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

**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 v/cell.
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 v/cell.

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 v/cell.
- 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.

**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. 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.

<table>
<thead>
<tr>
<th>IEC macro cycle #</th>
<th>Phase A + Phase B cycles</th>
<th>Capacity at C_{10} rate</th>
<th>Percent of rated C_{10} capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>150</td>
<td>577.4</td>
<td>104.9%</td>
</tr>
<tr>
<td>2</td>
<td>300</td>
<td>597.5</td>
<td>109.6%</td>
</tr>
<tr>
<td>3</td>
<td>450</td>
<td>597.8</td>
<td>109.7%</td>
</tr>
<tr>
<td>4</td>
<td>600</td>
<td>598.4</td>
<td>109.8%</td>
</tr>
<tr>
<td>5</td>
<td>750</td>
<td>590.1</td>
<td>108.3%</td>
</tr>
<tr>
<td>6</td>
<td>900</td>
<td>594.6</td>
<td>109.1%</td>
</tr>
<tr>
<td>7</td>
<td>1050</td>
<td>567.7</td>
<td>104.2%</td>
</tr>
<tr>
<td>8</td>
<td>1200</td>
<td>566.7</td>
<td>104.0%</td>
</tr>
<tr>
<td>9</td>
<td>1,350</td>
<td>575.2</td>
<td>105.5%</td>
</tr>
<tr>
<td>10</td>
<td>1,500</td>
<td>572.5</td>
<td>105.1%</td>
</tr>
<tr>
<td>11</td>
<td>1,650</td>
<td>569.4</td>
<td>104.5%</td>
</tr>
<tr>
<td>12</td>
<td>1,800</td>
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</tr>
<tr>
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<td>1,950</td>
<td>567.3</td>
<td>104.1%</td>
</tr>
<tr>
<td>14</td>
<td>2,100</td>
<td>549.5</td>
<td>100.8%</td>
</tr>
<tr>
<td>15</td>
<td>2,250</td>
<td>560.1</td>
<td>102.8%</td>
</tr>
<tr>
<td>16</td>
<td>2,400</td>
<td>565.9</td>
<td>103.8%</td>
</tr>
<tr>
<td>17</td>
<td>2,550</td>
<td>450.4</td>
<td>82.6%</td>
</tr>
</tbody>
</table>

![Sustained Capacity over IEC Life Test](image)

**Figure 1**

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

<table>
<thead>
<tr>
<th>Battery type</th>
<th>Equivalent service life</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Solar Industrial models</td>
<td>17 years</td>
</tr>
</tbody>
</table>