# HISTORY REPEATING ITSELF: AN ESSENTIAL UNDERSTANDING FOR THE ADOPTION OF NEW BATTERY TECHNOLOGIES

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## ABSTRACT

Up until the early 1980s the majority of stationary battery installations consisted of vented lead-acid batteries and simple constant potential chargers. The technology of these batteries was mature, and classic studies, beginning with Lander in the 1950s and followed up by such luminaries as Milner, Willihnganz and Feder, ensured that the industry had an in-depth understanding of the charging and aging characteristics of this battery type.

When VRLA batteries were introduced in the early 1980s, most users assumed that these batteries would behave in the same way as their vented counterparts, with the exception of not requiring maintenance. The same simple chargers were used, but it was quickly discovered that these batteries were much more sensitive to high temperature operation and were susceptible to thermal runaway, and charging-related failures were quite common. Developments in the industry's understanding of the complexity of VRLA charging mechanisms, coupled with advances in electronics, ultimately led to the widespread use of more sophisticated chargers with advanced temperature compensation and safety features, particularly in the telecom sector.

Widespread deployment of Ni-Cd batteries in telecom cabinets began in the late 1990s. Despite recommendations that temperature compensation should not be used with these batteries, many of them were installed with no changes to the VRLA charge settings, resulting in undercharging and low (but reversible) states of charge.

The history of the introduction of new battery technologies, then, has been one of charging problems brought about by the use of existing charging equipment and methods. Now lithium-based batteries are starting to appear in demonstration systems. These batteries are unlike anything that the stationary battery industry has seen, in that they are dependent on electronic charging controls to maintain safe operation. Very little is being done, however, to evaluate in a systematic way the functionality, durability and fault tolerance of these systems.

So, the question must be asked: Is the industry doomed to re-learn the same lesson all over again? Will the introduction of lithium-based batteries be accompanied by the same missteps and charging problems that we have seen too often before? The answer to these questions lies in the qualification process. In this first of two papers, the authors discuss the historical perspective and the characteristics that make lithium-based batteries so attractive. Also described are the functions of the charge control electronics and their importance to these systems. Some specific ideas on qualification will be provided in a follow-up paper later this year. The outcome of these efforts, together with the level of enthusiasm on the part of users in adopting the recommendations, will determine whether history will indeed repeat itself.

## INTRODUCTION

The battery industry, taken as a whole, has a body of experience concerning the introduction of new battery technologies. This common knowledge is built in large part thanks to Technical Conferences, where experience is shared and discussed. Moreover, some manufacturers, by virtue of their large portfolio of technologies and because they serve industrial sectors as varied as standby, automotive, railways, military and aerospace, have this experience in house. This privileged position usually pushes these manufacturers to pause, step back and think about the process of introducing new solutions to industrial sectors.

The attractive features of lithium-based battery systems have led them to be widely adopted in portable consumer markets and to become an integral part of our professional life. Hence, some might consider them as being certified for industrial applications such as standby power backup in telecom networks. Experience with the introduction of VRLA and Ni-Cd in this sector calls for caution, however. In addition, familiarity with the introduction of lithium in other sectors such as automotive or aerospace shows that it is worth considering what should be the process for a successful adoption of lithium by the telecom industry.

## THE SWITCH FROM VENTED LEAD-ACID TO VRLA

Our detailed knowledge of the characteristics of vented lead-acid batteries in floating service dates back to landmark studies by such battery luminaries as Lander in 1956[1] and Willihnganz in 1968[2]. This work demonstrated that there was an optimum charge voltage for these cells, measured in the form of positive plate polarization. Figure 1 shows the relationship between aging rate and positive polarization from Willihnganz, with refinement by a further study by C&D. Such studies paved the way for an in-depth understanding of the characteristics of these batteries, and users generally achieved predictable operating lives using simple constant potential chargers.

Enter VRLA. Valve-regulated lead-acid batteries were introduced in the early 1980s, ushering in radical changes in the architecture of telephone networks and the packaging of UPS systems. To be sure, some designers were a little too radical with their new systems; taking the manufacturers at their word when they said these new batteries were ‘sealed’ and building them into non-ventilated enclosures. Hydrogen explosions and thermal runaways were the obvious signs that users should not accept all sales claims at face value.

Beyond these obvious (and sometimes spectacular) failures, however, many at that time did not fully appreciate the electrochemical complexity of VRLA batteries, and most of these products were hooked up to the same simple chargers as their vented cousins. Users learned the hard way about the sensitivity of these batteries to operation at elevated temperatures and their susceptibility to thermal runaway. Simply applying the same charging equipment and methodologies frequently resulted in premature charging-related failures. To make matters worse, some manufacturers endorsed damagingly low float voltages for their batteries in an attempt to avoid thermal runaway.

Evolving understanding of these batteries, coupled with improvements in electronics capabilities, have led to more sophisticated charging systems with advanced monitoring and temperature compensation algorithms. Such chargers are able to mitigate to some extent the sensitivity of VRLA batteries to high temperature operation, and to safeguard the system if a thermal runaway event does occur. Now, around 20 years after the introduction of VRLA, users are finally achieving more predictable results with these batteries. Predictability, however, is not the same as long life, and some users have sought alternatives to VRLA, particularly for application in hotter climates in telecom outside plant (OSP) cabinets.

## REINVENTING NI-CD FOR TELECOM NETWORKS

Although nickel-cadmium (Ni-Cd) batteries have been around since the 1900s, they had not occupied a significant place in telephone networks until quite recently. Advances in plate designs and packaging improved the energy density of these batteries to the point where they could be deployed to replace VRLA in outside plant cabinets. The inherently long life of the Ni-Cd product, coupled with its resistance to the effects of high temperature, allows users to reduce the costs associated with the procurement and installation of replacement batteries.

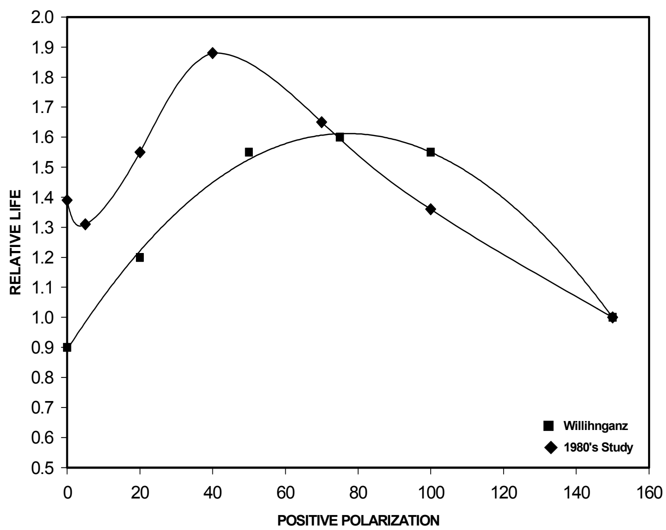


**Figure 1 – Relative life of vented lead-acid batteries as a function of positive plate polarization**
Source: Presentation by Sudhan Misra, C&D Technologies at the Critical & Backup Power conference, Boston, MA, November 2003

As with the introduction of VRLA, however, the tendency was for users to retain the settings of their existing chargers. Because of a reduction in the recharge efficiency of the positive electrode at high temperature, at least one Ni-Cd manufacturer recommends that temperature compensation of the charging voltage be switched off. A recent paper by Lansburg[3] detailed the temporary reduction in state of charge that can arise when a user fails to do this.

The lesson that should be learned from these introductions of new technologies is that different batteries have different charging requirements for optimum operation. When users ignore this lesson – and, regrettably, many do so – they risk compromising the efficient operation of their systems and, in the case of an uncontrolled thermal runaway, may also jeopardize system safety and integrity.

## OVERCHARGE RESISTANCE IN AQUEOUS BATTERIES

The saving grace with vented lead-acid, VRLA and Ni-Cd batteries is that they all have aqueous electrochemical systems. Whether sulfuric acid or potassium hydroxide, the electrolyte is a water-based solution. Although reactions with water are the main source of charging inefficiency, the other side of this coin is that water provides a means to 'spill' excess charging energy from the battery in a more or less safe manner. When the active materials have been fully converted to their charged state, additional charging energy will dissociate water. In vented batteries the hydrogen and oxygen from water are released to the atmosphere, requiring periodic replenishment of the water. In batteries based on the oxygen recombination cycle, such as VRLA, charging gas is recombined back into water, releasing heat. In normal operation, both mechanisms provide a safe means for dissipating excess charging energy.

This is not the case with lithium-based technologies. Whether lithium ion, lithium ion polymer, or lithium metal polymer, lithium-based cells operate at voltages that are too high for water to exist. The absence of any significant side reactions in these non-aqueous technologies results in extremely high charging efficiency, but this also means that there is no inherent mechanism for ‘spilling’ excess charging energy. Without a means for self-regulation, the overcharging of lithium batteries can be damaging and can even lead to battery fires in unprotected systems. Such a regulating mechanism is obviously essential, so it must be provided by external means. Electronic systems balance the cell charging voltages within a lithium battery and also protect it from overcharge. Such systems are built into every lithium-based laptop computer and cell phone battery. They also provide a means to communicate with a ‘smart’ charging source that will modulate its output precisely in accordance with the battery’s needs. We will see later that such smart chargers are not found in telecom applications.

The industry is moving towards more fault-tolerant cells using technologies such as shutdown separators and internal fusible links, which are now standard in many portable batteries. Such devices must be considered as a last line of defense, however, and the active management of lithium batteries will still depend on the internal electronics.

## THE ATTRACTION OF LITHIUM

Interest in lithium-based batteries remains high despite this apparent weakness. The advantages of this technology are so overwhelming in portable applications that many industrial users are eager to realize these benefits from the larger batteries that are now being developed by a number of companies. The superiority of lithium-based batteries as a group can be seen in figure 2, which shows the relative merits of a number of battery systems with regard to the main characteristics required of stationary battery systems. These radar charts refer to the relative importance of these characteristics in telecom outside plant applications. Notably missing from the charts is any measure of life, or more importantly life cycle cost. The reason for this is that the life cycle cost varies from application to application and even from site to site, while a parameter such as battery volume has more universal applicability. The following is a brief explanation of the way in which each of these characteristics has been ranked.

### Volume

Rankings for volume are based on the ‘ideal’ case of lithium cells without electronics. The electronic controls are of course necessary, but they increase the volume of the battery and thus reduce the ranking of lithium batteries with electronics.

### High Temperature Operation

The ideal case refers to the ability of a battery to operate at high temperatures with the minimum possible impact on safety, reliability, life or charging efficiency.

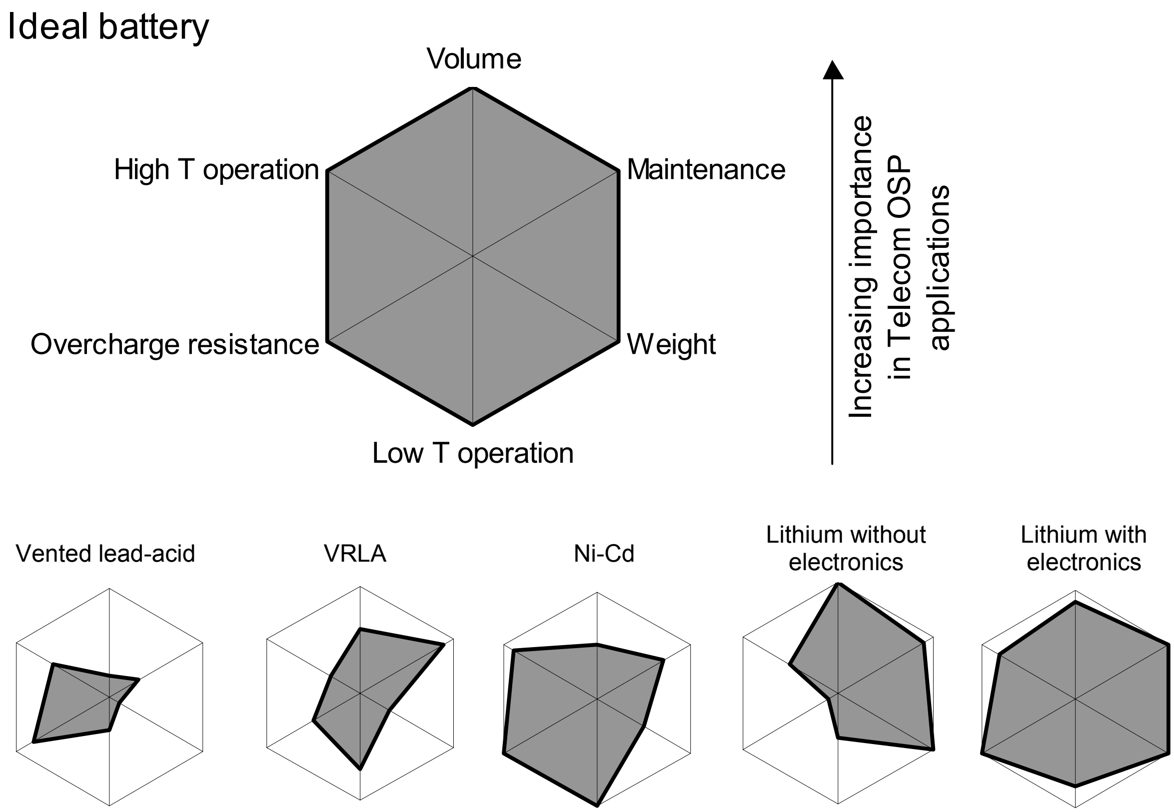


**Figure 2 – Relative merits of various technologies for telecom OSP applications**

**Maintenance**

The ideal battery requires zero preventive maintenance, and this is the case for lithium batteries with electronics. The following maintenance operations have been assumed for each of the other types in outside plant installations:

| | |
|---|---|
| Vented lead-acid | – voltage and specific gravity measurements; water additions |
| VRLA | – ohmic measurements |
| Ni-Cd | – water additions |
| Lithium without electronics | – voltage measurements (hypothetical case only) |

**Overcharge Resistance**

This is the measure of a battery's ability to accept overcharging with minimal short-term or long-term effects, for example on safety or aging. Ni-Cd batteries and lithium batteries with electronics are taken as the ideal cases.

**Weight**

Lithium batteries (with and without electronics) are taken as the ideal case.

**Low Temperature Operation**

While the largest impact of low temperature is on capacity availability on discharge, the ranking also consider safety effects (e.g. the ability of lithium batteries to accept high charge current safely at low temperatures) and life issues (e.g. lowered recombination efficiency or the impact of negative self-discharge in VRLA batteries). Ni-Cd is taken as the ideal product for low temperature operation.

The charts in figure 2 give a strong visual indication of the relative merits of each technology in this particular application. The larger the shaded area, the closer that technology comes to the ideal model. The combination of this type of assessment and the life cycle cost is the driving force behind the adoption of a new technology. It can readily be seen that the benefits of lithium-based batteries are considerable, but also that the correct functioning of electronic charge controls is vital to the full realization of those benefits.

## THE QUALIFICATION QUESTION

This leads us to question the typical approach towards the qualification of lithium-based batteries, particularly as they will predominantly be used with the existing base of installed chargers. Testing the electrochemistry alone is essential but not sufficient. Traditional long term float tests on bare cells, looking at evolution of parameters such as capacity, power ability and impedance over time are still critical, as are detailed analysis and understanding of failure modes and aging mechanisms. Beyond these tests, however, it is no longer sufficient to install a few trial batteries and to approve the product if none of them fails. A proper qualification process requires a rigorous evaluation of each aspect of the system, including

- Quality of electronic components
- Algorithms for charge control
- Software for implementing those algorithms
- Cell electrochemistry (charge/discharge characteristics, aging mechanisms, failure modes, etc.)

When these tasks have been completed, only then should the battery system be evaluated and qualified as a whole.

## CONCLUSIONS

Ideally, new stationary systems with lithium batteries would use smart chargers, but this is unlikely to happen any time soon. This is particularly the case for large users such as telecom operators, who would find it extremely difficult to juggle two types of charging systems while introducing a new battery technology. These users will rely on the battery electronics to shield their lithium cells from harmful overcharging by 'dumb' chargers, and this will emphasize further the criticality of those electronics.

So, the question must be asked: Is the industry doomed to re-learn the same lesson all over again? Will the introduction of lithium-based batteries be accompanied by the same missteps and charging problems that we have seen too often before? The answers to these questions lie in the qualification process. The authors intend to provide some specific ideas on this subject in a follow-up paper later this year. The outcome of these efforts, together with the level of enthusiasm on the part of users in adopting the recommendations, will determine whether history is doomed to repeat itself.

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