EVALUATION OF HIGH TEMPERATURE VRLA BATTERIES IN DESERT CELL SITES WITH NO TEMPERATURE CONTROL

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Abstract

In recent years, battery manufacturers have advertised several new VRLA products as being heat tolerant or high temperature resistant.

In 2016, a major cellular telephone company initiated a trial of several high-temperature VRLA products at cell sites around Phoenix, Arizona. The battery cabinets at these sites were not temperature-controlled and had internal cabinet temperatures ranging from lows in the 40°F's to highs over 120°F. The goal of this trial was to evaluate the annual performance degradation of the different products through capacity testing.

The battery products were baseline tested in a laboratory at 77°F to determine initial capacities and then installed in battery cabinets at the cell sites. Two 48V strings for each product were tested: temperature compensation was enabled on one string and disabled on the other. Monitoring systems were installed to continuously record float voltage, float current, string temperature, and ambient temperature at the sites.

"Control" strings for each product were also installed in a temperature-controlled laboratory and maintained on float charge at approximately 77°F.

Each year an IEEE 1188 capacity test was performed on every string. The capacity tests were performed at the manufacturer-specified three-hour constant current rate to 1.75vpc.

This paper presents findings from the high-temperature VRLA product trial, including annual capacity test results beginning in 2016.

Introduction

Valve-regulated lead acid (VRLA) batteries have become prevalent in many industries, largely due to the small relative footprint and installation flexibility. All lead acid batteries are subject to failure modes that accelerate at high temperatures such as dry out, grid corrosion, and positive plate growth. As such, historically lead acid batteries have been primarily used in applications where the temperature can be controlled. The need for temperature control significantly increases annual operating costs of lead acid batteries over those of more temperature tolerant products.

A recent trend in the stationary battery industry is to produce and market new products as being resilient to high temperatures. In general, there is little publicly-available evidence to support the claims of improved temperature tolerance. When data is provided, it is often based on accelerated life testing performed in a laboratory.

This is why in 2016, a large telecommunications company began a product trial of six high-temperature VRLA battery products from five prominent manufacturers in desert cell sites with no environmental controls. The intent of the product trial was to analyze the degradation of each product over time and estimate the float life in a real-world application.

This paper describes the products that were evaluated, the installation sites, and a general overview of the evaluation process. Analysis of the temperature, annual capacity degradation, and internal ohmic trends are also presented.

Product Evaluated

The battery products selected for the evaluation were front terminal 12V VRLA modules with amp-hour ratings between 170Ah-185Ah. All products were marketed as high temperature telecommunications batteries. The manufacturer's data sheets all specify similar float voltage ranges and allow for operation at 2.25 volts per cell (13.5 volts per module) at 77°F.

Modules of each product were obtained directly from the manufacturers and used to create 48V strings consisting of four modules per string. The strings were then designated for three different test conditions:

- Desert cell sites with no temperature control - temperature compensated charging enabled
- Desert cell sites with no temperature control - temperature compensated charging disabled
- Temperature-controlled laboratory environment maintained at 77F

The manufacturer and product names have been anonymized in this paper. Each product is identified using a Greek letter Alpha through Zeta. Individual strings are identified B through U. Figure 1 summarizes the products that were tested.

Figure 1: Summary of Products Tested

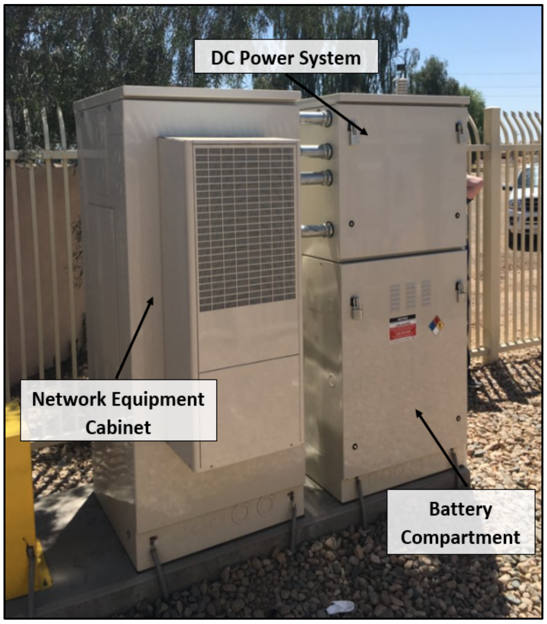
String ID	Mfgr ID	Mfg Date	Temp. Comp. Enabled? (Y/N)
Products Installed at Phoenix Cell Sites			
B	Alpha	4/2016	Y
C	Alpha	4/2016	N
J	Alpha	4/2016	Y
K	Alpha	8/2016	N
E	Beta	12/2015	Y
F	Beta	3/2016	N
L	Epsilon	4/2016	N
M	Epsilon	4/2016	Y
N	Delta	6/2016	N
O	Delta	6/2016	Y
P	Zeta	2/2018	N
Q	Zeta	2/2018	Y
G	Gamma	5/2016	Y
I	Gamma	5/2016	N
Product Installed in Temperature-Controlled Laboratory			
R	Alpha	2/2018	NA – Controlled Temp
S	Beta	2/2018	NA – Controlled Temp
U	Zeta	2/2018	NA – Controlled Temp
T	Epsilon	10/2016	NA – Controlled Temp

Field Test Sites

Phoenix, Arizona was selected as the location for the field evaluation as it was likely to expose the products to extreme heat.

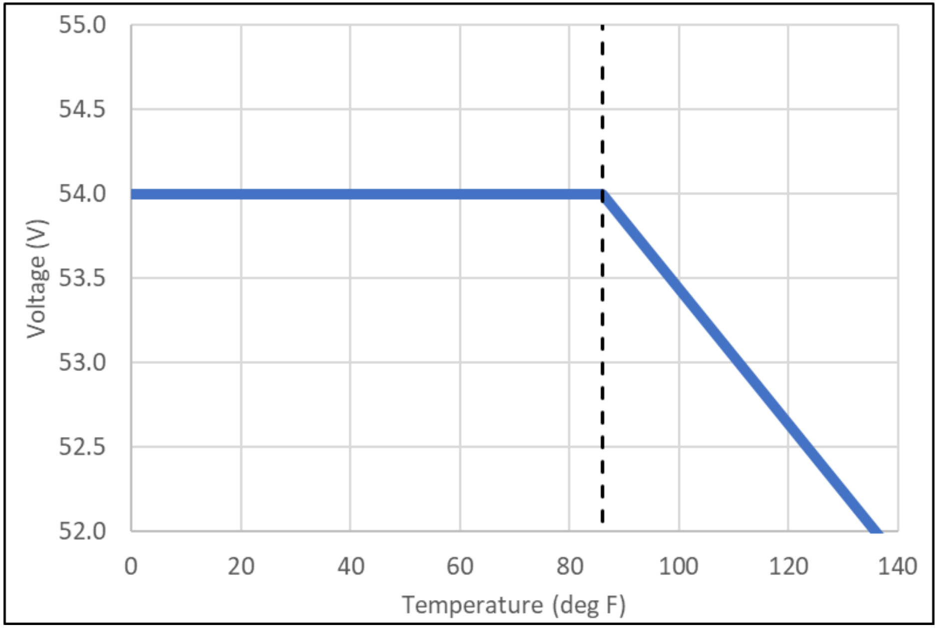
Four new-build cell sites around Phoenix were used. The cell sites were cabinetized systems with separate spaces for the dc power system, batteries, and network equipment.

Figure 2: Example of Cabinetized Cell Site Used in Product Trial



The cell sites used a modular dc power system for charging batteries and powering the load equipment. The dc power systems at all four sites were configured to output 54.0V (2.25 volts per cell) under normal operation. Temperature compensation was enabled on two of the sites and configured to decrease the voltage by 72mV per °C for temperatures above 86° (30°C). Temperature compensation was disabled on the other two sites.

Figure 3: Temperature Compensation Scheme Used at Two of the Four Phoenix Cell Sites



The battery compartments have three battery shelves (top, middle, and bottom) with space for three 48V battery strings in the compartments. The battery compartments have two dc fans that bring outside ambient air into the cabinet.

The strings were connected to a common dc bus via Anderson SB connectors.

Monitoring System and Data Collection

Monitoring systems installed at each cell site continually recorded the following measurements:

- Individual battery string voltage for each string
- Float current for each string
- Temperature of most-negative module of each string
- Ambient temperature inside the battery cabinet
- Ambient temperature outside the battery cabinet

The measurements were recorded at approximately 20-minute intervals. The monitors only recorded measurements from the system. The monitors did not perform individual cell equalizing or any other active conditioning.

Solar shields were installed outside of the battery cabinets to prevent solar loading of the outside ambient temperature sensor.

The monitoring systems were integrated into the cellular network so that the data could be downloaded remotely.

Laboratory Test Site

Four of the products (Alpha, Beta, Epsilon, and Zeta) were installed in the laboratory and connected to a common dc bus fed from a modular telecom dc power system. The voltage of the dc bus was maintained at 54.0V. The ambient battery temperature was maintained at approximately 77°F. Temperature compensation was not necessary for the laboratory strings and was disabled in the modular dc power system.

Process Overview

Baseline Testing

Before being installed at the Phoenix or laboratory sites, each string was capacity tested in a lab to establish individual module baseline capacities. The strings were received from the manufacturers and placed on float charge prior to the baseline test. After the float charge, a constant current capacity test was performed based on IEEE 1188 [1]. After baseline testing, the strings were installed at the trial locations.
The baseline test results were used as points of reference for all future testing.

Installation and Monitoring

The strings were installed at the test sites after baseline testing.

Data from the monitoring systems was reviewed on a weekly basis to ensure the batteries and monitoring systems were operating normally.

Field Testing

Personnel visited the sites each year to perform capacity testing and to visually inspect the dc power system, batteries, and monitoring system.

Technicians recorded individual module float voltages, ohmic readings (conductance measured with a Franklin Electric Celltron Ultra or Celltron Advantage), and temperatures prior to the test. Then the battery strings were disconnected from the dc plant and capacity tested using an automatic load bank. Each string was tested individually.

The capacity tests were performed in accordance with IEEE 1188 [1] using the manufacturer’s three-hour constant current discharge rates to 1.75 volts-per-cell. The onsite testing was scheduled to occur during a period where the outside ambient temperature was approximately 77°F to limit the need for temperature correction adjustment in the battery capacities. During the capacity tests, the string was discharged until every module reached the target end voltage of 10.5V.

Summary of Temperature Data from Phoenix Cell Sites

Temperatures in the battery cabinets ranged from lows in the 40°Fs to highs over 120°F. Figure 4 shows histograms of the temperatures recorded by the battery monitor at one of the test sites during one year. The colors in the figure represent the various locations of the sensors.

- Green - Temperature of string installed in the top shelf of the battery cabinet
- Orange - Temperature of string installed in the middle shelf of the battery cabinet
- Blue - Temperature of the string installed in the bottom shelf of the battery cabinet
- Red - Ambient temperature inside of the battery cabinet
- Gray - Ambient temperature outside of the battery cabinet

A bimodal distribution is apparent in the battery string temperatures and the inside ambient temperature. This is most likely caused by the battery cabinet fans. The default configuration for these cabinets is to turn on the fans when the inside ambient temperature is greater than 86°F and turn them off when the temperature is less than 74°F.

Figure 4: Histogram of Temperature at Phoenix Cell Sites Over One Year

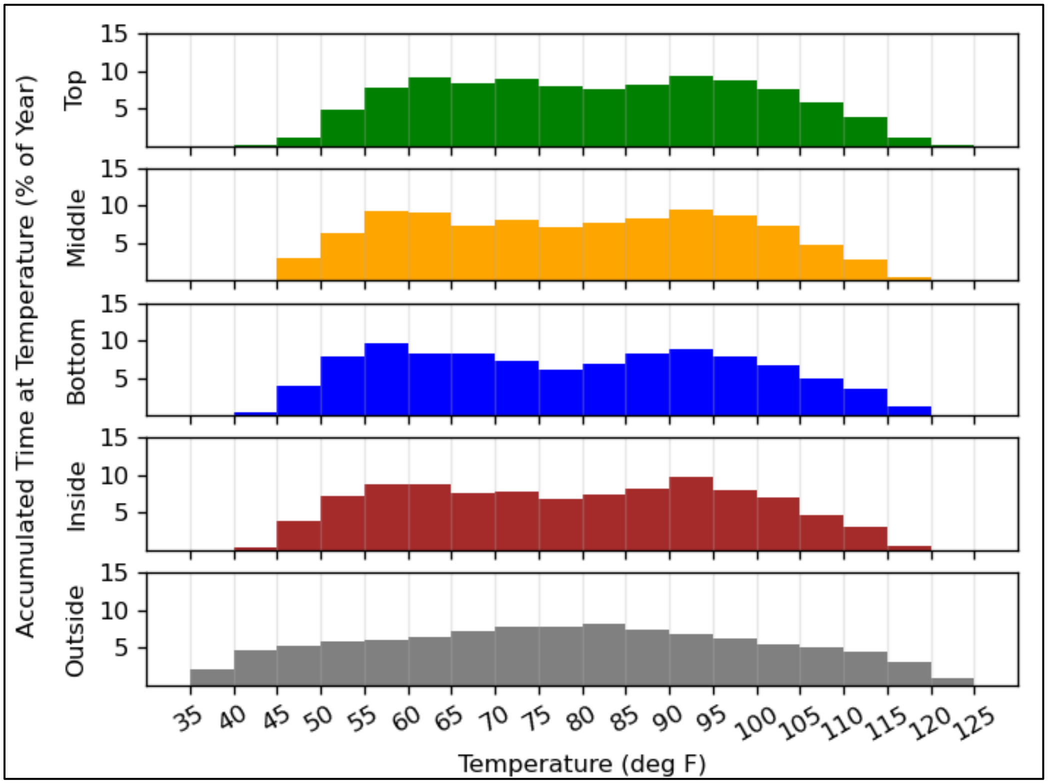
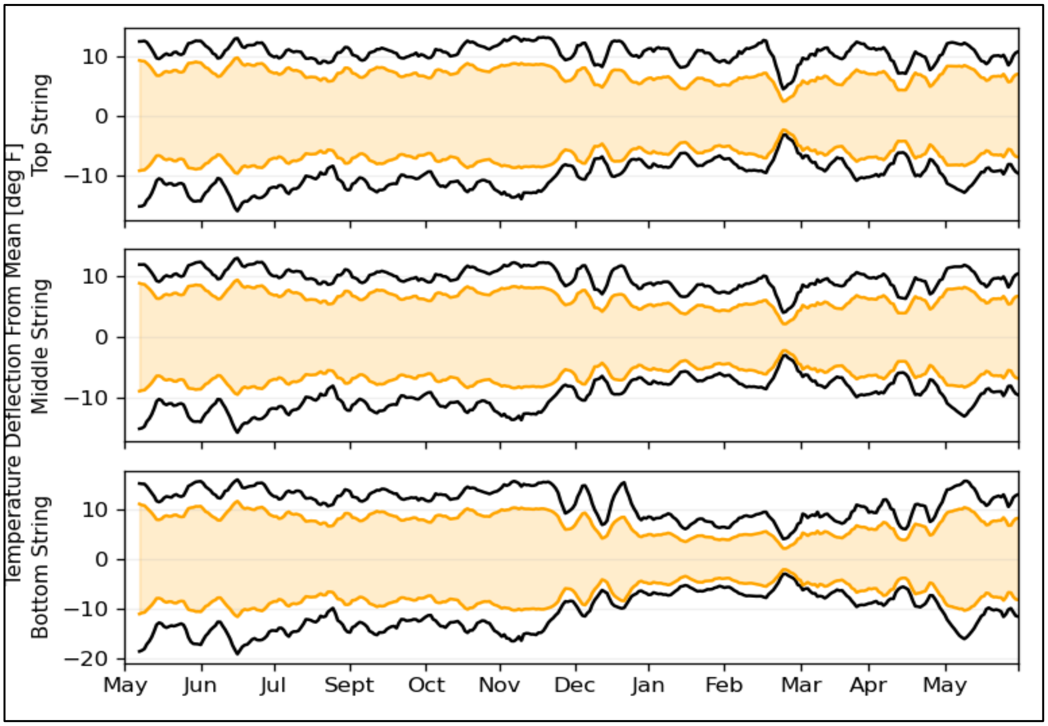


Figure 5 shows how the temperatures varied on a daily basis over the same year.

- Black Lines – How far the temperature deviated from the mean each day
- Orange Lines – Standard deviation of the temperature for each day

Figure 5: Daily Temperature Change



Capacity Test Results of Field Strings

Figure 6 shows the module capacity test results per year for strings installed at the Phoenix cell sites. The results have been normalized to the results of the baseline capacity tests on a per-module basis. Circles indicate that the module is at a site with temperature compensation. X's indicate no temperature compensation.

Beta, Delta, and Zeta showed noticeable capacity loss after the first year. The capacities for these products tended to decrease linearly each year, and the majority of these products had less than 80% of the baseline capacity after three years. One string of the Beta product was removed from the evaluation after the 2020 testing due to individual module failure.

Two products (Alpha and Epsilon) show little to no capacity loss for several years. The majority of the modules for these products had capacity >80% of the baseline test for at least five years.

Alpha, Beta, and Gamma had individual modules with significant capacity loss over one year, which suggests failure modes that were not observed in the other modules and not related to normal aging.

- Alpha, String B, Module 7: 91% -> 0%
- Beta, String F, Module 24: 75% -> 28%
- Gamma, String G, Module 28: 101% -> 10%

Modules installed at sites with temperature compensation enabled tended to be lower capacity than modules at sites with it disabled.

Figure 6: Module Capacities Normalized to Baseline Test – Strings Installed at Phoenix Cell Sites

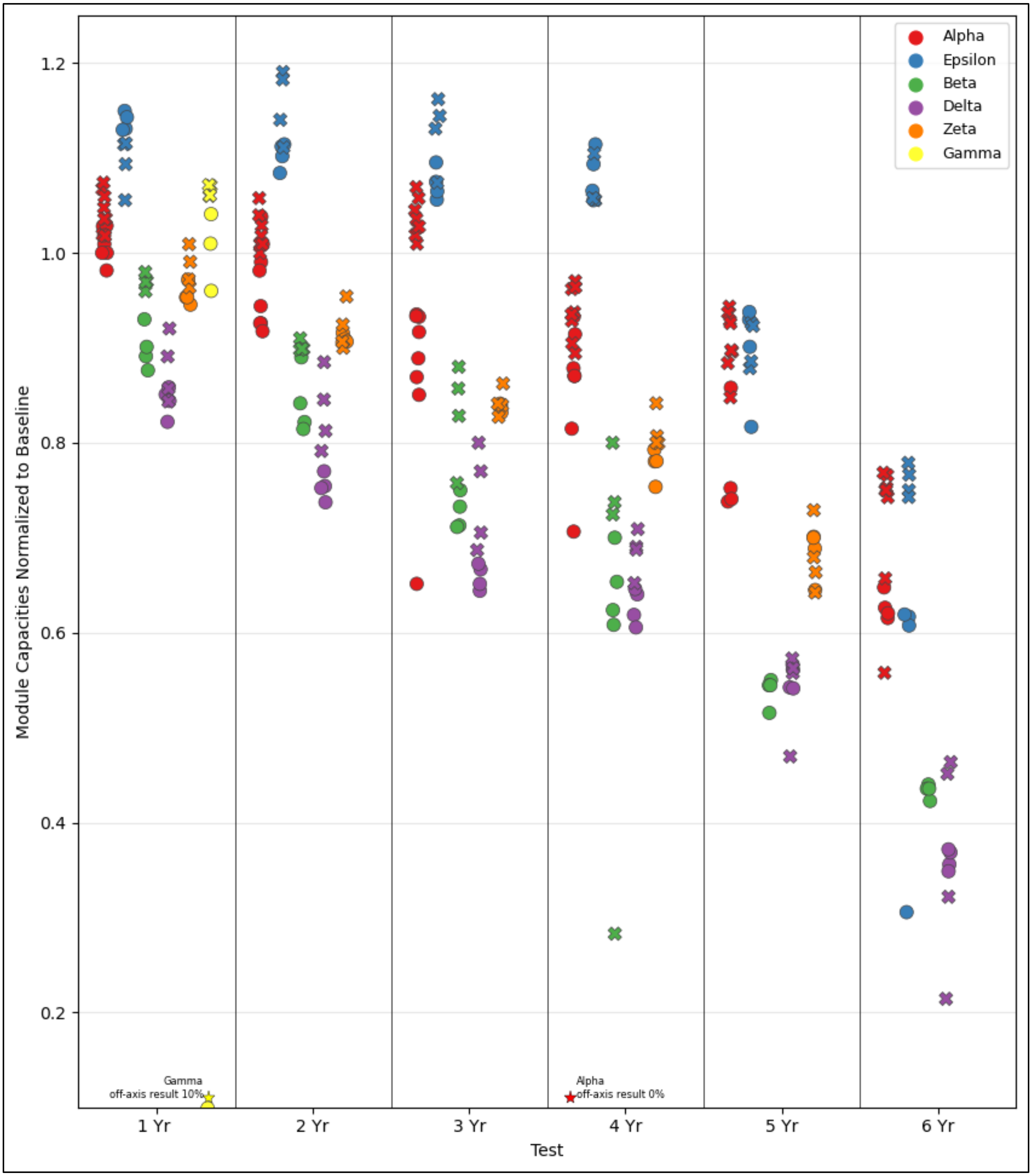
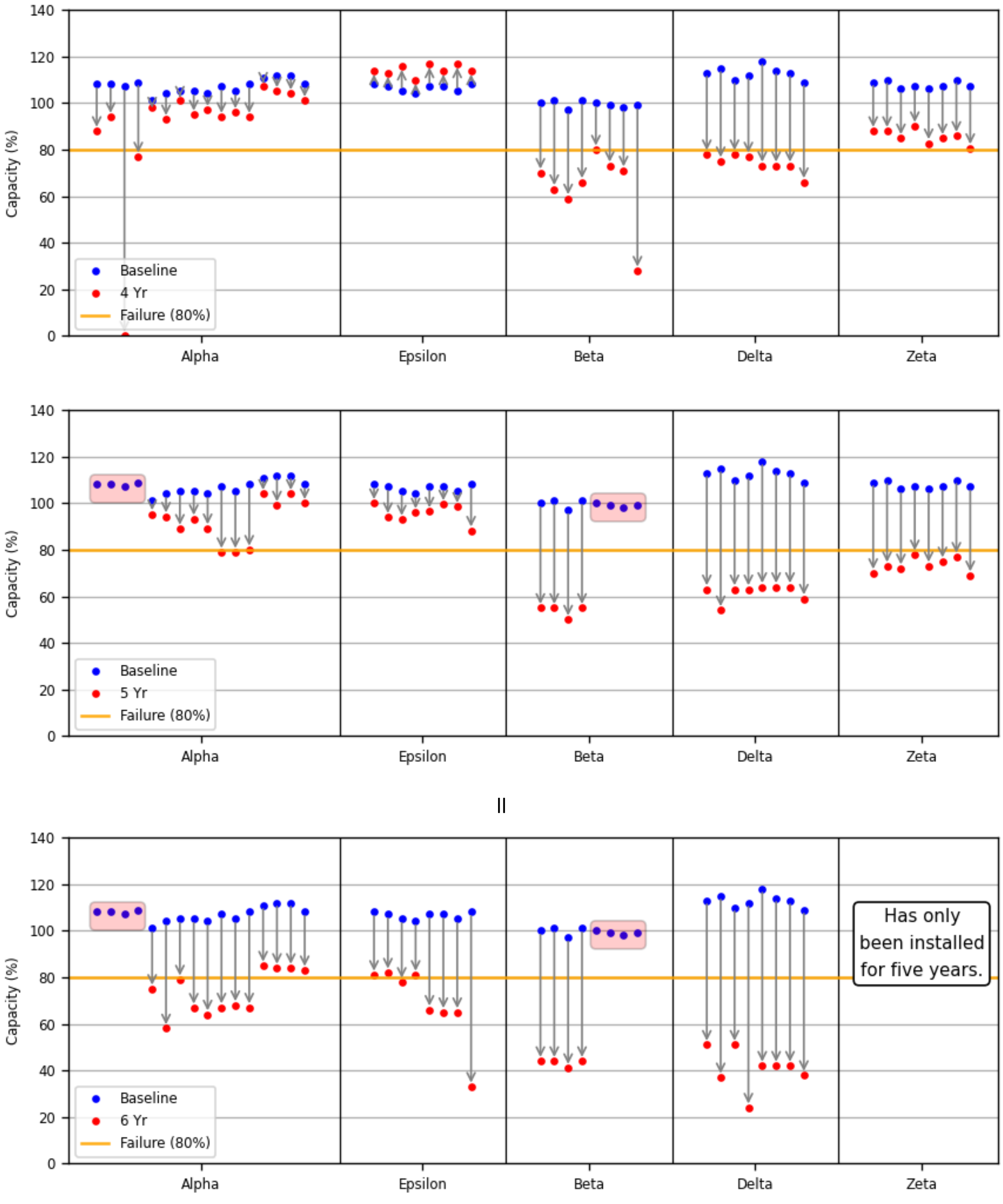


Figure 7 on the next page shows how the individual module capacities changed after being installed at the Phoenix cell sites for four, five, and six years. Note that the red boxes in the five-year and six-year charts indicate that strings were removed from the trial due to very low-capacity modules.

Figure 7: Module Capacity Change from Baseline Test After Four, Five, and Six Years– Strings Installed at Phoenix Cell Sites



Internal Ohmic Analysis of Field Strings

Figure 8 shows the individual module conductance per year normalized to the manufacturer-publish baseline reference values. The trend in conductance values is similar to the trend in module capacities.

Some strings with less than 80% capacity continued to have more than 100% of the manufacturer's reference conductance.

Figure 8: Module Conductance Normalized to Mfgr's Reference – Strings Installed at Phoenix Cell Sites

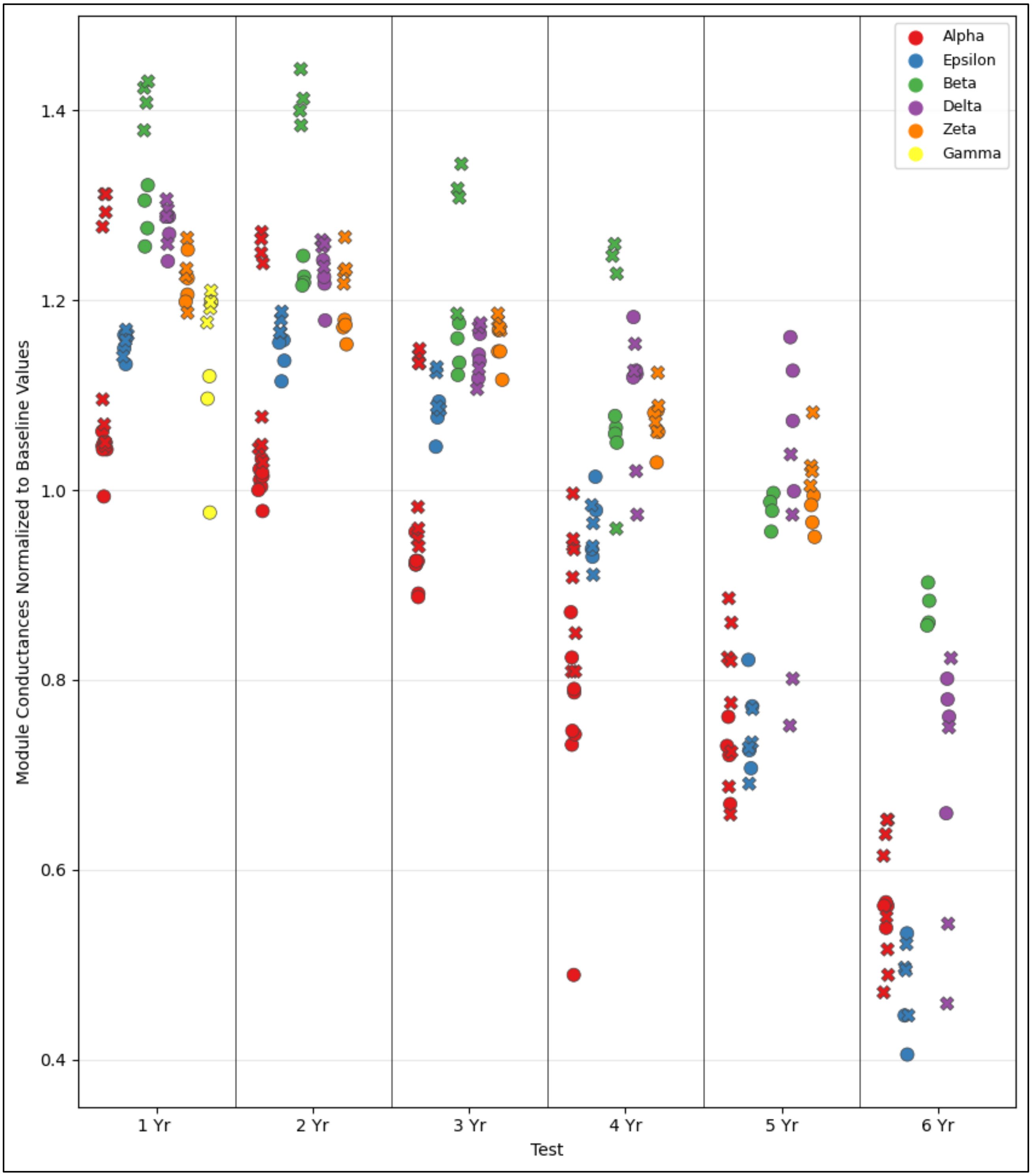


Figure 10 compares module conductance versus capacity. The conductance values in the chart are normalized to the manufacturer's reference conductance value. The capacities are normalized to the baseline test capacities.

The module conductance for each product trends with capacity. The least squares regression is different for each product.

Figure 9: Least Squares Approximation of Normalized Module Conductance Vs Normalized Module Capacity

Product	Slope	Y Intercept	R^2 Value
Alpha	0.526	0.436	0.727
Epsilon	0.612	0.432	0.828
Beta	0.985	-0.427	0.900
Delta	0.752	-0.155	0.853
Zeta	1.058	-0.359	0.833
Gamma	*Not enough data		

Figure 10: Module Conductance Normalized to Mfg.'s Reference Vs Normalized Module Capacity – Strings Installed at Phoenix Cell Sites

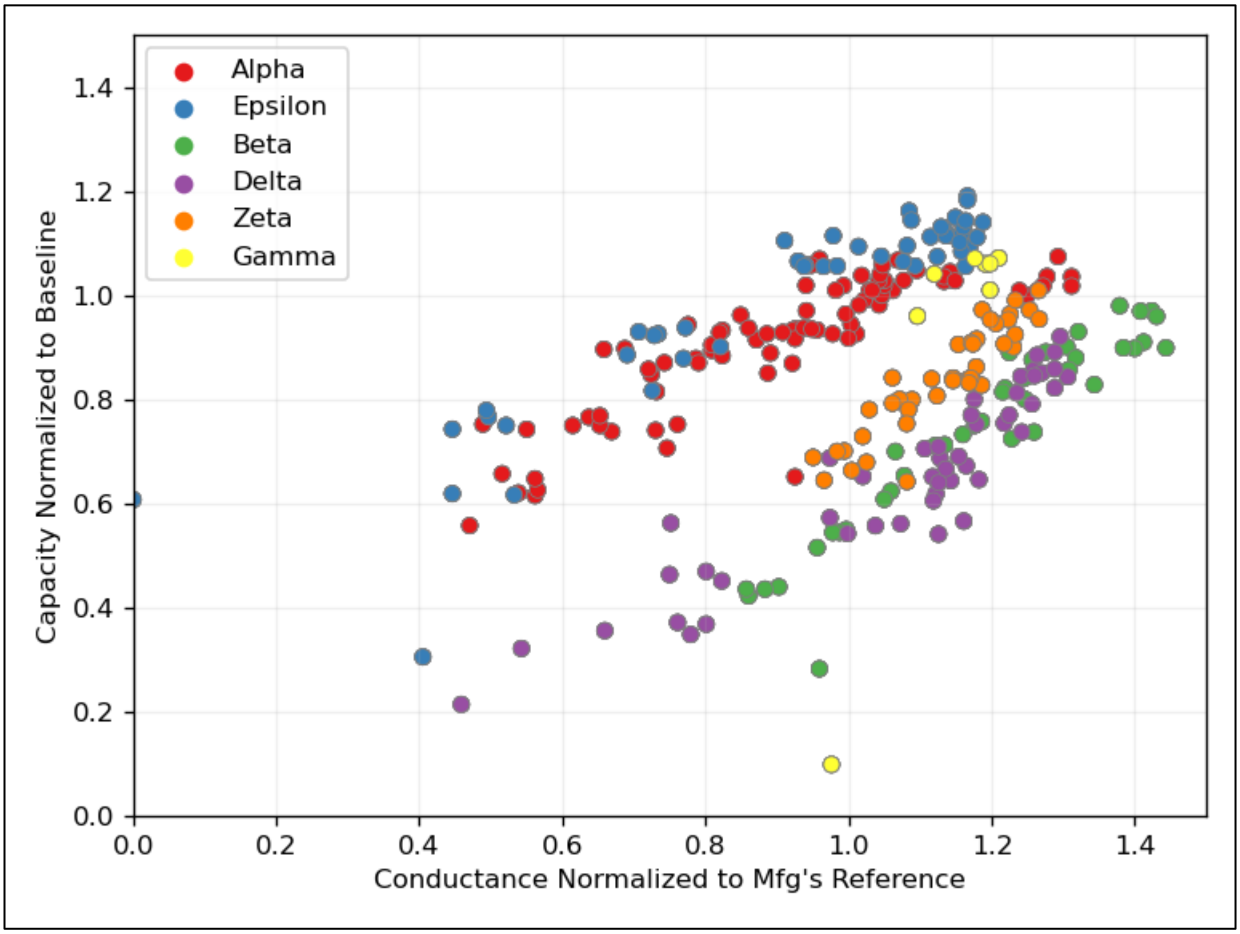
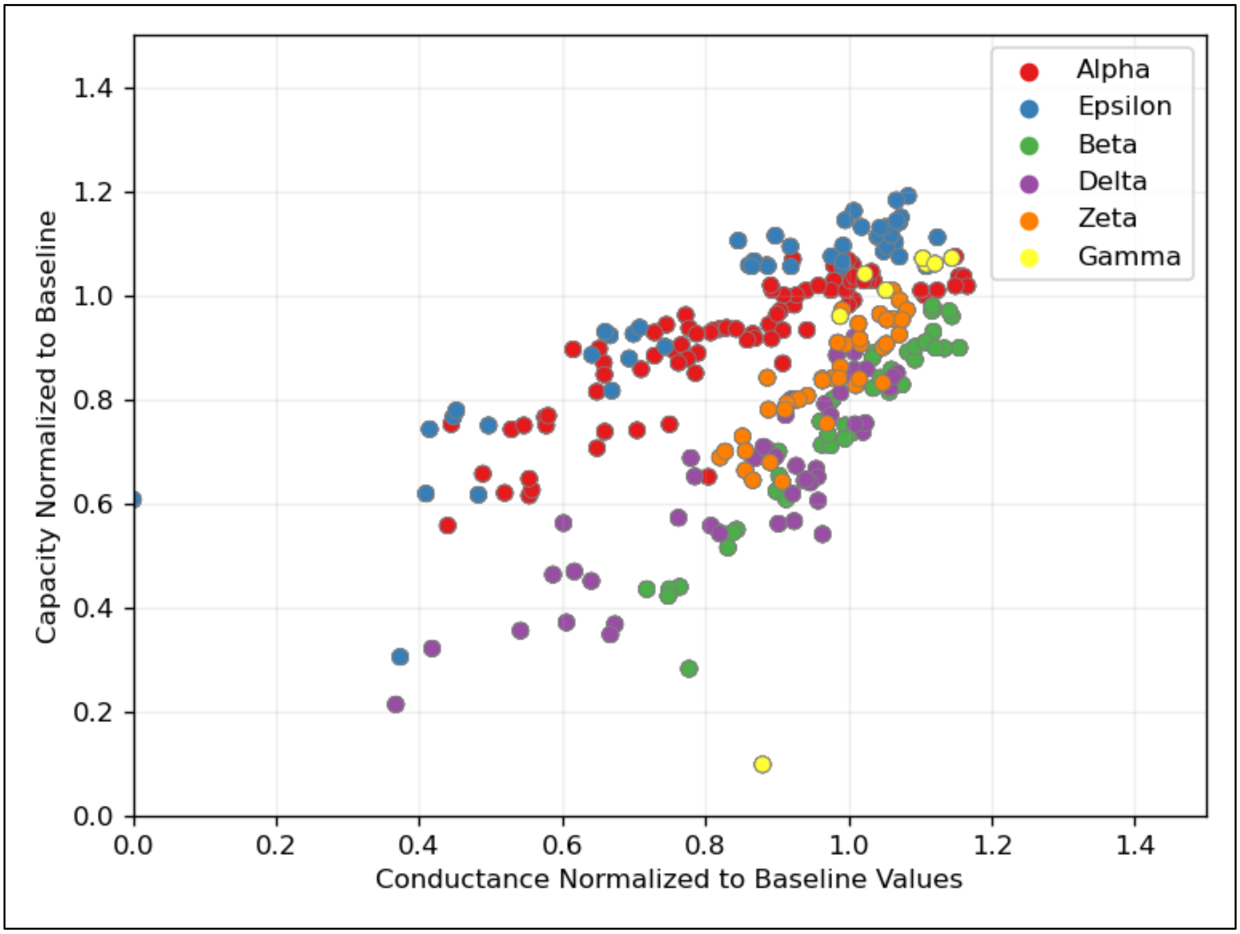


Figure 12 also show module capacity versus conductance. The capacities and conductance values in this figure are normalized to the values from the baseline tests.

Figure 11: Least Squares Approximation of Normalized Module Conductance Vs Normalized Module Capacity

Product	Slope	Y Intercept	R^2 Value
Alpha	0.603	0.407	0.758
Epsilon	0.663	0.433	0.826
Beta	1.374	-0.608	0.938
Delta	0.874	-0.104	0.775
Zeta	1.177	-0.303	0.774
Gamma	*Not enough data		

Figure 12: Module Conductance Normalized to Baseline Conductance Vs Module Capacity Normalized to Baseline – Strings Installed at Phoenix Cell Sites



Capacity Test Results of Laboratory Strings

Figure 13 shows the module capacity test results per year for strings installed in the laboratory and maintained on float charge at 77°F. The results have been normalized to the results of the baseline capacity tests on a per-module basis.

Only four of the six manufacturers were included in the lab trial. The results for all four strings indicate that these products have at least a five-year life in controlled environments.

Figure 13: Module Capacities Normalized to Baseline Test – Strings Installed at Laboratory

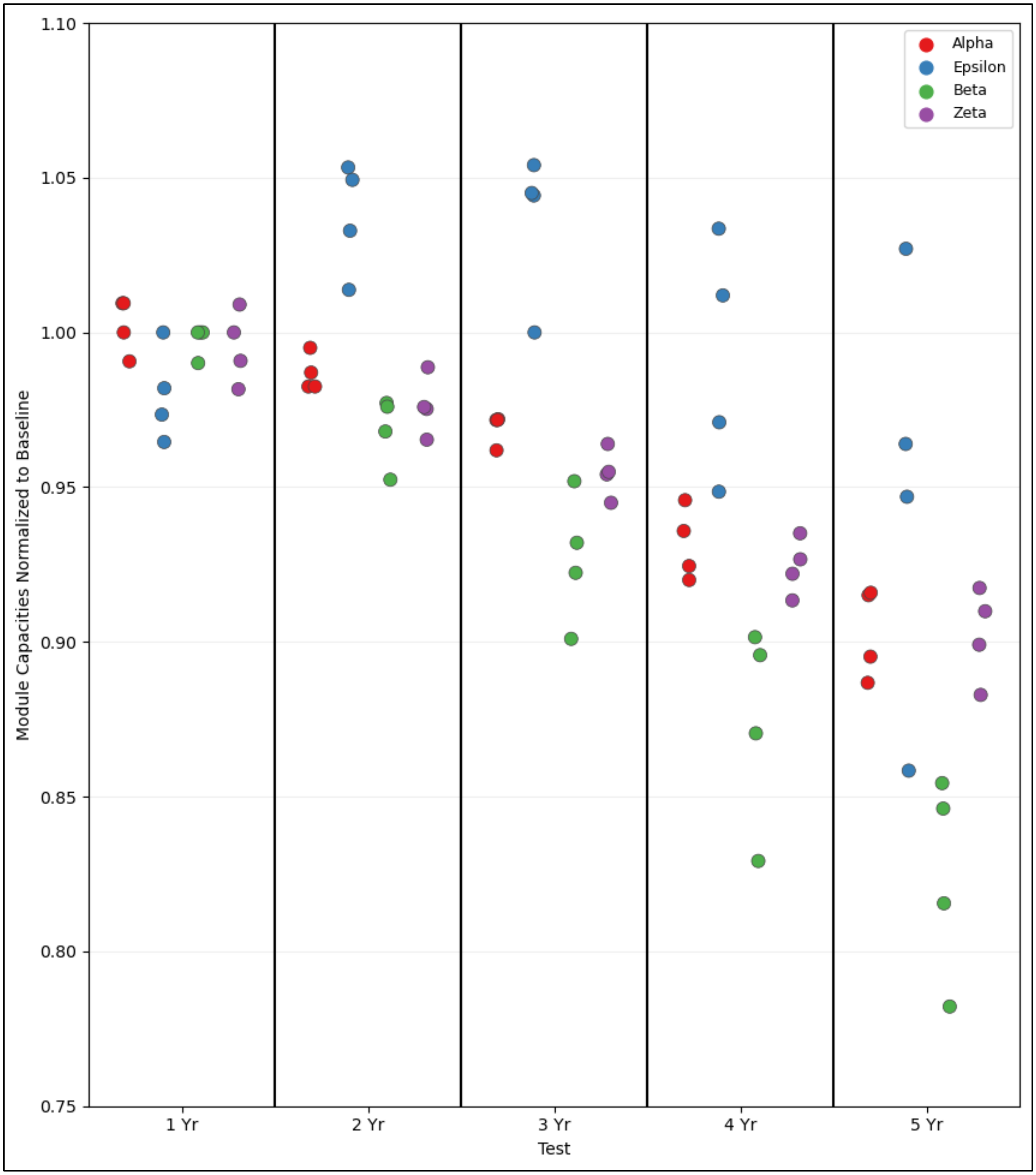
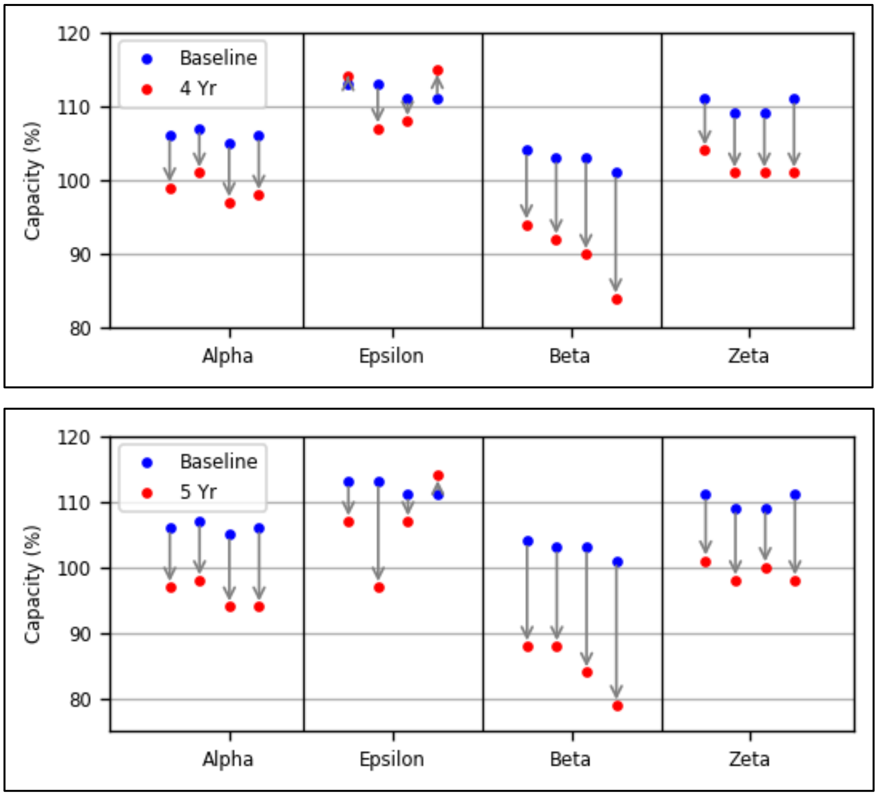


Figure 14 shows how the individual module capacities changed after being installed at the laboratory for four and five years.

Figure 14: Module Capacity Change from Baseline Test After Four and Five Years – Strings Installed in Laboratory



Conclusions

1. Although many manufacturers claim to produce high temperature VRLA batteries, not all similarly-advertised products have the same float life in uncontrolled desert applications.
    - Of the products tested, two showed minimal degradation four years after being installed in the cell sites. The module capacities remained above 80% for over five years.
    - The other products showed noticeable capacity loss after one year. The module capacities tended to decrease linearly, reaching 80% capacity after approximately three years.
    - Three modules had sudden capacity loss over one year, indicating failure modes not observed in the other modules and not related to normal aging. This includes one module from the Alpha product which tended a better performing product in the trial.
2. Module conductances generally decreased with module capacity. Many modules had conductances greater than 100% of the manufacturer's reference even when the capacity was less than 80%. The least squares approximation between module conductance and module capacities is different for each product. This indicates that it is not possible to create an accurate general model that maps conductance to capacity in this experiment.

3. Modules at sites where temperature compensation was enabled tended to have lower capacity than modules where it was disabled. This is an indication that temperature compensation negatively affected the module capacities in this experiment. Although this ultimately represents a small sample size of product in a very specific application (cabinetized cell sites with no temperature control), this warrants future investigation into the benefits of temperature compensation in specific applications.

Further Study and Analysis

- Analysis of the string float currents recorded at the cell sites has not been performed. Additional investigation can be performed to determine whether a correlation between capacity and float current exists for these products.
- Additional investigation on the benefits of temperature compensation on a larger sample size is warranted to improve the confidence in observations from the Phoenix trial. Isolation of other variables, such as daily temperature swing or minimum and maximum temperatures, should be considered.
- As manufacturer's continue to change and improve their products, a repeat trial may be warranted.

References

1. "IEEE Recommended Practice for Maintenance, Testing, and Replacement of Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications," in IEEE Std 1188-2005 (Revision of IEEE Std 1188-1996), pp.1-44, Feb. 8 2006