ADVANCED ELECTROCHEMICAL ENERGY STORAGE TECHNOLOGIES FOR STATIONARY POWER APPLICATIONS

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ABSTRACT

Lead acid batteries are the most widely deployed technology for providing stored energy for emergency power to critical DC power systems for applications including telecommunications, uninterruptible power systems (UPS), electric utility switchgear, and other stationary power systems. As the user's applications have evolved to include more remote, uncontrolled environments, the desire to evaluate and deploy alternative energy storage technologies that may enhance life, performance, safety, economics, and reliability has become an important consideration in the strategic system engineering plans for many corporations. This paper will present an overview of various technologies that are currently considered as potential alternatives to the traditional lead acid battery approach. Key attributes of each technology will be presented and compared to other storage technologies, including lead acid, to assist the system designer in evaluating the applicability of each potential solution to the DC system requirements.

INTRODUCTION

There have been numerous developments in secondary (rechargeable) electrochemical energy storage technologies for stationary power applications over the past several years and an attempt to review all of them would be beyond the practical limits for this paper. Accordingly, this paper intends to present to the reader an overview of some of the technologies that appear to have the most opportunity for commercial use in the near term. As lead acid is the predominant technology currently used, it will act as the baseline for comparison and contrasting purposes to assist the lead acid user in evaluating the merits of certain alternative technologies.

There are two primary sections that will be covered. The first is an overview of the technology, presenting a general description of the technology, along with potential advantages and limitations that should be considered when evaluating the application of the technology to one's specific application.

The second area applies values to key attributes of each technology, compared to lead acid. This gives the user a summary of potential advantages or disadvantages of each technology to assist in evaluating the applicability of a given technology to their needs. Further reference can be found in draft IEEE P1679 – Draft Recommended Practice for the Characterization and Evaluation of Emerging Energy Storage Technologies in Stationary Applications.

TECHNOLOGY OVERVIEW

Lead Acid

Originally developed by Gaston Planté in 1859, the lead acid cell design has been the primary technology applied to stationary applications for decades. The basic design is a combination of a lead-dioxide positive electrode, a lead negative electrode, in a dilute sulfuric acid electrolyte, resulting in a nominal 2V cell. Over the years, refinements to alloys and manufacturing techniques have created several distinct cell designs for the various applications encountered by stationary batteries. This includes lead antimony and lead calcium grid alloys as well as long duration, general purpose, and high rate cell designs. The advent of valve regulated lead acid (VRLA) designs further enhanced the scope of applications that could be addressed by what many have long considered to be a mature technology with limited opportunity for design advancements. Continued development of advanced lead acid designs, including thin plate pure lead (TPPL), further acknowledge the evolutionary advancements that continue to be practical for developing applications.

Lead acid offers several advantages that contribute to its high level of use in stationary applications:

- High reliability
- Long life
- Easily recyclable
- Well understood technology
- Economical solution
- Services a broad range of applications

Some of the limitations of Lead Acid designs include:

- Heavy
- Reduced life in high temperatures
- Risk of thermal runaway in VRLA
- New, less understood failure modes appeared in early VRLA designs

Nickel Cadmium

Nickel Cadmium (NiCd) designs, originally developed in the late 1800's, consist of a nickel hydroxide positive electrode and a cadmium negative electrode in an electrolyte solution of potassium hydroxide, resulting in a nominal voltage of 1.2V. The traditional design is pocket plate, but, over the years, the development of sintered plates, fiber plates, plastic bonded electrode (PBE) and foam plates have brought refined attributes for specific applications. Generally, NiCd batteries designs have found areas within the traditional stationary applications where the advantages of its design outweigh the cost disadvantage when compared to lead acid solutions.

Some of the advantages of Nickel Cadmium designs include:

- High power delivery for short duration applications
- Works well in low temperature applications
- Tolerates abuse including over-discharge
- Long shelf life

Some of the limitations of Nickel Cadmium designs include:

- High self discharge rate
- More complex to charge and maintain full state of charge
- Memory effect
- Cost to Recycle

Nickel Metal Hydride

The construction of Nickel Metal Hydride (NiMH) cells is similar to NiCd with the cadmium electrode replaced by a metal alloy that can store large amounts of hydrogen during the charging process. This approach offers more environmentally friendly materials as well as providing for better energy density than the NiCd cell. Currently, the capacity range of NiMH is limited, leaving the predominant applications in relatively low power requirements such as portable appliances (cameras, cell phones, lap top computers as examples) many of which have now moved on to Lithium based technologies.

Some of the advantages of Nickel Metal Hydride designs include:

- Environmentally friendly materials
- Higher energy density than NiCd
- Reduced memory effect

Some of the limitations of Nickel Metal Hydride designs include:

- Limited capacity range
- Limited high current delivery capability
- More complex charging algorithm than NiCd

Lithium Ion

Lithium has long been recognized as an ideal material for energy storage devices due to its light weight and high electrochemical energy potential. There are many variations developers have used in the electrochemical approach to create a lithium ion design with the characteristics required for a practical technology as a secondary battery design for stationary applications. The positive electrode is typically a lithium metal oxide, with various metals used such as cobalt, nickel, and manganese. The negative electrode is typically a carbon compound or graphite. The electrolyte typically is a lithium salt solution dissolved in organic carbonates. The electrodes are typically separated by a plastic membrane made of microporous polypropylene or polyethylene. The most common cell design is cylindrical. The resulting nominal voltage is about 3.6V or 3 times that which is achieved in nickel based electrochemistry, which results in a very high energy density.

Some of the advantages of lithium ion based designs include:

- Light weight
- High energy density
- Low self discharge rate

Some of the limitations of lithium ion based designs include:

- Requires complex charging circuitry to maintain stability
- High cost
- Not easily scalable to large capacities
- Shorter operational life than other technologies

Lithium Polymer

The primary difference in the lithium polymer design is the use of a dry solid polymer as the electrolyte. This can offer improved safety, flexibility in cell design (prismatic vs. cylindrical) and simplified manufacture over the traditional lithium ion cell design, but also reduces conductivity and hence energy density. There are also lithium metal polymer (LMP) developments, which use highly reactive lithium metal as the positive electrode. These designs typically need to have heating elements to operate properly and can be volatile in a failure event.

Some of the advantages of lithium polymer based designs include:

- Can be manufactured as thin, prismatic cells
- Improved safety over lithium ion
- Light weight

Some of the limitations of lithium polymer based designs include:

- Requires complex charging circuitry to maintain stability
- High cost
- Not easily scalable to large capacities
- Heating elements required (LMP)

TECHNOLOGY COMPARISON

In this section, key attributes are presented in Table 1 for comparison purposes to assist the reader in evaluating each of the technologies potential applicability to the users needs.

Definitions

Energy Density **-** The energy density is a measurement of how much energy can be delivered from a battery per unit of battery weight or volume. This is generally expressed in units of watt-hours per kilogram (Wh/kg) or watt-hours per liter (Wh/l) respectively.

Cycle Life - The cycle life represents the expected number of charge discharge cycles the battery technology would expect to deliver before reaching end of life.

Power Density - The power density is a measurement of how much power can be delivered from a battery per unit of battery weight or volume. This is generally expressed in units of watts per kilogram (W/kg) or watts per liter (W/l) respectively.

Relative Cost - For the purposes of this paper, this is expressed as watt-hours/dollar (W-h/$) and is an index rating with 100 representing the most cost effective technology for the energy delivered.

Recycling Rating - For the purposes of this paper, this is an index with 100 representing the most cost effective and available processes for reclaiming batteries that have reached the end of useful life.

Safety Rating **-** For the purposes of this paper, this is an index that represents the inherent safety of a given technology when used in a stationary application

	Technology				
Property	**Lead Acid**	**Ni-Cd**	**Ni-MH**	**Li-Ion**	**Li Polymer**
Energy Density Wh/kg	40	50	80	125	110
Energy Density Wh/l	100	120	300	300	250
Cycle Life	800	1000	500	600	600
Power Density W/kg	400	300	300	300	100
Relative Cost Wh/$ (100 = Best)	100	40	25	20	15
Recycling Rating (100 = Best)	100	60	20	10	10
Safety Rating (100 = Best)	100	60	65	20	20

Table 1 – Attribute Comparison of Advanced Electrochemical Energy Storage Technologies

DATA ANALYSIS AND CONCLUSIONS

As expected, lead acid rates fairly low in the energy density measurements as it is a heavy material, especially when compared to Lithium. However, when we look at other attributes, the long standing advantages of lead acid begin to show through. It is recommended that careful consideration is given to all aspects of a prospective technology in evaluating the installation into a stationary application. While advanced technologies have shown some desirable attributes for certain niche applications, the lead acid technology remains a preferable solution in many areas where long life, high performance, safety, and reliability are critical in an electrochemical energy storage solution that has excellent economic value.