AGM LEAD ACID BATTERY TEST REPORT

(COVERS ALL AGM MODELS: U1-AGM, 12-AGM, 22-AGM, 24-AGM, 27-AGM, 31-AGM)

Product group:	Absorbed glass mat (AGM) lead acid cells with flat plates
Type designation:	27-AGM, 12V, 82Ah battery (10-hr rate at 25° C)
Endurance in cycles according to	IEC 61427:2005-05
Test, Chapter:	IEC 61427:2005-05: Secondary cells and batteries for PV energy systems – General requirements and methods of test Chapter 8.4: Cycle endurance test in photovoltaic application (extreme conditions)
Test laboratory:	Trojan Battery Company
Test temperature:	40° C ± 3° C
Test started:	January 2013
Test ended:	April 2014

Test Description

In photovoltaic (PV) applications the battery will be exposed to a large number of shallow cycles but at different states of charge. The cycle endurance test is an accelerated simulation in extreme conditions of the battery operation in a PV energy system and is conducted by submitting the single 2V cell repeatedly to 150-cycle sequences (50 cycles with the phase A and 100 cycles with the phase B) until the cell reaches end of life.

Each of these 150-cycle sequences is considered one macro cycle, while the Phase A and Phase B cycles themselves are considered micro cycles. Thus, 50 Phase A micro cycles plus 100 Phase B micro cycles equal one macro cycle.

Table 1 below summarizes the test methodology for Phase A low state of charge (LSOC) and Phase B high state of charge (HSOC) cycles.

Phase A: Low state of charge (LSOC) cycling protocol			
Step	Discharge Time (hrs)	Charge Time (hrs)	Current, A
(a)	9		I_{10}
(b)		3	$1.03I_{10}$
(c)	3		I_{10}
Repeat steps (b) and (c) 49 times, then proceed to Phase B			

Phase B: High state of charge (HSOC) cycling protocol			
Step	Discharge Time (hrs)	Charge Time (hrs)	Current, A
(a)	2		$1.25I_{10}$
(b)		6	I_{10} (Voltage limited to manufacturer's recommendation)
Repeat steps (a) and (b) 99 times			

Table 1: LSOC and HSOC micro cycles per IEC 61427.

Test Process

The test began with a fully charged battery, which was brought to a temperature of 40° C ± 3° C and stabilized for 16 hours. The temperature was maintained for the entire duration of the test.

The Phase A micro cycles (see Table 1) of the test simulated shallow cycling at a LSOC. Each micro cycle subjected the cell to the following steps. As shown in Table 1, the three steps were repeated 49 times, thus subjecting the battery to a total of 50 Phase A LSOC micro cycles.

1. **Discharge at I_{10} amps for 9 hours or until the voltage drops to 1.75 VPC.**
2. **Recharge the battery for 3 hours with a current 1.03 times the I_{10} amps.**
3. **Discharge at I_{10} amps for 3 hours.**

The Phase B micro cycles of the test (see Table 1) simulated shallow cycling at a HSOC. Each micro cycle subjected the cell to the following steps. As shown in Table 1, the two steps were repeated 99 times, thus subjecting the battery to a total of 100 Phase B HSOC micro cycles.

1. **Discharge at 1.25 times the I_{10} amps for 2 hours.**
2. **Recharge the battery for 6 hours with a current of I_{10} amps; the charge voltage was limited to 2.40 VPC.**

A capacity check at the 10-hour rate (C_{10}) was performed after the Phase B micro cycles were completed. The battery was first cooled down to room temperature and stabilized at this value for 16 hours before the capacity tests.

The capacity was checked after each period of 150 Phase A and Phase B micro cycles. The value of actual capacity delivered after each macro cycle (or after 150 micro cycles) is recorded in Table 1. The cycle life is expressed in number of 150 micro cycle sequences completed, or the number of macro cycles completed since one macro cycle is equal to 150 micro cycles.

The test was complete when either of the following criteria was met:

- **If the voltage measured during a Phase A discharge was less than 1.5 VPC**
- **If the capacity delivered after Phase B was less than 80% of rated capacity.**

The standard requires measuring the water consumption of flooded battery types and cells with partial gas recombination (Chapter 8.4.5). Since the battery tested was of the AGM type with full gas recombination, no water addition was required and therefore this section is not applicable in this instance.

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Test Results

Table 2 below shows the raw results of the 10-hour (C_{10}) capacity tests, each performed after 150 micro cycles or after 1 macro cycle. As noted before, the test concluded when the C_{10} capacity delivered by the battery was less than 80% of its rated capacity.

Figure 1 below plots percent capacity as the 27-AGM battery is subjected to the IEC 61427 cycles. Note that one IEC 61427 cycle is equivalent to one year of service life.

IEC macro cycle #	Phase A + Phase B cycles	Capacity at C_{10} rate	Percent of rated C_{10} capacity
1	150	93.2	114%
2	300	89.1	109%
3	450	85.8	105%
4	600	84.8	103%
5	750	85.5	104%
6	900	87.2	106%
7	1,050	84.0	102%
8	1,200	76.0	93%
9	1,350	54.2	66%

Table 2: Capacity test results after each macro cycle

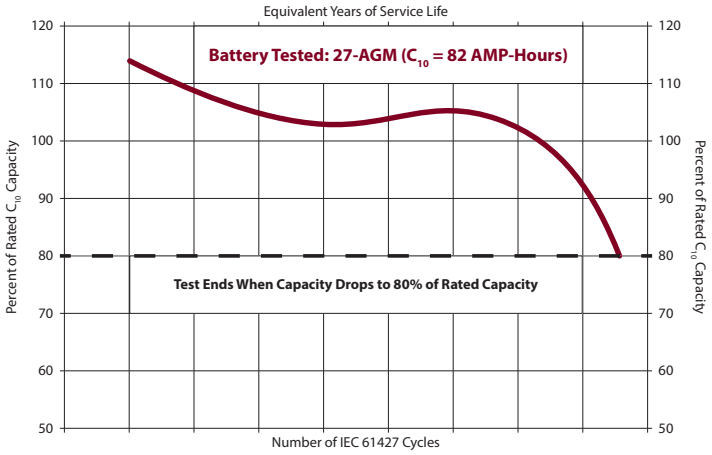

Figure 1: IEC 61427 cycles and percent capacity delivered

Conclusion

As shown in Table 2 and Figure 1, the 27-AGM battery performed well when subjected to the IEC 61427 test protocol. This is a particularly harsh test because not only does it subject the battery to partial state of charge (PSOC) cycling but it also does so at an elevated temperature of 40°C ± 3°C that the battery is exposed to throughout the test. Because of these two factors (PSOC cycling and cycling at a continuous temperature of 40°C ± 3°C) each macro cycle that the battery successfully delivered is considered to be the equivalent of one year of the battery's service life.

Therefore, since the 27-AGM battery delivered about 1,275 IEC cycles before it failed to deliver at least 80% of its rated capacity, we can say that Trojan Battery Company's AGM battery line has a service life of at about eight and one-half (8½) years, and this is reflected in Table 3 below.

Finally, the results obtained from testing the 27-AGM model apply fully to all other AGM models (current and future) by virtue of similarity of design.

Battery type	Equivalent service life
All AGM models	8½ years

Table 3: IEC 61427 service life of Trojan Battery Company's AGM line

Trojan BATTERY COMPANY

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