COMPARING APPLES AND ORANGES:
GUIDANCE ON THE ADOPTION OF NEW TECHNOLOGIES

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ABSTRACT

Standby battery users have not been exposed to anything more than incremental changes in battery technologies for decades, with the last major shift—the introduction of valve-regulated lead-acid batteries—taking place some 30 years ago; and even that change could be seen as just a hiccup in the century-old tradition of employing lead-acid and nickel-cadmium technologies in industrial applications. In recent years, however, we have witnessed a rapid expansion in the number of battery developments, driven by such diverse applications as handheld consumer devices and electric vehicles.

Inevitably, some of these new battery technologies are offered for standby applications, with their manufacturers extolling the virtues of the product and, sometimes, glossing over the shortcomings. Rapid advances in other areas have instilled a greater willingness in many engineers to embrace new technologies, but they have lacked the tools to enable a complete evaluation of the pros and cons of a new battery system and a proper comparison with traditional options.

2010 saw the completion and publication of IEEE Std 1679-2010, *IEEE Recommended Practice for the Characterization and Evaluation of Emerging Energy Storage Technologies in Stationary Applications*. This new document provides a framework for manufacturers to present their product information to a prospective user, and for that user to analyze the suitability of those products for their intended application. IEEE 1679 is a standalone recommended practice, but it will be supplemented by a series of subsidiary documents that will provide guidance for the implementation of IEEE 1679 with specific product groups. The first of these sub-documents will become IEEE 1679.1, *Guide for the Characterization and Evaluation of Lithium-Based Batteries in Stationary Applications*.

This paper describes the background for the origination of IEEE 1679, the outline of the document, and some examples of situations that it can help to avoid, especially where emerging technologies don't quite line up with standard practices used with traditional batteries.

THE ORIGIN OF IEEE 1679

The concept for IEEE 1679 came from a presentation at the 2003 Annual Meeting of the Electricity Storage Association (ESA) by Haresh Kamath[1], then with a subsidiary of the Electric Power Research Institute and now with EPRI proper. The original intent of the presentation was to provide an update on testing of aqueous nickel asymmetric supercapacitors by Sandia National Laboratories. However, in Sandia's cycling tests the product failed after less than 1,000 cycles, whereas the manufacturer had claimed over 300,000 cycles. It transpired that the manufacturer, based in Russia, had not provided details of the testing regime, and the Sandia test team had unwittingly subjected the product to conditions outside its normal operating envelope.

Ultimately, consultation with the manufacturer allowed the cells to be reconditioned and the cycling test was able to proceed under the correct conditions, but Kamath was struck by the incident and attributed it to a lack of standards. One of the graphics from his presentation is reproduced in Figure 1.

Figure 1. Call for Standards by Haresh Kamath[1]

Kamath went on to suggest that a standard be created to allow for proper comparisons to be made between technologies. His proposed starting point for such a standard was to establish standard test protocols for various energy storage applications. Kamath and the author, both directors of ESA, discussed this concept in some depth and agreed that a standard developed under the auspices of IEEE would be ideal. There was some delay while various stakeholders in the energy storage community were polled for their thoughts on the idea, and ultimately the author presented the concept at the Winter 2005 meeting of the Stationary Battery Committee (StaBatt) of the IEEE Power and Energy Society (PES), which approved the creation of a task force to make recommendations for a new standards project. The task force comprised members of StaBatt, representatives of storage device manufacturers and other interested parties. The technologies represented included a broad range of battery types, electric double-layer capacitors (EDLCs, *aka* supercapacitors, ultracapacitors, electrochemical capacitors), flywheels and power electronics.

At this stage it is appropriate to mention the different types of IEEE standards documents. As listed by the IEEE Style Manual[2] these are:

1. **Standards**, which specify mandatory requirements ("shall")
2. **Recommended Practices**, which provide recommendations ("should")
3. **Guides**, which furnish information ("may")

The task force reported back to StaBatt at the Summer 2005 meeting, recommending creation of the following documents:

- A recommended practice covering the characterization and evaluation of <u>*all*</u> emerging energy storage technologies.
- A series of subsidiary documents to provide guidance on the application of the recommended practice for specific classes of storage devices, such as lithium-based batteries.

The committee voted to sponsor these documents and the process for submitting a Project Authorization Request (PAR) was begun. The task force then became the Emerging Technologies Working Group. One problem that was encountered was that the inclusion of non-battery energy storage technologies in the main recommended practice was beyond the scope of StaBatt's activities, which specifically cover batteries and other parts of dc systems. The solution to this was to process the initial PAR to cover 'emerging battery technologies' only, so that the working group could begin drafting the document. At the same time, discussions were begun to make the PES Emerging Technologies Coordinating Committee (ETCC) a co-sponsor of the document, so as to justify the inclusion of non-battery technologies. ETCC co-sponsorship was finally approved by the PES Vice President for Technical Activities in August 2006, and a PAR change to include the expanded scope was approved by the IEEE Standards Board the following month.

Work proceeded on the document over the next couple of years, leading to balloting in December 2008. While 50 members of the ballot group (94% of respondents) voted affirmatively there were three negative votes cast, and a number of the ‘yes’ voters submitted comments to improve parts of the document. One of the comments was to include an annex covering the interpretation of data for the variable cycling regimes that are often encountered in grid-connected energy storage applications, and the drafting of this annex resulted in several months’ delay in recirculating the document. The new annex resulted in an additional negative vote, which necessitated an additional round of comment resolution and another recirculation. The whole process was completed in March 2010 and the final draft was submitted to the IEEE Standards Board Review Committee for approval, which was granted in June 2010. The IEEE editorial staff then polished the draft, leading to final publication of IEEE Std 1679-2010 in November 2010.

The sad fact is that it took over six years to get from Kamath’s concept to a published IEEE standard. This is mostly due to the fact that IEEE battery standards are almost all generated by volunteers on the basis of the time that they are able to spend on these endeavors, and partly due to the deliberative and consensus-building standards process

GETTING MANUFACTURERS AND USERS IN SYNC

Two key words in the title of IEEE 1679 define the target audience—‘characterization’ and ‘evaluation.’ ‘Characterization’ targets manufacturers, many of whom may have developed their technologies for other markets, such as electric vehicles, and may be unfamiliar with application conditions and typical terminology used in stationary battery markets. ‘Evaluation’ targets potential users, who may be interested in seeing what benefits emerging technologies could bring to their operations but lack the proper information or expertise to conduct a valid review of the pros and cons.

The concept here is not to force all manufacturers to rate their products as if they were lead-acid batteries but to have them state the exact conditions under which certain test results were achieved, leading to claims of particular benefits. It is only with this type of full disclosure that true comparisons between dissimilar technologies can actually be made.

The need for full disclosure goes well beyond product ratings, of course. IEEE 1679 also includes recommendations for describing the technology and all its application interfaces, qualification and standards compliance, regulatory issues and evaluation techniques. Some of the main points from those recommendations are discussed below.

INTENDED APPLICATIONS

It can be very useful for a prospective user to examine the roots of a new technology. Was it developed for cycling applications and is now being offered for standby? Did it start life in consumer applications? A classic example is the packaging of lithium-ion consumer cells in modules for telecom and other standby applications. Such cells are typically operated for maximum energy availability in devices where the useful life may be three years or less and in which the battery may spend most of its life in cycling mode. Operating the same cells in an industrial standby application requires compromises in energy availability in order to achieve reasonable calendar life, as discussed in a previous Battcon paper by the author[3]. Going beyond basic energy availability there are several other questions that should be asked:

- Can the new technology be charged using conventional chargers, at levels that are compatible with the connected loads?
- Is the overall operating voltage window compatible with the application?
- Can the technology operate under all expected conditions of ambient temperature and humidity?
- Are special support structures required and is the floor loading acceptable?
- What are the maintenance requirements for safe and reliable operation?

In addition it is important to look at components such as active electronics and internal disconnect devices to ensure that the technology is suitable for the intended battery system architecture, as discussed in our Battcon 2010 paper[4].

Another area relating to application compatibility – and one that is all too frequently ignored – is that of aging mechanisms and failure modes. IEEE 1679 goes into some depth on this subject, recommending that the device manufacturer provide information that is relevant to the application (and not try to make do with aging data on cycling for a standby application, for example). The user should consider how the battery will ultimately fail, and design the installation accordingly. For example, if the predominant failure mode is in open circuit the user should consider implementing parallel strings with some level of redundancy.

QUALIFICATION AND STANDARDS COMPLIANCE

For a manufacturer producing the first samples of a new product the first step is validation – making sure that the product has the intended characteristics. The next, and more challenging, step is qualification. As stated in IEEE 1679, “Qualification testing is essential for determining the robustness and suitability of a product prior to deployment.” This process is accomplished in three steps:

- **Functional testing:** operation of a fully functional system with normal application parameters and under controlled and optimal conditions.
- **Abuse tolerance:** operation of a fully functional system under all foreseeable abuse conditions, such as overcharge, external short-circuit, etc. Such testing is frequently carried out under the most extreme expected environmental conditions. Ideally the product should remain operational after this testing.
- **Fault tolerance:** this testing is typically a repeat of abuse-tolerance testing, but with primary protective devices (if any) disabled to simulate a product fault. The product may be rendered inoperable during this testing but should not give rise to any fire or explosion.

User testing is frequently geared to these qualification steps. Testing in a user’s laboratory may be carried out upon completion of functional testing, followed by limited field trials after abuse tolerance has been verified. Full-scale deployments should not begin until fault-tolerance testing is complete.

Sometimes these qualification steps are called out in standards. For example, Telcordia GR-3150[5] outlines generic requirements for lithium batteries in telecom applications, with those requirements split between three levels corresponding to the above steps.

Telcordia GR-3150 is an example of an application-specific standard, in which the requirements are geared to the needs of telecom operators and the abuse situations that can arise in their applications. There are also more generic cross-cutting standards that are frequently related to product safety. One such example is UL 1642, Standard for Lithium Batteries[6]. Compliance to UL 1642 at cell level is certainly desirable, but that standard does not detail module- or system-level tests and does not relate to any particular application.

REGULATORY ISSUES

IEEE 1679 recommends that manufacturers identify potential hazards with their products, transportation issues, spill containment and ventilation needs. Such information will be required by a prospective user for the purpose of obtaining special permits that might be required by Authorities Having Jurisdiction for first use or field trials. Users ignoring these issues do so at their own risk!

Users should also discuss end-of-life recycling or disposal arrangements with manufacturers. It is certainly not unusual for manufacturers to bring a product to market before full-scale recycling processes are in place.

EVALUATION TECHNIQUES

Last but not least, IEEE 1679 provides recommendations for end users to assess the suitability of new technologies for their applications. In addition to evaluating application-specific criteria the user should examine balance-of-system component requirements (which may or may not be included in the manufacturer’s offer), personnel and environmental safety as related to the specific circumstances (close proximity to personnel vs. remote unmanned facility), and code compliance.

Life-cycle costing (LCC) is a useful tool for comparing different technologies, and guidance for a complete LCC analysis is provided in IEEE 1679. In some cases this approach may uncover benefits that may justify the higher cost of a pre-commercial product, although this requires a rigorous approach to identifying and quantifying all costs and benefits relating to the use of a new storage technology.

PITFALL AVOIDANCE

Receiving manufacturer data in accordance with IEEE 1679 and following the recommendations for evaluation should allow users to avoid pitfalls in applying new technologies. An example of this is in the charging of lithium-ion batteries in telecom applications.

As discussed at Battcon 2008[3], Li-ion technologies based on metal-oxide positive materials have a sloping characteristic of open-circuit voltage versus state of charge (SOC). Figure 2 shows this characteristic for lithium cobalt oxide ($LiCoO_2$) and lithium nickel-cobalt-aluminum oxide (NCA) materials for both single cells and 14-cell batteries, as might be offered for telecom service.

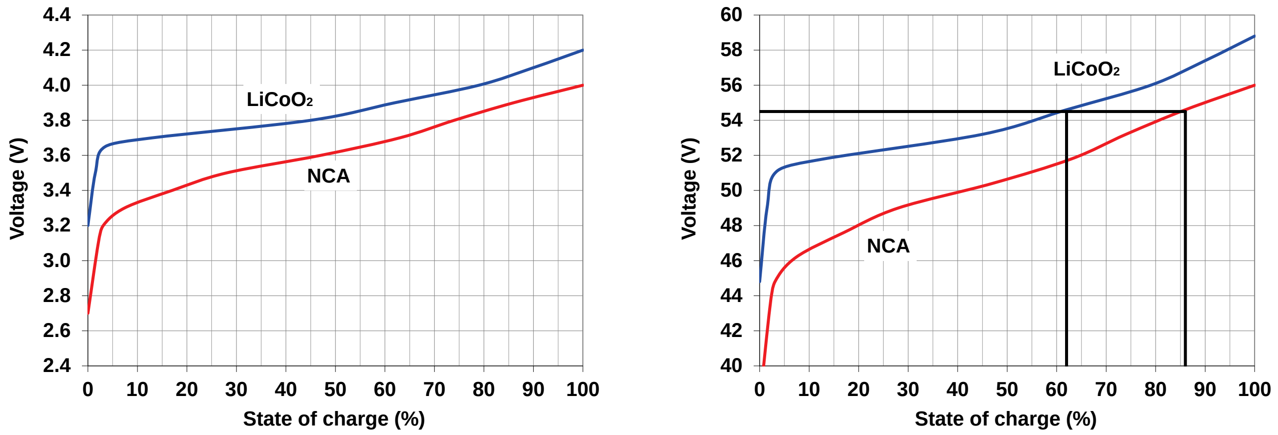

Figure 2. Open-circuit voltage vs. state of charge for Li-ion cells with cobalt and NCA positives – single cells (left) and 14-cell batteries (right)

Suitably enlightened by IEEE 1679, a prospective user would examine the operating voltage range of these batteries and compare it with the application parameters. If that user is unwilling to raise the charge voltage above the normal 54.5 V for VRLA batteries, it would be seen that the cobalt battery would be charged to only 62% SOC and the NCA battery to 86% SOC, and these values would be used in the evaluation of these options.

To be sure, a 13-cell cobalt battery could be chosen so that 100% SOC (4.2 V/cell) would be reached at 54.5 V, but then the operating life would likely be very short, particularly if high temperatures would be encountered. Furthermore, Telcordia GR-3150 calls for an overcharge test at 60.0 V and 75°C, and charging a 13-cell battery at 4.62 V at that temperature is not likely to be safe. Such an overcharge test is not directly called out by IEEE 1679, but the recommendation to evaluate application-specific abuse scenarios should lead the user to more or less the same conclusion.

SUMMARY

This paper has described the origins of IEEE 1679 and has provided some insight into its content. IEEE 1679 is a standalone document that provides useful recommendations to manufacturers of emerging energy storage technologies and prospective users alike. The working group expects to enhance the value of the recommended practice with the subsequent publication of ‘dot’ documents, beginning with what will become IEEE 1679.1 on lithium-based batteries, providing specific guidance in the application of the parent document to those technologies.

Armed with these tools, users really will have the capability to perform a battery version of comparing apples and oranges.

REFERENCES

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