IMPORTANT CONSIDERATIONS IN SELECTING A FLOODED LEAD ACID BATTERY FOR A UTILITY SWITCHGEAR APPLICATION

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ABSTRACT

The electric utility market has experienced an influx of various flooded lead acid battery designs as lower cost solutions to the traditional 20 year design life batteries that have been used for many decades. These batteries are often presented as comparable substitutions to the existing installed batteries without a comprehensive review of the specific requirements of the site.

Pressures within the utility industry driven by the desire to reduce capital outlay and the shrinking pool of senior engineers with extensive expertise in the selection and application of the critical DC battery systems within their infrastructure have enabled lower cost flooded lead acid batteries to gain acceptance within certain applications in the utilities.

This paper will address the design differences in various flooded lead acid switchgear battery designs and how they impact the switchgear application. Grid/plate designs including Planté, flat plate, and tubular designs will be addressed, as well as how the attributes of grid alloying agents including calcium, antimony, and selenium affect operating characteristics in the utility application.

The results of these differences will provide the basis for guidelines and recommendations that the utility engineer can use to assist in evaluating the various technologies to assure that the reliability, operation, cost, battery life, performance, safety, and specifications requirements yield the most appropriately balanced solution for their needs.

UTILITY SWITCHGEAR APPLICATION OVERVIEW

Unlike many other stationary battery applications that have a constant load applied to the battery, the electric utility switchgear application is typically characterized by a complex duty cycle that has changing loads throughout the discharge period. An example of this is depicted in Figure 1. The duty cycle will typically have a high, short duration load in the beginning of the discharge, for applications such as breaker tripping, followed by one or more constant loads for applications such as control circuits, communications and monitoring circuits, or lights and alarms as an example. These other loads could occur at various times in the duty cycle, depending on the particular needs of the customer. This complex duty cycle application is typically served by a flooded lead acid cell that is described by most battery manufacturers as a "general purpose" cell design. General purpose cells are characterized by the ability to provide high current, short duration loads as well as lower current, long duration loads in an economical and space efficient design for the switchgear application.

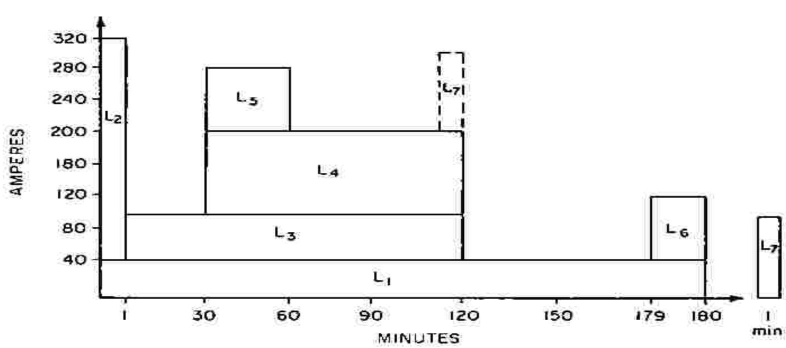


Figure 1 – Example of a complex duty cycle

UNDERSTANDING BATTERY RATINGS

Throughout the battery industry, the typical unit of measure to rate batteries is Ampere-hours (Ah). The important thing for the user to understand is the qualifiers that are tied to the Ah rating. There are four factors that need to be known along with the Ah rating to truly understand the number – time period (or rate), final voltage per cell, temperature, and specific gravity. For a typical North American manufacturer or cell design, one might see the following – 100Ah at the 8 hour rate to 1.75 volts per cell (VPC) in 1.215 specific gravity (sg) at 77°F (25°C). For a typical European manufacturer, one might see the following – 100Ah at the 10 hour rate to 1.80VPC in 1.240 sg at 20°C(68°F). More than likely, these two batteries are not the same and do not have the same discharge characteristics.

Since the utility application is typically comprised of a complex duty cycle for which a particular sizing calculation has to be performed (see IEEE-485) to determine the proper cell size to do the duty cycle, one should not select a battery based on Ah rating alone.

GRID/PLATE DESIGNS

Planté

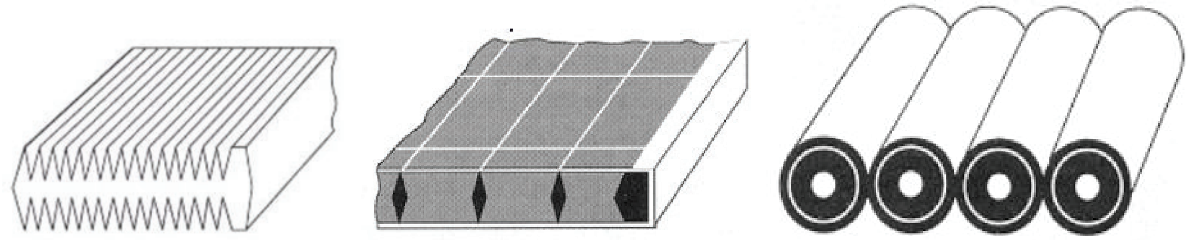
Named after the designer that originated the lead acid cell design circa 1859, Gaston Planté, the Planté plate is basically a sheet of pure lead which has the surface scored to increase the surface area and capacity of the plate - see Figure 2. Pure lead plate designs have a very low corrosion rate since they do not have any impurities or alloy additives in the pure lead. This leads to a very long float life expectation, in many cases beyond 20 years. They also have a very low gassing rate, which reduces water usage and reduces maintenance costs. These positive attributes can be offset by cost and footprint disadvantages. Since pure lead is very soft, it is inherently more difficult to manufacture, which increases the overall cost of the product. It is also not as efficient in high rate applications, which tends to cause the need for a larger Ah rated battery to meet the high rate component of breaker tripping and closing, thereby demanding a physically larger battery (more footprint) to do the same duty that a corresponding general purpose design battery would support. For the user that has the space and is willing to pay the cost premium, Planté batteries offer an excellent solution for a switchgear application. However, they are rarely used today as the economic and physical space drivers tend to lead users toward the other available flooded lead acid battery solutions.

Flat Plate

Flat plate designs have been around for over 100 years. They are the principal plate design that is found in stationary applications throughout North America, including telecommunications, uninterruptible power supply (UPS), and electric utility/switchgear applications. A flat plate consists of a grid structure of alloyed lead (lead calcium or lead antimony) which serves the dual purpose of the electrical conductor and the mechanical support for the lead dioxide and sponge lead active material of the respective positive and negative plates (see Figure 2). The flat plate design has proven to be a robust design that can be manufactured economically with modern plant manufacturing equipment. It is a flexible design in that manufacturers can modify plate characteristics (such as thickness, alloys, wire radius and placement) with relative ease to create a battery design that is optimized for a particular application (such as float service, cycle service, long duration, high rate, general purpose, etc).

Tubular Plate

The tubular plate consists of lead spines that act as the conducting medium, surrounded by active material that is encased in a fiberglass tube to retain the active material – see Figure 2. This type of design is prevalent in European lead acid battery designs as well as some motive power designs. The alloy used in these plates is antimony based to facilitate the casting of the lead spines. These types of designs are principally used in applications where many cycles are required, such as fork lift trucks and solar applications because of the antimony alloy approach. Recently, however, European designs that use these types of plates (OPzS cells) have been increasingly marketed to the traditional stationary float applications such as utility/switchgear as a potentially lower cost solution with claims that they can perform similarly to the calcium flat plate designs that have been the prevalent choice of discriminating utility customers for many years.



Planté Plate Flat Plate Tubular Plate

Figure 2 – Various plate designs for flooded lead acid batteries

ALLOYS FOR FLOODED LEAD ACID BATTERIES

The earliest form of lead acid batteries used pure lead (ie, the Planté plate). The attributes of this design were discussed earlier (see Planté section of the paper), so I won't repeat them here. The other two principal alloys used are antimony and calcium, each of which adds hardness to the grid/plate structure to ease manufacturing, but each of which have very different properties with respect to how they are applied, operated, and maintained which warrants additional discussion here.

Lead Antimony

Antimony was the first impurity introduced into the manufacturing process of lead acid cells around 100 years ago. For the most part, throughout the first half of the 20th century, manufacturers refined their processes with the use of antimony alloys in the range of 9-12%. The addition of antimony brought about several new characteristics of the lead acid cell's behavior.

The lead antimony design offers excellent cycling characteristics and can provide upwards of 1500-1800 deep discharge (80% depth of discharge) cycles. This makes it the primary choice in applications where many charge/discharge cycles are required, such as forklift trucks and solar applications.

There are, however, several operational drawbacks of antimony designs when used in float applications. These include high water consumption, high float current, antimony poisoning of the negative plate, and a high self discharge rate. In general, these characteristics can be explained as follows. The antimony used in the positive grid will plate out into the electrolyte solution over time. This free antimony attacks or "poisons" the negative plate, causing it to lose charge. This depolarization of the negative plate then causes more float current to flow to attempt to keep the plates fully charged. This increase in float current increases the gassing rate evolved from the plates, thereby increasing water consumption. This process continues and accelerates as the battery ages. The net result over time is increasing float current (energy cost to charge the battery and heat generation), increasing grid corrosion rates (accelerating the aging process), increasing gassing rates (including hydrogen evolution) and increasing water consumption (more maintenance).

Starting in the 1960's, much work was commissioned in an effort to reduce these negative aspects by reducing the antimony content used in the grids. At best, manufacturers were able to get down to a level of about 6% antimony and still be able to produce a quality plate. Below that level, other approaches were necessary to keep the metallurgical structure in place. Selenium was introduced in very small quantities (50-100 parts per million) to refine the grain structure of the grid and reduce the antimony level. It was also found that other elements, including copper, arsenic, sulfur, and tin could be used as well to enhance the grid casting process and properties in the manufacturing environment. These discoveries have lead to what is typically referred to as low antimony (<4%) alloys (some as low as 1% antimony) that are used today to reduce the negative effects of antimony when used in float applications. Some manufacturers have chosen to call these cells lead selenium cells, which is a misnomer as they are a low antimony cell (typically around 1.5% - 2% antimony) that uses trace amounts of selenium as a grain refiner. It must also be recognized that these low antimony alloys do not eliminate the antimony poisoning effects discussed earlier, but only reduce the rate at which they occur.

Lead Calcium

Around the same time as the antimony reduction research was commencing, a new alloy impurity was being considered – calcium. Because of the drawbacks of antimony discussed earlier, there was a need in the industry to find an alternative to antimony that would promote the types of characteristics desired in float applications – low water consumption, low gassing rate, longer shelf life, and reduced maintenance. This lead to the introduction of the binary lead calcium alloy. While it was found that lead calcium generally did not provide many deep discharge cycles (which is of minimal importance anyway in a stand-by float application), it was found that calcium provided the low maintenance properties the users desired. Lead calcium quickly became adopted as the alloy of choice in standby float applications like telecommunications, UPS, and utility switchgear because of these attributes.

Early lead calcium designs did present some challenges in manufacturing control and grain size control as it was difficult to maintain and control the appropriate level of calcium in the manufacturing process. Through research, other elemental additives like tin and aluminum were found to enhance the manufacturing process and final product to the point today where lead ternary alloys (lead-calcium-tin) are the prevalent mix used in lead calcium alloys.

CONSIDERATIONS IN BATTERY SELECTION

Today's utility switchgear engineer is faced with many challenging aspects of the battery specifying and purchasing decision. Many are faced with shrinking budgets and the desire to reduce procurement or maintenance costs, but they are still tasked with the responsibility of maintaining or improving the reliability of their network. With so many possible solutions for the utility engineer to select from, there are some important items that should be considered when making a battery selection.

Many electric utilities have used North American designed 20 year general purpose flooded lead calcium cells for many years in their applications. Today, there are many suppliers marketing the European flooded cell designs as a lower cost equivalent solution as a replacement for these batteries. One will generally find that a European OPzS lead antimony cell will cost less initially than a comparable North American general purpose 20 year life design cell. While this can be an important and respectable factor based on the specific capital budgets of a user, careful attention should be given to the operating and life cycle costs, as well as the different inherent properties of the different cell designs before embarking in this direction.

One Minute Rate

Earlier, the complex duty cycle characteristic of the utility switchgear application was discussed. In many cases, the first minute of the duty cycle, where critical breaker tripping operations occur, will be the determinant factor in the size (or capacity) of the battery required. In general, one will find that for a similar Ah rating of an OPzS cell compared to a North American general purpose cell the one minute rate of the OPzS cell is significantly lower. It is critical that the designer review the sizing calculations for the particular site before selecting a battery based on Ah rating alone. See Table 1.

Design/Operational Life

There are many different life claims that the user is bombarded with, but most manufacturers claim some form of 20 year life. It is important that the user understand the difference between warranty term and design life. Earlier, the European specifications were discussed, and it was noted that these specifications are typically based around 20°C and 1.240 specific gravity. North American designs are generally specified at 25°C and 1.215 specific gravity. These differences will have a profound affect on what the real life of the battery is. If you see 20 year life on an OPzS design and want to compare it to a North American design, the OPzS battery should be derated to approximately a 12-15 year life at 25°C and 1.215 specific gravity, as higher temperature and higher specific gravity will increase the grid corrosion rate, and therefore decrease the life expectancy.

Shelf Life

It is not uncommon to find that one purchases a battery, but does not install it right away. In this case, the user needs to consider the shelf life of the battery and the maximum storage time before a freshening charge is needed. In general, at normal room temperature, a lead antimony cell can be stored up to 3 months and a lead calcium cell can be stored up to 6 months before a freshening charge is required. If you expect to store a battery for an extended time, you will need to make arrangements to spend the funds required for a freshening charge before placing the battery in service. You should also consider the cost of this in the procurement decision.

Hydrogen Evolution

In many cases, substation designs and equipment installed was sized and selected many years ago. One of the items that is considered in the design of the enclosure or building that houses the battery is the hydrogen evolution rate created by the charging process of the battery system. It is imperative that the ventilation system provide adequate air exchanges to keep the hydrogen levels below explosive limits. In general, antimony cells will generate a higher gassing rate that increases over time when compared to a calcium cell. Therefore, it is important that the designer review the ventilation system to verify an appropriate level of air exchange exists if changing from a calcium alloy cell to an antimony alloy cell.

Life Cycle Cost

Ultimately, it is the users choice as to which particular battery is selected for use in the utility switchgear application. The lower initial cost enticement of OPzS cells needs to be weighed against the increased life cycle costs associated with the battery. In table 1, you can see the weight and specific gravity of comparable 350Ah cells – OPzS and North American designs. Intuitively, one can conclude that lower specific gravity and more weight (lead) will yield a longer operational life. Additionally, the expected life differences discussed earlier due to the difference in temperature and specific gravity characteristics of the two cell design approaches will lead to more frequent battery replacements. These factors are an important economic fact that should be considered in the battery selection and procurement process.

	Mfg A	Mfg B	Mfg E	Mfg X	Mfg E Gen'l Purpose
Model	5OPzS350	5OPzS350	5OPzS350	5OPzS350	350Ah
L (mm)	124	126	124	126	130
W (mm)	206	208	206	208	279
H (mm)	521	535	520	520	475
Weight (kg)	29	26.9	26.9	26.7	37.6
SG	1.240	1.240	1.240	1.240	1.215
Alloy	Low Sb	Low Sb	Low Sb	Low Sb	Ca or Sb
Plate Type	Tubular	Tubular	Tubular	Tubular	Flat
1 hr Amps	175	194	186	199	200
End Volts	1.75	1.75	1.75	1.75	1.75
Temp (°C)	20	25	25	25	25
1 min Amps	N/A	315	344	349	440
End Volts		1.75	1.75	1.75	1.75
Temp (°C)		25	25	25	25

Table 1 – Cell Attributes

SUMMARY

The battery selection decision for the utility switchgear application should include the consideration of several important factors such as those presented here. The engineer, faced with several competing forces driving the selection decision will find that attention to the factors presented here will assist in making a well informed decision and selection of the appropriate battery that will provide the economical cost profile, reliability, operating characteristics, battery life, and performance that are critical to a successful application of the battery system.