

# UNDERSTANDING LITHIUM-ION TECHNOLOGY

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## ABSTRACT

To the average person, lithium-ion technology, at least until the last year or so, was represented by the black-box-like batteries in high-end consumer devices such as laptop computers. Mobile phone batteries use similar chemistry, although in that case the batteries are often lithium-polymer types that are frequently described as if they constitute an entirely different technology. The mystique of lithium-ion batteries even seems to extend to the industry lexicon, with cognoscenti talking about cathode and anode materials—words familiar from physics or chemistry courses at school but rarely used in the world of lead-acid batteries.

Now, amid news stories about safety issues and consumer battery recalls we are seeing lithium-ion batteries being promoted for power tools, electric vehicles and also standby-power applications. New terminology is appearing, such as iron phosphate and lithium titanate, and nanotechnology is being incorporated into some designs. Confusion reigns, because all of these products fall into the same broad ‘lithium-ion’ category.

This paper describes the various electrochemical couples that together form the lithium-ion family. The characteristics of the main couples will be described, particularly with respect to safety improvements and their potential operational tradeoffs. The aim of the paper is to provide a basic understanding of lithium-ion batteries and their potential for use in a variety of stationary applications.

## THE BASICS

Lithium-ion technology has its roots in primary batteries with metallic lithium negatives. Early attempts to produce rechargeable lithium batteries were thwarted by the poor cycling characteristics and safety issues associated with metallic lithium and it was not until an announcement by Sony in 1990<sup>1</sup> that the lithium-ion battery of today could be envisaged. Sony developed a carbon negative that allowed the intercalation (insertion) of ionic lithium and paired it with a high-voltage positive material using lithiated cobalt oxide. Additional historical information can be found in other papers<sup>2,3</sup>.

This historical background explains some of the terminology used in the lithium battery community. For example, the positive and negative electrodes are frequently described as the cathode and anode, respectively. These names work well enough for primary batteries but become confusing when applied to rechargeable battery electrodes. By definition, the anode is the electrode undergoing oxidation and the cathode is the electrode being reduced. This means that the positive electrode is the cathode only on discharge, and becomes the anode on charge. For the float applications normally discussed at Battcon the battery spends over 99% of its life on charge, so it seems inappropriate to describe the positive as the cathode when it is almost always the anode! Be that as it may, it is not the purpose of this paper to push the lithium battery industry to change its ways but to inform the reader of the terminology used by that industry.

The reaction mechanism of lithium-ion batteries is represented by Figure 1. The positive and negative materials usually have a layered structure to facilitate intercalation of lithium ions. The net effect of the charge and discharge reaction is the movement of lithium ions back and forth between the electrodes, matched by a corresponding flow of electrons in the external circuit. Although it is tempting to think of this process, called a “rocking-chair” mechanism, in purely physical terms the process is indeed electrochemical, being driven by the respective electrode voltages. In fact, the term ‘lithium-ion’ refers not to just one electrochemical system but to a range of systems in which lithium ions are exchanged between the electrodes on charge and discharge. Moreover, the use of different electrode materials can impart markedly different characteristics for the resulting lithium-ion cells.

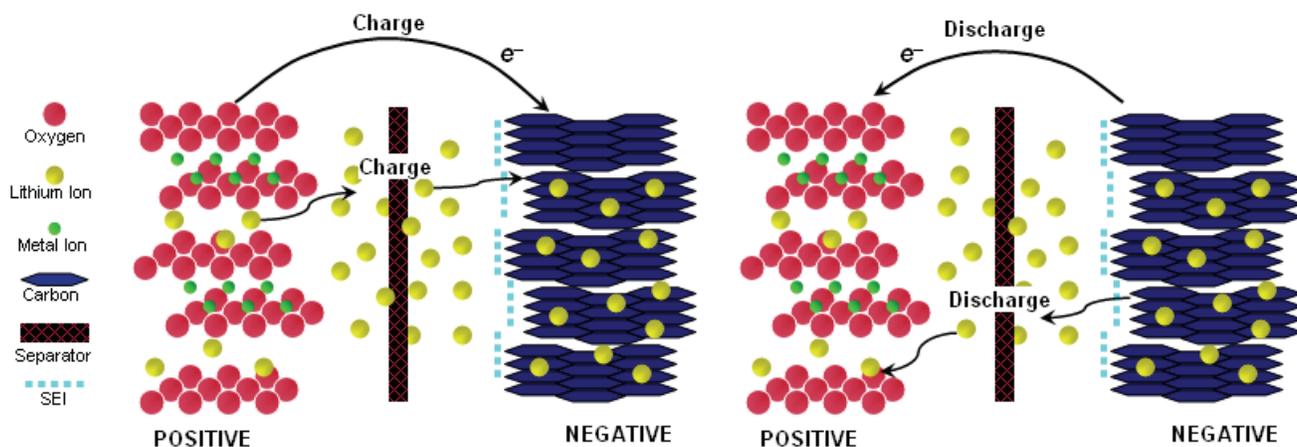


Figure 1. Representation of lithium-ion reaction mechanism

### Positive Active Materials

The use of lithiated cobalt oxide ( $\text{LiCoO}_2$ ) by Sony has already been mentioned, and this material has remained the predominant positive material in the portable battery industry. Cells using  $\text{LiCoO}_2$  have high energy density and cycle life of around 500-700 deep discharge cycles, making them a good choice for many consumer applications. The main issue with this material, as highlighted by the laptop battery recalls of 2006 and beyond, is that when abused it can release large amounts of energy, potentially resulting in a fire.

The adverse safety aspects of  $\text{LiCoO}_2$  have led researchers to search for alternative materials for the positive electrode. One such material that is in limited production for consumer applications is lithiated manganese oxide,  $\text{LiMn}_2\text{O}_4$ , also known as spinel for its crystal structure. This material yields cells with similar voltage characteristics and energy density to cobalt-based cells. Safety is much improved but unfortunately these cells exhibit rather rapid capacity fading, as will be discussed later in this paper.

Other companies have explored mixed-oxide materials, in which a large portion of the  $\text{LiCoO}_2$  is substituted by one or two other transition-metal oxides. Two such materials are based on lithiated nickel oxide,  $\text{LiNiO}_2$ . The first is known as NCA material since it is a mixture of lithiated nickel, cobalt and aluminum oxides. NCA is somewhat safer than  $\text{LiCoO}_2$ , largely by virtue of the fact that it has a slightly lower voltage at full charge and therefore a larger margin to accept overcharge. NCA also has far superior life characteristics, both on float and in cycling, and is therefore the positive material of choice for many automobile manufacturers for the next generation of hybrid electric vehicles.

The second nickel-based material is known as NMC and is a mixture of lithiated nickel, manganese and cobalt oxides. Considering only safety on overcharge, NMC ranks between NCA and  $\text{LiMn}_2\text{O}_4$ . This material should also have better cycle life than  $\text{LiCoO}_2$  although the inclusion of manganese oxide makes NMC subject to increased capacity fading compared to NCA. A number of portable battery manufacturers are working with NMC.

For a significant improvement in safety in a positive electrode material it is necessary to move away from oxide materials to ones based on phosphates. Lithiated iron phosphate ( $\text{LiFePO}_4$ ) was developed by a team led by Dr. John Goodenough while working at the University of Texas<sup>4</sup> (Goodenough was also one of the principal researchers at Sony in the original development of lithium-ion technology). Phosphate bonds are much stronger than those in oxides, with the result that when abusively overcharged,  $\text{LiFePO}_4$  cells release very little energy. Cells using  $\text{LiFePO}_4$  have reasonable calendar life and excellent cycling characteristics as long as they are operated at moderate temperatures. Unfortunately, however, the added safety comes at the cost of significantly lower energy density (which in itself contributes to enhanced safety), so it is no coincidence that commercial success for this material has been achieved in products designed for short-duration, high-power discharges, such as those now used in commercial power tools.

## Negative Active Materials

The vast majority of commercial lithium-ion cells have graphite as the negative active material, as depicted in Figure 1. Figure 1 also shows a layer on the surface of the negative denoted 'SEI' for Solid-Electrolyte Interface. This is actually the significant enabling feature of lithium-ion technology, since the graphite electrode potential is so low (so negative) that the intercalated lithium ions would be expected to react immediately with the solvent of the electrolyte. What happens, however, is that on the first charge a permanent passivation layer, the SEI, is formed, which then protects the lithium ions in the negative. The SEI is permeable to lithium ions but not to the electrolyte and its stability is an important requirement for long operating life.

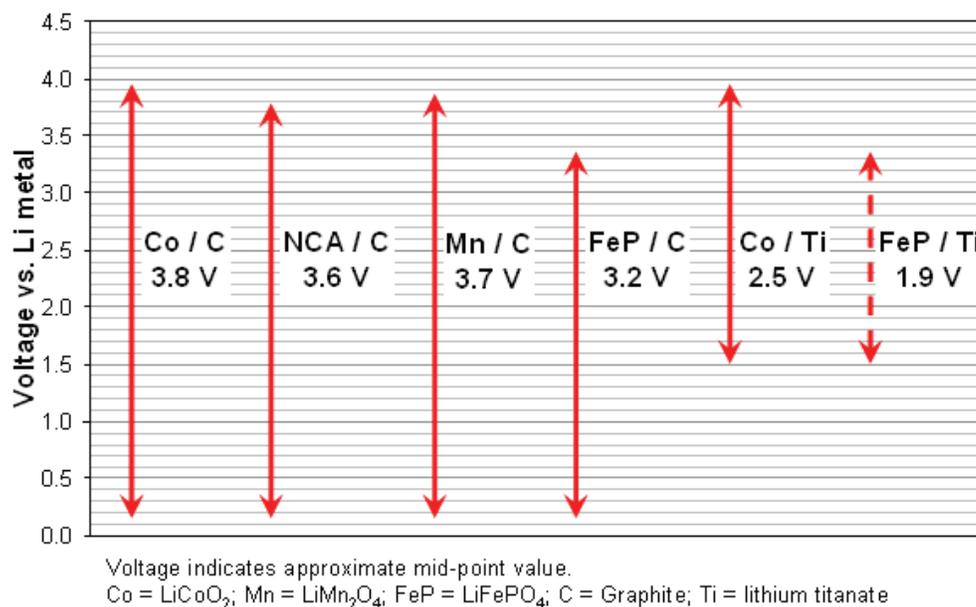
The SEI is stable at normal operating temperatures but when heated to around 110 °C it will break down and allow an uncontrolled reaction between the stored lithium ions and the electrolyte (thermal runaway). This process occurs regardless of the positive material used but, depending on the positive material and thermal characteristics of the cell and battery, the heat released may also destabilize the positive and result in a fire.

Lithium titanate negative material operates at a higher (less negative) voltage, at which lithium ions are stable with respect to the electrolyte. An SEI does not form and the overheating problem (for the negative) is eliminated.

An additional benefit for lithium titanate is seen in fast charging. Conventional graphite negatives operate at a voltage only about 150 mV higher than that of lithium metal. The SEI on those negatives has a certain resistance to passing lithium ions and if the charge current exceeds a value that would result in a 150 mV drop across the SEI, lithium ions will be deposited on the surface of the SEI instead of passing through. When not taken to extremes, this lithium plating process does not constitute a safety risk but nevertheless damages the cell and reduces its life. The higher voltage of lithium titanate negatives allows them to be charged at a much higher rate, sometimes in as little as five minutes. Of course, higher negative electrode voltage leads to lower cell voltage, so energy and power density suffers accordingly. Thus cells with lithium titanate negatives will be of little practical value except in the few applications in which fast charging is vitally important.

## Cell Electrochemistry

Any of the positive active materials described above can be combined with either of the negative materials to form a discrete electrochemical system. Some of the more common combinations are depicted in Figure 2, which shows their operating voltages for around the middle of discharge. It can readily be seen that the safer materials, LiFePO<sub>4</sub> and lithium titanate, result in lower cell voltage and correspondingly lower energy and power density. For ultimate safety a lithium titanate negative would be paired with an iron phosphate positive. However, the resulting cell voltage would be lower than that of a lead-acid cell.



**Figure 2. Voltages of common lithium-ion electrochemistries**

## Electrolyte

The electrolyte in lithium-ion cells is normally lithium hexafluorophosphate ( $\text{LiPF}_6$ ) dissolved in a mixture of organic solvents (mainly carbonates), which must be formulated to match the electrode materials used. For example, a cobalt-based cell has a full-charge voltage of 4.2 V and the electrolyte must be able to withstand this level; the resulting electrolyte formulation could be quite different from that of a lower-voltage phosphate-based cell. Certain electrolyte constituents can also contribute to stabilization of the SEI, and vinylene carbonate is particularly effective in this regard<sup>5</sup>. The electrolyte composition may also be fine-tuned to operate at lower or higher temperatures.

The electrolyte in consumer cells often includes so-called overcharge additives. These are compounds that are intended to decompose during moderate overcharge, producing gas that increases internal cell pressure and causes an internal circuit breaker to open, thus sacrificing the cell but preventing further overcharge. In floating operation, however, there is evidence that overcharge additives can polymerize in normal operation causing a catastrophic increase in cell impedance<sup>6</sup>.

It should be noted that the solvent of the electrolyte is flammable, and that in itself is a safety concern

## CELL CONSTRUCTION

### Cylindrical Lithium-Ion Cells

The best known lithium ion product is the cylindrical '18650' cell used for many consumer applications such as notebook computers. The numerical designation indicates that the cell is 18 mm in diameter and 65.0 mm long. For such cells the active materials are coated onto both sides of metal foils: aluminum for the positive and copper for the negative. Lengths of these foils are interleaved with a separator and wound around a circular mandrel or spindle to produce a 'jelly roll.' The jelly roll is placed inside a metal tube, forming the basis of the cell. There are also pseudo-prismatic (rectangular) cells that are made in the same way except that the jelly roll is produced by winding the electrodes around a flat mandrel. Examples of cylindrical and pseudo-prismatic cells are shown in Figure 3.



**Figure 3. Cylindrical and pseudo-prismatic lithium-ion cells**

Altering the electrode coating thickness and other parameters allows cells of different performance levels to be produced. Moving from a design optimized for hours of discharge to one optimized for short discharges may, depending on the specific design, reduce the ampere-hour capacity by 40-50% but allow around a four-fold increase in the high-rate capability.

### Lithium-Ion Polymer Cells

The term 'lithium-polymer cell' can refer either to lithium-metal-polymer cells such as those formerly produced by Avestor for telecommunications applications, or to lithium-ion cells in which prismatic positive and negative plates are bonded together with a polymer, which also acts as the separator. Liquid electrolyte is infused into the polymer and effectively becomes a gel. Bonding the plates together in this manner removes the need for support from an external metal container and lithium-ion polymer cells are typically packaged in a foil pouch such as that shown in Figure 4.

The electrochemistry of lithium-ion polymer cells is exactly the same as that of their 'standard' lithium-ion counterparts. It is simply the packaging that is different.

The use of a pouch allows greater flexibility in cell geometry and more efficient stacking of cells for higher energy density at the battery level. However, it is questionable whether these benefits can be maintained when cells are scaled up to larger capacities, where the additional support and protection provided by a cylindrical container becomes more important.



**Figure 4. Lithium-ion polymer cell (from NASA website)**

As with their non-polymer counterparts, lithium-ion polymer cells can be constructed in high energy (long discharge) or high power (short discharge) versions.

### **CONTROL ELECTRONICS**

Aqueous electrochemistries such as lead-acid and nickel-cadmium systems are largely regulated on charge by side reactions involving water. Charging such cells just above the point where these side reactions begin to occur tends to minimize cell-to-cell voltage variations. Furthermore, the regulating aspect of these reactions means that these systems can typically tolerate moderate levels of overcharging.

Lithium-ion systems are non-aqueous, so water-based side reactions are absent and charging is highly efficient, with virtually 100% of the ampere-hours supplied being stored. The downside of a non-aqueous system is that it lacks the regulating mechanisms supplied by the side reactions, so this regulation must be provided electronically.

The first level of control is cell voltage balancing, most often accomplished by switching shunting resistors across the cell terminals to bring high-voltage cells into line. Without this balancing, the voltage of cells with lower self-discharge rates would gradually drift upwards, possibly into an area of destabilizing overcharge. Balancing is most easily accomplished when the electrochemistry exhibits a sloping open-circuit voltage versus state of charge (SOC) characteristic, as will be discussed later in this paper.

If an individual cell should reach a certain voltage, typically around 0.10 V above the nominal charge voltage, a switch will typically be opened to prevent additional charge current from flowing through the battery. This gives the balancing circuits more time to bring the high cells into line. This second level of electronic protection prevents overcharging and is frequently implemented with a diode in parallel with the switch so that a discharge current can still flow and the load is protected.

In most lithium-ion batteries a discharge switch is also included to prevent cell damage associated with overdischarge. If a cell is discharged to the point that all available lithium ions are removed from the negative, the current-carrying copper foil starts to be corroded. This process leads to the creation of micro-shorts that will prevent proper functioning of the cell.

## SAFETY ISSUES

The two main safety issues that affect lithium-ion batteries are overcharging and overheating. In addition there are situations such as physical abuse (crushing or penetration) or short circuits that can also lead to overheating.

### Overcharging

Overcharging affects the positive electrode. The normal charging process transfers lithium ions from the positive to the negative and, if continued past the normal end point, the positive active material continues to increase its SOC and may become delithiated to the point of instability, causing thermal decomposition and the possibility of fire. As discussed previously the choice of positive active material affects the safety consequences of overcharging, but unfortunately the safest materials are generally accompanied by less desirable tradeoffs such as reduced energy density or more rapid aging, and these tradeoffs limit the acceptance of those safer materials in many applications.

$\text{LiMn}_2\text{O}_4$  and  $\text{LiFePO}_4$  materials cannot be overcharged and at the end of charge there is a steep voltage rise. This clear advantage regarding safety actually becomes a disadvantage for battery management because the charge can be limited by the first charged cell. Overcoming this issue can necessitate the use of more aggressive balancing circuits. The issue of 'slope' and balancing is discussed further below.

### Overheating

Overheating affects the negative electrode. As discussed above the safety issue relates to decomposition of the SEI above about 110 °C and the resulting exothermic reaction between lithium ions and the electrolyte. The heat source may be internal, through Joule heating, or external, from excessively high ambient temperatures or phenomena such as brush fires. In the case of Joule heating safety issues can be avoided through the use of active cooling systems or by inhibiting charge or discharge of the battery. For external heating there is little that can be done; insulation around the battery may protect it from short spikes in temperature that might be experienced from a fast-moving brush fire, but it is important to balance the amount of insulation used with the need to be able to dissipate Joule heat from normal charging and discharging operations.

### Cell-Level Safety Devices

In addition to the external electronic controls that provide the normal means to prevent safety events, each cell is equipped with a number of safety devices.

- Positive Temperature Coefficient (PTC) devices provide a current limiting function, primarily for low-current applications in consumer equipment, and have the benefit of resetting themselves when the overcurrent condition is corrected.
- Current-interrupt devices are non-resetting circuit breakers that are typically activated by high internal pressure.
- Pressure-release valves may be incorporated with the current-interrupt devices or may be separate components. These valves allow release of excessive internal pressure (cell venting) in abusive situations.
- Shut-down effect separators partially melt and lose porosity in response to temperature rise, in particular resulting from high currents due to external short circuits.

Until recently there was no protection possible against internal short circuits, as Sony found to its cost in the laptop battery recalls of 2006. In certain cells, minute metallic fragments from a groove-cutting operation fell inside the cell and could cause small shorts. Discharging through those shorts could cause local heating and full melting of the separator in that area. The worsening short that resulted would eventually lead to thermal runaway. A possible solution to this problem is the use of new ceramic separators. These separators could be combined with layers of other materials to provide the shut-down function mentioned above, while the ceramic layer would be resistant to full melting.

## AGING MECHANISMS

Aging processes in aqueous batteries are primarily driven by reaction kinetics, with phenomena such as exchange current density, diffusion coefficients and ion transference being driven by charge currents, particularly in float operation. The situation in lithium-ion batteries, particularly in float applications, is fundamentally different because the lack of side reactions involving water results in virtually no current flowing through the cells on float. In this case, aging processes are driven by the thermodynamics of operating electrodes at significant potentials. The active materials are less thermodynamically stable at those potentials, resulting in chemical, rather than electrochemical, degradation.

The important consequence of this situation is that in most standby applications it makes no difference whether a battery is maintained on float charge or is periodically disconnected from the charger. The aging rate will be the same in both cases, and is strongly influenced not just by temperature but also by the voltage to which a cell is charged.

There are aging processes occurring at both the positive and the negative electrodes. Which process determines the eventual cell life depends on factors such as the operating temperature and whether high-rate or low-rate discharges are required, in addition to the active materials involved.

### **Aging at the Negative**

The aging process in graphite negative electrodes involves a gradual ‘leakage’ of lithium ions through the SEI. The positive materials tend to release metallic ions (Mn, Fe, Ni and Co), which are reduced to metal on the negative, forming metallic clusters in the SEI that provide a conduit for lithium ions to pass through. These ions react with the solvents in the electrolyte and the resulting material is deposited on the surface of the SEI, which gradually thickens and increases its impedance. Furthermore, the lost lithium ions constitute the ‘fuel’ for the cell reaction so there is also a loss of capacity.

Metal dissolution from the positive is exacerbated by temperature. Manganese (spinel) is particularly soluble, resulting in rapid capacity fading. Iron phosphate also shows solubility above 40 °C to 45 °C, making it less suitable for high-temperature applications such as telecom outside plant. NCA and to a lesser extent NMC exhibit the lowest solubility of their metals, which translates into longevity, especially at elevated temperature.

It should be borne in mind that graphite negative material cannot be produced with lithium ions already mixed in. These ions originate from the positive material and are intercalated in the graphite during the first charge at the factory, with around 10% of the lithium being ‘sacrificed’ to form the SEI. For most systems this results in cell capacity being negative-limited. In some NCA systems, however, a lithium reserve is established in the negative after the first charge, resulting in positive-limited capacity. This difference contributes to more favorable aging characteristics for those NCA systems<sup>7</sup>.

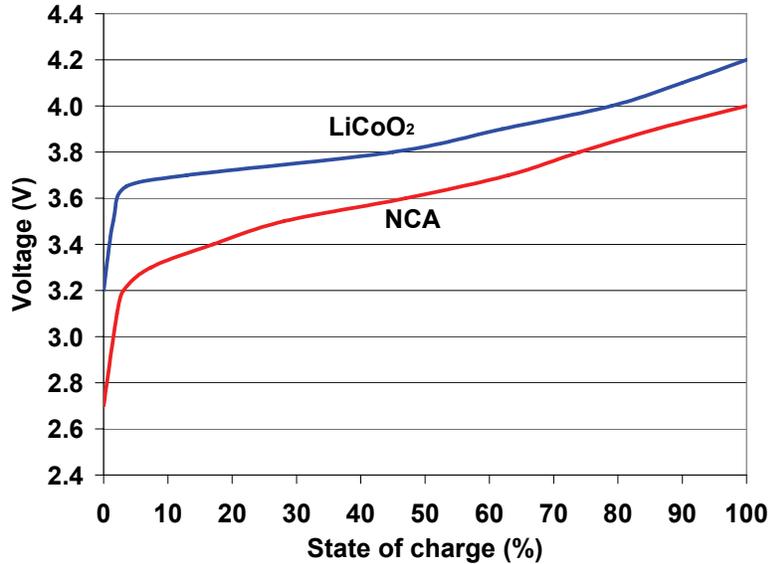
As mentioned above lithium titanate negatives do not form an SEI. As a result it would be expected that the rate of aging at the negative of such cells would be either greatly reduced or completely eliminated.

### **Aging at the Positive**

The primary aging process for positive electrodes using cobalt- and nickel-based materials is oxidation reactions that occur with the electrolyte. These reactions affect the intercalation ability of the material and lead to impedance increases. This process, while temperature-dependent, is also strongly influenced by the voltage to which the cell is charged.

## THE PROS AND CONS OF ‘SLOPE’

Some lithium-ion systems exhibit a sloping characteristic of SOC versus open-circuit voltage. Figure 5 shows this characteristic for cells with LiCoO<sub>2</sub> and NCA positives.



**Figure 5. SOC vs. voltage characteristic for LiCoO<sub>2</sub> and NCA technologies**

It should be noted that the open-circuit voltage is the same as the stabilized float voltage for these cells, since there is virtually no current flow on float. In fact, if the cells are charged and discharged at low rates the voltage will follow the curves of Figure 5 quite closely.

As already discussed, lithium-ion batteries must use electronics for cell balancing, so systems with sloping curves of this type are easy to balance; if the cells are at the same voltage they are necessarily also at the same SOC.

Other systems have much flatter SOC vs. voltage profiles and therefore face greater difficulties in cell balancing. Cells with LiFePO<sub>4</sub> positives, for example, have very flat voltages over virtually the whole SOC range, steeply ramping up only at the very end of charge. This means that they must be charged into the sloping part of the curve in order to balance them. This requirement is fine for systems such as power tools that require full charging and are designed around the battery, but presents challenges for operation at partial SOC levels, such as in hybrid electric vehicles. In stationary applications LiFePO<sub>4</sub>-based batteries could not be charged over a range of voltages, if doing so would mean that their cells would not be charging in the area with slope.

The biggest disadvantage of slope is that non-ideal charging can impact SOC in service. With lithium-ion cell voltages typically above 3 V there is little possibility to fine-tune the number of cells to meet specific application requirements. This issue is illustrated in Table 1, which shows operating voltages for 13- and 14-cell batteries using LiCoO<sub>2</sub> cells. For a range of cell charge voltages the overall battery voltage is given and the available capacity (SOC) is taken from Figure 5.

**Table 1. Operating voltages for nominal 48 V batteries using LiCoO<sub>2</sub> material**

Cell float voltage	13-cell battery voltage	14-cell battery voltage	Available capacity (% of rated)
4.2 V	54.6 V	58.8 V	100%
4.1 V	53.3 V	57.4 V	90%
4.0 V	52.0V	56.0 V	76%
3.9 V	50.7 V	54.6 V	59%

When these batteries are applied in 48 V telecom outside plant systems it is quite likely that they will be charged at the normal VRLA float voltage, which is quite close to the 54.6 V value shown in Table 1. A 13-cell battery operating at 54.6 V will be at 100% SOC, but operating at 4.2 V/cell would also exhibit rapid aging. A 14-cell battery at the same overall voltage, corresponding to 3.9 V/cell, would age at a much slower rate but would be operating at less than 60% SOC.

If the float voltage cannot be changed, the choice is rather unpalatable: a 13-cell battery with life reduced by well over 50%, and possibly as much as 80%; or a 14-cell battery with SOC reduced by 40%. It might be tempting for a battery packager to ignore the aging problem and offer 13-cell batteries with optimized capacity availability. Fortunately, such practices can be largely prevented by adequate qualification requirements, as will be discussed below.

In this particular example, batteries using cells with NCA positives have an advantage. For a 14-cell battery operating at 54.6 V and 3.9 V/cell, it can be seen from the NCA curve in Figure 5 that the SOC will be at a much more attractive level of 88%. This factor, coupled with the better aging characteristics of NCA positives, make this material a better choice for telecom applications.

The variability of SOC with charge voltage also means that broad-ranging temperature compensation of the charge voltage cannot be used, especially in the case of the higher voltages that are applied to lead-acid batteries at low temperature. Having said this, a limited application of temperature compensation at high temperatures could lower the rate of aging of positive electrodes, if the resulting lower SOC can be tolerated.

## **CHARACTERIZATION, EVALUATION, QUALIFICATION & DESIGN**

As lithium-ion batteries are more widely offered and considered for stationary applications it will be increasingly important for manufacturers and users alike to make wise choices and avoid potentially hazardous situations. Manufacturers must characterize their products clearly and completely to avoid misunderstandings and users must evaluate those products carefully to ensure compatibility with their application. To assist in this effort the IEEE/PES Stationary Battery Committee is close to completing P1679, "Draft Recommended Practice for the Characterization and Evaluation of Emerging Energy Storage Technologies in Stationary Applications" and will then start drafting a subsidiary document dealing specifically with lithium-based batteries. Among other subjects, P1679 recommends conventions for the submittal of data by manufacturers and the way in which they describe their technologies. On the user side the document makes recommendations for evaluation and qualification, as well as highlighting potential safety and regulatory issues.

While P1679 provides guidance for adequate qualification of emerging energy storage technologies, it cannot provide a complete qualification program. Qualification is best handled in application-specific terms, relating to specific environmental and abuse conditions to which batteries may be subjected. The first document in this arena is Telcordia GR-3150-CORE, "Generic Requirements for Secondary Non-Aqueous Lithium Batteries." Among numerous other tests, GR-3150 includes an overcharge test that is related specifically to possible rectifier failure modes in outside plant environments. Telcordia determined that the maximum voltage to which batteries could be subjected during such failures is 60 V, and the overcharge test calls for this voltage to be applied for 24 hours at 75 °C, with charge control electronics disabled.

Relating this overcharge test to the 13- and 14-cell batteries in Table 1, an overall voltage of 60 V corresponds to 4.62 V/cell and 4.29 V/cell, respectively. It is quite unlikely that a cell with LiCoO<sub>2</sub> positives could pass the overcharge test at 4.62 V, so application of the Telcordia qualification procedure would effectively eliminate 13-cell batteries from consideration. Of course, it is incumbent on the user to require that these qualification procedures be followed by the manufacturer before large-scale deployments are begun.

An effective battery design process must consider qualification requirements as a design element. As a result, designing a lithium-ion battery solution for a given application involves

- Selection of the optimum electrochemistry
- Development of a battery system to meet application requirements for performance, operating life, electrical and mechanical interfacing and safety
- Testing and qualification against the specific operating conditions and abuse scenarios of the application

In practice, lithium-ion systems are often designed within the overall development process of the equipment with which they are interfaced, in close cooperation with the OEM; or for systems in which the charging and operating conditions are broadly standardized, like telecom. This development process inevitably means that widespread adoption of lithium-ion technology will proceed at a somewhat slower pace than it would for a more commodity-type product.

### SUMMARY

It is hoped that this paper will provide Battcon attendees with a better understanding of lithium-ion technology and the family of lithium-ion products. These systems will undoubtedly become increasingly widespread in stationary applications and for this deployment to proceed safely it is important that lithium-ion batteries be properly designed, properly qualified, properly evaluated and properly applied.

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