Understanding and Differentiating Design Life, Service Life, Warranty and Accelerated Life Testing for Lead Acid Batteries

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Abstract
Users employ stationary batteries for a variety of applications. Most think of stationary batteries serving three major industry segments: [1] telecommunications, [2] data centers/UPS, [3] utilities and industrial. But within each of these groups are several subsets of application parameters that introduce unique impacts upon the stationary battery installation and expected life.

Battery manufacturers design a battery to do certain things within a given set of parameters. This design life is generally predicated on certain conditions that may be generic to the specific application. Separate from this, but integrated in some fashion, is the warranty against manufacturing defect that forms the manufacturer's warranty statement.

On the other hand, additional factors have a profound effect on the actual service life of the batteries once installed. These circumstances can have a profound effect on how long the batteries will perform at >80% of capacity.

In the meantime, certain standards, including IEEE 535, mandate battery evaluation procedures that will provide a predictable expected life from the batteries. In Europe, certain testing mechanisms are required to certify a battery meets published criteria and the laboratory testing contributes values that lead to expected life under normal service conditions.

Add to the equation the fact that European manufacturers may offer a different warranty for the same battery in the US, and the user can be understandably confused. This paper will address these aspects and provide the user with a valid understanding of the differences between these various life-attributes. A careful look at differentiating warranty from both design life and service life will be explained.

Introduction
It is accepted industry practice that a battery is considered "good" or reliable as long as it can deliver ≥80% of its rated capacity [1]. IEEE 450 and 1188 prescribe best industry practices for maintaining a lead-acid stationary battery to optimize life to 80% of rated capacity. Thus it is fair to state that the definition for reliability of a stationary lead-acid battery is that it is able to deliver at least 80% of its rated capacity.

To compensate for the loss of up to 20% of its rated capacity due to aging and thus provide 100% performance as required by the duty cycle at end of life, IEEE 485 practice recommends adding an aging margin, sometimes referred to as an aging factor, of 125% when sizing a battery for a given load and duty cycle. Therefore, when IEEE 485 is utilized in sizing a battery, it is customary to expect that the battery will handle the defined/required load or duty cycle for its full stated life. For a 20-year battery, we are often surprised that if we run a capacity test at year 17, or even year 15 or 12, the capacity measures less than 80%.

Our first thought is to think that we have a bad battery and we should blame the manufacturer for a "defective" battery. We are often befuddled when the manufacturer pushes back and states that the situation is not covered under warranty. Now this is not to say that a battery may not have achieved its full life potential when it should have. However, the answer as to why the battery did not achieve its fully stated life is a bit more complex than just saying the battery is bad or defective.

To understand this, we need to answer several questions: [1] what was the manufacturer's stated design life for the battery? [2] Does the manufacturer distinguish design life from warranty? [3] What is the expected service life based upon actual installation and service conditions, and how does it relate to design life and affect warranty?

Let's see if we can put all of this into perspective and provide some insight into the reality of design life vs. service life and put both in the context of warranty. And, what role does accelerated life testing play in this?

What is Design Life?

We often hear that a stationary battery is designed for a telecommunication application, or it is called a UPS battery, or the literature states that a model is defined as a general purpose battery. What do these terms mean? Is it fair to say that any battery can perform any application, or is it more accurate to state that certain types of batteries will perform better or longer in certain types of applications? Or are both statements actually true.

The answer to the questions above lies in answering two important questions that only the user can answer: [1] how long should the battery last in the application for which I am planning to use it? And, [2] how well will it handle the specific application for which I am specifying the battery, i.e. what are its performance characteristics for this type of application?

The IEEE Stationary Battery Committee is in the process of revising two best practices that will provide guidance in these areas when released – IEEE 1189 and IEEE 946. IEEE 1189 is being rewritten as a guide for the selection of stationary batteries for the majority of stationary battery applications in addition to VRLA batteries. IEEE 946 is being rewritten as *IEEE Recommended Practice for the Design of DC Auxiliary Power Systems*.

However, in order to understand the expected life of a given battery type we really need to begin with its design life. The design life should not be compared with service life as the two are actually separate. And neither should be confused with warranty.

First, like so much of what we experience today, there has been an evolution in both the manufacture and the use of stationary batteries.

In its early history, the stationary battery was a pure lead cell encased in a rubber container and the plates were separated by rubber or wood [2]. Its application was fairly simple as well. Today we use stationary batteries to back up cell sites on mountain tops; switchgear in utility and industrial control houses, central offices spread throughout the landscape; UPS in cloud data centers; motors, pumps and turbines in power generation plants including nuclear Class 1E sites; and to store electric energy and provide backup power for use in photovoltaic or wind installations.

As a result, battery manufacturers make Planté plate, flat plate and tubular plate cells, some with thin or thicker plate construction, some with pure lead, others with lead antimony, lead calcium or lead selenium alloys; both VLA cells and VRLA cells – many with an absorbed glass mat (AGM) topology and others with a silica that produces a gelled electrolyte concentration(GEL); and now with the advent of newer technologies (many yet to be proven for cost-effective applicability for stationary application) we see lithium, sodium or flow type battery models, to name only a few.

Each of these were designed to meet certain criteria taking into consideration the alloys, grid structure, electrolyte, topology, and expected usage. This resulted in a 20-year, 10-year, or possibly other stated design life.

In Europe, design life is applied to components used in the battery and the limiting factors that might affect lifetime as established from endurance [3]. Endurance values are the result of combining standardized and accelerated testing results. For example, in Germany, battery manufacturers designed and tested lead-acid batteries to certain criteria defined in DIN standards, e.g. DIN 40742 (gelled electrolyte single 2V cells) or DIN 40744 (gelled electrolyte multi-cell bloc units). Today these standards, still referenced in literature, have been incorporated into the global IEC body of standards, e.g. IEC 60896-21 or IEC 60896-22.

In Europe, there is a distinct way that batteries are considered. Table 1 defines these distinctions.

Generic Term – Lifetime (Lebensdauer)		
Use in Theory	*Use in Laboratory*	*Use in Practice (Praxis)*
Design Life	Endurance	Service Life
Value is deduced considering design and implementation of the single components and the life time limiting parameters established from endurance tests	Values are measured under defined parameters; in part standardized and in part from accelerated conditions	Values established from field experience under optimized conditions, defining the time in which a specified capacity or power can be used.
Test standard-specification has to be indicated	Test standard-specification has to be indicated	Optimum application and operating conditions must be specified
	Three subsets: Endurance in cycles Endurance in overcharge Endurance in float service	

Table 1-Generic Terms to Define "Lifetime"

It was common to state that batteries would endure for a period of years depending upon type regardless of manufacturer in order to facilitate common expected results. In Germany, these endurance characteristics were divided into 3 subtopics: [1] endurance in float service, [2] endurance in overcharge and [3] endurance in cycles[4].

In an earlier Battcon paper it was stated that some preliminary testing results suggested that a 20-year design life for a VRLA was possible [5]. Europe took a different tack. *The Eurobat Guide for the Specification of Valve Regulated Lead-Acid Stationary Cells and Batteries* defines design life as follows: "The design life is the estimated life determined under laboratory conditions, and is quoted at 20°C using the manufacturer's recommended float voltage conditions." [6]

To facilitate user requirements, design life was sometimes called expected life which was structured into four main groups as shown in Table 2.

Time of Design/Expected Life[1]	Type of VRLA[2]	Explanation[3]
3-5 years	Standard Commercial	Used by consumer end of standby applications; popular in small emergency equipment.
6-9 years	General Purpose	Used when an improved life is required in comparison to the Standard Commercial product; also in cases where operational conditions are more severe.
10-12 years	High Performance	Used where high power, long life and high safety standards are required.
>12 years	Long Life	Used in applications where longest life and highest safety standards are required.

Table 2-Grouping of VRLA Design Life Expectations

Note [1]: "The following characteristics may be qualified by test methods in the International Specification, IEC 60896-21."

Note [2]: "This description applies equally to 'Absorbed (AGM)' and 'Gelled' electrolyte."

Note [3]: It was recognized that this was not to be considered a standard, and that "the classifications were arbitrary with overlaps so that the four groups could not be distinguished clearly" [7]

How Does Design Life Differ from Service Life?

This takes us to the tricky part . . . "how come I bought a battery with 20-year design life and I only get 15 years or less from my battery?" We must discuss service life and understand how it differs from design life.

First, let's define service life. Service Life has been defined as the "period of time during which, with a given load and by following the maintenance instructions, the specified limits of reliability characteristics will be fulfilled for all contemplated units, (e.g. same type of batteries)." [8] If we can paraphrase with a simple English translation, service life is "the actual battery life experienced from a cell or group of cells under actual installed conditions."

It is important to understand at the outset, there are several things that affect service life:

1. Temperature – probably one of the most important factors
2. Frequency and depth of discharges
3. Maintenance practices – considered by many to be a root cause of many failures
4. Lack of understanding the true load profile and/or the application
5. Type of battery chosen for the given application
6. Undercharging or overcharging the battery due to an incorrect voltage setting of rectifier/charger to the required battery voltage
7. Undercharging or overcharging the battery due to a lack of synchronization between the voltage reading and the actual voltage at the battery terminals.
8. Excessive ripple to the battery
9. Other environmental factors – temperature or voltage gradients within the string, flooding, etc.
10. Quality of Installation
11. Actual manufacturing defect(s)

Each battery manufacturer outlines expected maintenance practices that must be followed in order to ensure that the battery will perform correctly. What these operating instructions do not state is what happens if these practices are not followed, nor do they account for many of the variables listed above that a user experiences in his day to day applications. We do know though that these "stress factors" can shorten battery life.

Let's look at just a few of these factors and highlight the effect that could impact service life. It is a given that temperature plays a major part in either extending or decreasing service life. However, it is important to note that the temperature effect is not linear. Increased temperatures on a battery cell are more severe in shortening service life than cooler temperatures are in extending it.

It is commonly accepted that for every 10°C rise in temperature continually applied to a battery, the result is a reduction in battery life by approximately 50% (See Figure 1 below).

Another "stress factor" that can severely affect service life is undercharging or overcharging the battery. Undercharging the cells will lead to plate sulfation with a resultant buildup in internal resistance within the cell while reducing capacity and eventually shortened battery life. Conversely, overcharging the cells leads to accelerated positive plate corrosion, and eventually shortened battery life as well.

Accelerated Life Testing

The US Nuclear Regulatory Commission accepts a VLA stationary battery for installation in Class 1E environments at a nuclear power station when the battery manufacturer qualifies his battery following the IEEE 535-2013 standard. Accelerated Life Testing is an accepted method to verify its design life [9]. It does add a level of cycling, especially when qualifying a battery for greater than 8 hours, in that a modified performance test must be performed at every 2-year period (and annually for the last 25% of the testing period) to validate its ability to remain at ≥ 80% of capacity. [10]

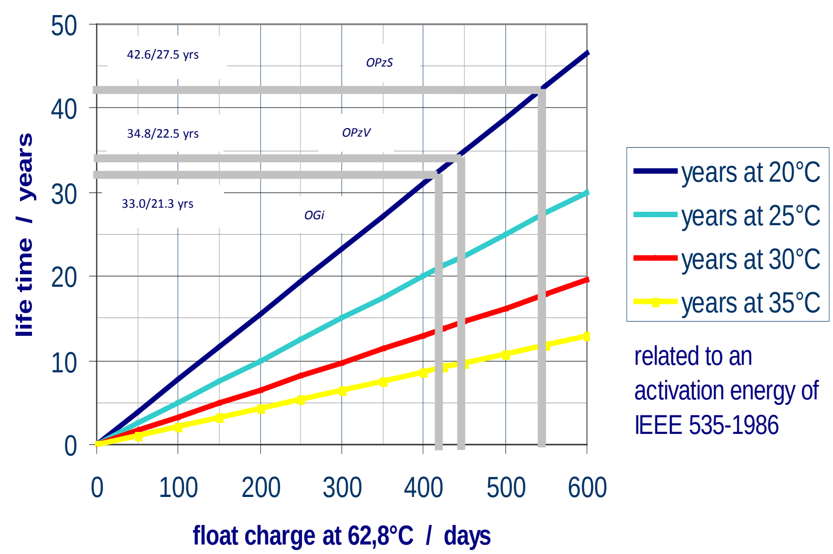

Figure 1- Equivalent Lifetimes Based on the ARRHENIUS Equation Method

Figure 1 is a graph that shows the results of testing we did to qualify batteries for Class 1E service for a nuclear plant in Belgium several years ago using this accepted IEEE 535-1986 methodology. This was documented in both an Intelec and a Battcon paper given by Dr. Wieland Rusch in 2005. [11]

The IEC publishes two standards that deal with accelerated life testing in concert with cycling. IEC 60-896-11 deals with cycling to 80% Depth of Discharges (DOD) while IEC 61427 deals with specific summer and winter cycling expected with photovoltaic installations as it relates to both number of cycles achieved and length of life.

A paper given by individuals from one battery manufacturer attempted to demonstrate potential life of VRLA batteries using accelerated life testing methodology prescribed by Bellcore TR-NWT-001200. The difficulty with accelerated life testing is that it attunes itself to positive grid corrosion, the most likely failure mechanism within a VLA cell. While positive grid corrosion is a factor with VRLA failures, there are other failure mechanisms with a VRLA as well. These, like dryout, are more pronounced with an AGM type of VRLA cell. Nevertheless, the manufacturer's testing proved useful in that it showed the anticipated life for the group of cells they tested to actually be between 5 and 7 years [12].

In the 2005 paper given at Battcon [13] that attempted to explain difficulties with warranty and detailed expected results for VRLA cells, it is important to keep in mind that most expected life estimates are based upon floating a battery at a constant temperature for a specified period of time devoid of any external variables except cycling.

What Does This Say About Warranty?

In O'Donnell's 2005 Battcon paper [14] a suggestion was made that manufacturers and the IEEE Stationary Battery Committee consider drafting a more realistic approach to equating service life against design life and adopting a different approach to warranty.

As can be seen, the difficulties lie in the fact that design life and service life are not synonymous. And warranty is in fact only a guarantee against manufacturing defect. A warranty statement can only assure a user that if he follows accepted and documented maintenance practices as outlined by the manufacturer, the battery (or cell) is warranted against manufacturing defect for a specific period of time.

Some battery manufacturers also have a stipulation that cycling of a stationary battery is confined to a finite number of cycles and exceeding that number will void the warranty. Other manufacturers place a stipulation on temperature. For instance, one manufacturer states that if the average ambient temperature exceeds 80°F, the warranty is void [15]. Another states as a Condition and Limitation, "The yearly ambient temperature in the area of use in any year may not exceed 77°F (25°C)."[16]

Due to the extreme variables that can affect service life, most manufacturers limit their full warranty to a specific period of time, e.g. 12 months, 24 months or up to 60 months [17] after date of manufacture. Most permit a 90 day window beyond the date of manufacture to allow time for transit and installation. Although it is common in North America to offer a twenty-year warranty, determinants such as stress factors and other variables can make the validity of the warranty questionable after a given number of years.

Some have stated that they believe warranty is just a marketing game. Given the way in which the 20-year warranty came into being and how it has been implemented over time, it is understandable how the warranty could be viewed that way. It may help to understand if we look at the typical failure characteristics of a lead acid battery. The curve characteristic below in Figure 2 is considered by many to show the typical failure characteristic of a lead-acid battery over time.

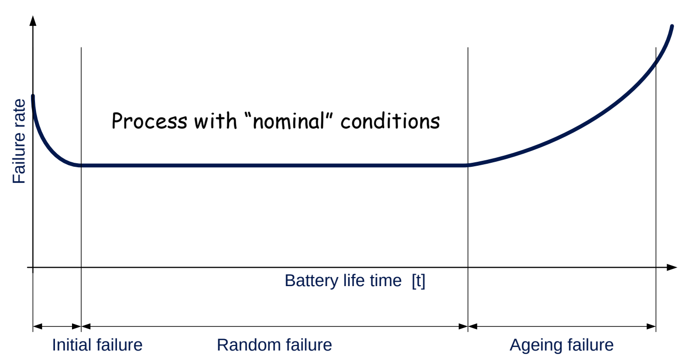

Figure 2

As can be seen in Figures 2 and 3, the failure characteristics resemble a bathtub diagram. Initial failures can be caught within a reasonably short period of time. While most initial failures can be considered the result of manufacturing defect, shipping, storage and manner of installation can contribute to initial failures. Random failures are typically, although not always, determined by operational conditions and more closely associated with "stress factors." [18]

As batteries age, however, the “stress factors” play a much more significant role in the actual service life achieved, although quality of manufacturing materials and processes will certainly aid or hinder the final result. In the final analysis, however, the attention to proper maintenance will have the biggest influence on achieving the desired lifetime result.

This can be shown by the following graph in Figure 3.

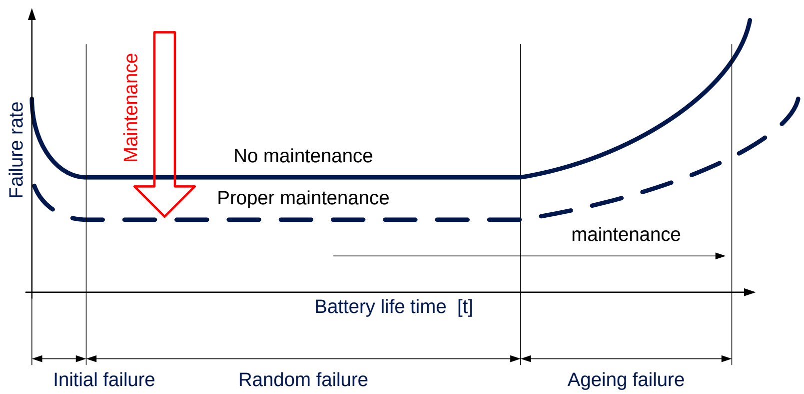

Figure 3

Thus, proving a battery is defective is not always easy given the variables described above. A more realistic approach to warranty would be beneficial. [19]

Conclusion

What can we take away from all this?

First, warranty provisions must be separated from design life and service life. Further, service life must be differentiated from design life.

Battery manufacturers could do a better job in defining the parameters and characteristics used to state design life, although expected lifetime is a blend of design life and actual service life. There is no substitute for performing proper maintenance and keeping good maintenance records to authenticate battery performance over its entire service life. It is important that all parameters affecting cell life be documented. This includes but is not limited to:

1. Individual cell and string voltages
2. Individual cell temperatures
3. Specific gravity or float current measurements
4. Internal resistance measurements
5. Connector resistance measurements

Accelerated life testing can be a valuable tool in understanding a battery’s expected potential. However, it must be understood that accelerated life testing is used to determine the rate of positive plate corrosion and is based upon the assumption that positive plate corrosion is the primary cause of cell failure. Other failure mechanisms, especially with VRLA AGM cells, may not be determined exclusively with accelerated life testing.

Accurate maintenance records are fundamentally important, and every battery user should ensure that he/she is keeping these records. It is important to understand and follow the battery manufacturer’s recommendations consistently throughout the battery’s service life.

Battery problems after installation are often blamed on manufacturing defect when in fact many times the true reasons have nothing to do with manufacturing defect.

The best solution to avoid difficulty with lead-acid batteries is to [1] make sure the battery you are choosing has been designed to meet your application; [2] strive to install the batteries in the most favorable environment with qualified installation technicians; [3] maintain the battery to the manufacturer's published recommendations ensuring that all cells are kept at the proper charge level, and [4] keep complete and thorough records of the maintenance activity performed on these batteries.

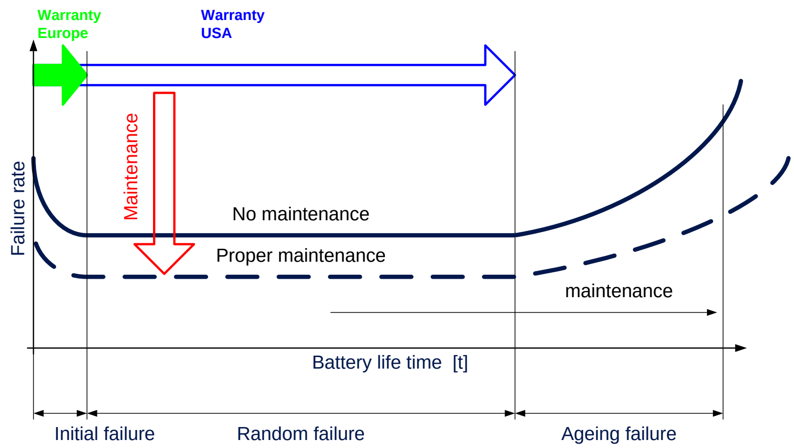

Figure 4

Finally, Figure 4 shows how many in Europe view warranty .[20] Perhaps it's time to take a fresh and more realistic approach to Warranty.

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