Trojan BATTERY COMPANY

FLOODED LEAD ACID BATTERY TEST REPORT

(THIS TEST RESULT COVERS ALL SOLAR INDUSTRIAL MODELS: SIND 06 610, SIND 06 920, SIND 06 1225, SIND 04 1685, SIND 04 2145, SIND 02 1990, SIND 02 2450)

Product group: Flooded/wet lead acid cells with flat plates
Type designation: SIND 06 920, 6V, 627Ah (10-hr rate) battery
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: June 22, 2010
Test ended: February 25, 2013

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. It is conducted by submitting the single 2V cell repeatedly to 150-cycle sequences (50 cycles in Phase A and 100 cycles in 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 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 steps outlined below. 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 steps outlined below. 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 completing the Phase B micro cycles. The battery was first cooled down to room temperature and stabilized at this value for 16 hours before performing 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 with one macro cycle being equal to 150 micro cycles.

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

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

The test standard requires measuring the water consumption of flooded battery types and cells with partial gas recombination (Chapter 8.4.5). During the cycle endurance test, the battery was topped off with water and the amount of water added was measured.

Test Results

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

The data presented in Table 2 is reproduced in graphical form in Figure 1 for the amp-hour capacity.

IEC macro cycle #	Phase A + Phase B cycles	Capacity at C_{10} rate	Percent of rated C_{10} capacity
1	150	571.4	104.9%
2	300	597.5	109.6%
3	450	597.8	109.7%
4	600	598.4	109.8%
5	750	590.1	108.3%
6	900	594.6	109.1%
7	1050	567.7	104.2%
8	1200	566.7	104.0%
9	1,350	575.2	105.5%
10	1,500	572.5	105.1%
11	1,650	569.4	104.5%
12	1,800	571.8	104.9%
13	1,950	567.3	104.1%
14	2,100	549.5	100.8%
15	2,250	560.1	102.8%
16	2,400	565.9	103.8%
17	2,550	450.4	82.6%

Table 2: Capacity test results after each macro cycle.

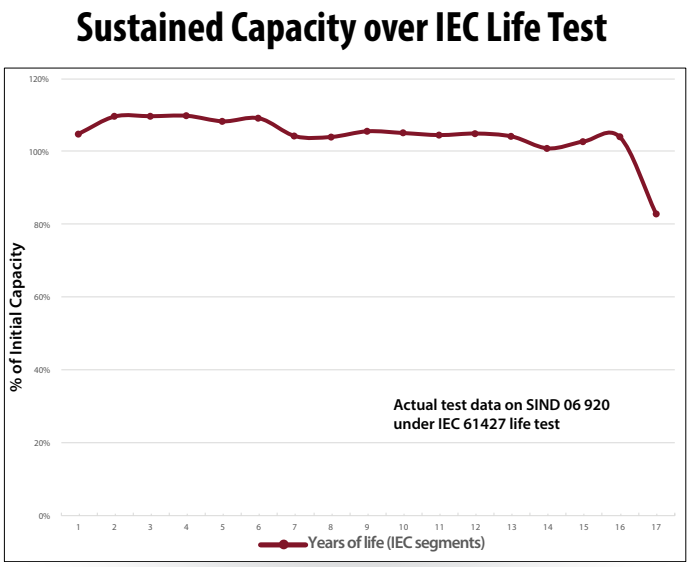

Figure 1

Conclusion

As shown in Table 2 and Figure 1, the SIND 06 920 battery performed extremely 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 is done at an elevated temperature of 40°C ± 3°C. 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.

Since the SIND 06 920 battery delivered approximately 2,500 IEC cycles before reaching 80% of it's rated capacity, the test concludes that the Trojan Solar Industrial battery line has a service life of 17 years,which is reflected in Table 3 below. The IEC test has shown real-life endurance of ~2,500 cycles at 40°C at an average 25% DOD. This result when adjusted

to 25°C battery temperature corresponds to ~7,500 cycles at 25% DOD, which is included in the cycle life vs DOD curve chart included in the Solar Industrial battery data sheets.

Finally, the results obtained from testing the SIND 06 920 battery apply to all other Solar Industrial models (current and future) by virtue of similarity of design.

Battery type	Equivalent service life
All Solar Industrial models	17 years

Table 3: IEC service life of the Trojan Battery Solar Industrial line.

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