thermal runaway, it will ignite and produce a large amount of heat. This will cause the cell next to it to heat up to the point of ignition. This creates a chain reaction leading to a catastrophic failure. If the battery packs are too close together, then this can lead to a chain reaction throughout the string. For this reason, the proper battery rack needs to be used. These racks will minimise any thermal runaway between battery packs. Contact the manufacturer for the proper containment racks.

If racks are not used, then there must be adequate spacing between the batteries to minimise any chain reactions due to thermal runaway. Reference local safety standards.

Fires involving lithium batteries cannot be extinguished with dry-chemical or oxygen-depleting extinguishers. Extinguishers that provide cooling are recommended.

Maintenance recommendations:

Cyclic Applications

Cyclic applications are those in which the battery string discharges and recharges on a regular cycle. These will include energy storage applications such as solar and wind energy storage.

In these types of applications, maintenance is minimal. The lithium-ion battery string does require a BMS. The BMS will provide continuous monitoring of the cell voltage, the cell balance, the cell temperature, the charge, and the discharge.

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In a cyclic application, the batteries are charging and discharging on a daily schedule. This is akin to having a daily discharge test performed.

The general battery maintenance in these uses should include:

- **Visual inspections**
- **Cleaning or replacement of air filters in cabinets**
- **Fire-suppression systems evaluations**

Failures can occur in lithium-ion strings in cyclic applications. These can be due to electronics failures, poor connections, or bad cells.

In these cases, troubleshooting may be needed.

Measurements of each battery's voltage and impedance can identify batteries that are dissimilar to the rest of the string. This can help isolate where there may be potential problems.

The Megger BITE5 will measure the voltage and the impedance of lithium-ion cells up to 200 V DC.

A thermal imager can be useful for identifying hot spots that may be due to poor connections.

The Megger TC3231 thermal imager is ideal for this application.

Stationary applications

When lithium-ion batteries are used in stationary applications, they must be configured differently than those in cyclic applications.

In cyclic applications, the lithium-ion battery BMS systems is designed to open the cell when any 'out of range' is detected. This is done to protect the cell. In cyclic applications, the battery is the key asset.

In stationary applications, the battery is backing up the key asset. In these applications, it is preferable to lose the battery instead of the asset. Therefore, the battery needs to be configured to only open in the case of potential battery failure.

NOTE: This can still lead to an open battery string and a loss of backup. In critical applications that utilise lithium-ion batteries, a parallel string configuration is needed to provide redundancy.

In stationary applications, the batteries are not being discharged and charged on a regular basis. The batteries remain on float for extended periods of time.

In these applications, periodic testing is recommended along with visual inspection.

The battery voltage and impedance should be measured on a periodic basis. Trending test results over time will identify SEI build up.

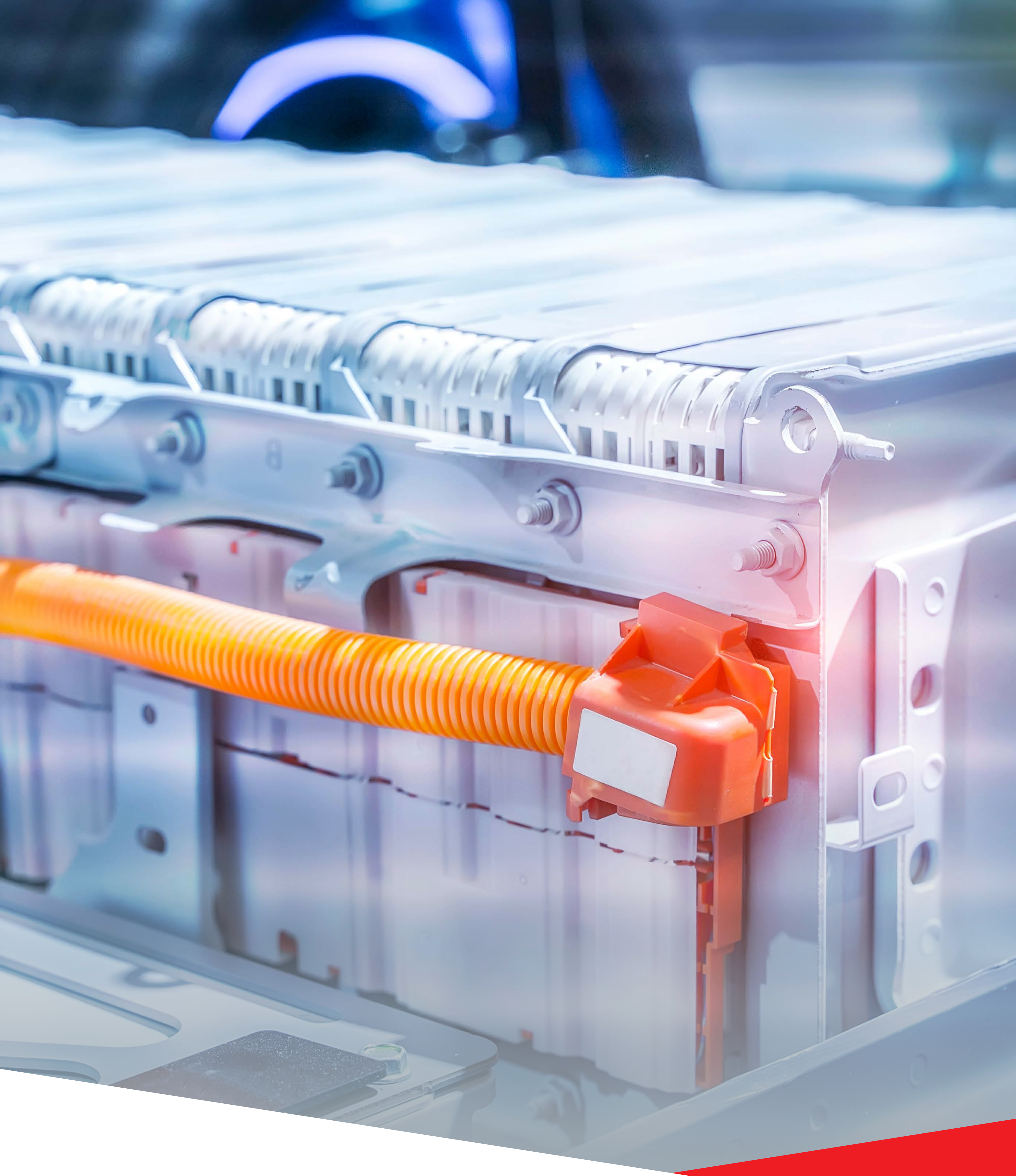
For some materials, the internal resistance increase that occurs with age can be relatively small, and for others, a doubling or tripling of internal resistance is not unusual. Check with the manufacturer for your particular battery.

The BITE5 can perform the voltage and impedance measurements on all lithium-ion batteries. It will store the results and allow you to trend them over time for each cell. You can also transfer the data to the Power DB PC-based software. This will allow for automated analysis and custom report generation.

Thermal imaging is also useful to identify hot spots that may exist. This can identify potential connection issues. The Megger TC3231 thermal imager can identify hot spots. The images can be saved and downloaded and then can be included in the Power DB report.

Periodic discharge testing every quarter of the battery life is also recommended. This is a direct measurement of available cell capacity at a given discharge rate.

The Megger Torkel 900 can provide a constant current load, a constant resistance load, or it can be programmed to provide a specific discharge profile. The BITE5 can be used to record the discharge voltage of each cell throughout the discharge process.



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