Synopsis: Since 1984, NGK Insulators, Ltd., (NGK) has been developing the sodium-sulfur (NAS) battery in cooperation with Tokyo Electric Power Company (TEPCO) for the purposes of load-leveling and stabilizing the electricity supply. The latest 6MW installation, located at TEPCO's Ohito Substation, is comprised of 120, 50kW battery modules using the NAS "T5" cell. This installation has been operating since March, 1999, and like earlier NAS projects, it has demonstrated good performance in commercial use.

Also in 1999, laboratory tests confirmed the pulse power delivery capability of NAS batteries for combined power quality (PQ) and peak shaving (PS) applications. Tests of individual T5 cells, as well as tests of a reduced scale model of a 50kW battery module, demonstrated the capability to deliver 5 times rated power for up to 30 seconds at any time during a peak shaving cycle. Combining power quality and peak shaving functions within the same system will enable NAS battery technology to be optimally used in high value industrial markets. Design optimization and full-scale testing of 50kW battery modules are being conducted this year. This paper presents the results of pulse power delivery tests and the status of NAS battery product development for combined power quality and peak shaving applications.

1. System Concept For Combined Power Quality And Peak Shaving Applications

Figure 1 illustrates the concept of a “Super Power” NAS Battery System which can deliver high-rate pulse power while peak-shaving. Ideally, a 2MW/PQ10MW system will be able to protect a 10MW critical load from power disturbances by delivering pulse power for up to 30 seconds at any time during 2MW peak shaving cycle. Thirty seconds is sufficient for critical loads to “ride-through” over 95% of faults that occur in the United States and, if necessary, transition to backup engine-generator.

Figure 1. System Concept for Super Power NAS Battery

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2. Pulse Power Performance Based On Reduced Scale Battery Tests

The pulse power capability of NAS batteries can be calculated from open circuit voltage and internal resistance with the expression\(^\text{[1]}\),

\[ P_{\text{max}} = \frac{V_{\text{ocv}}^2}{4*R} \],

where
- \(P_{\text{max}}\) = Maximum Power
- \(V_{\text{ocv}}\) = Open Circuit Voltage
- \(R\) = Internal Resistance of Battery Module

Figure 2 shows current versus power characteristics for a 50kW battery module as a function of internal resistance.

The capability to deliver 500% rated power for 30-second intervals each hour during rated discharge was demonstrated on a single T5 cell and cell assembly\(^\text{[1]}\). Before proceeding with tests of a full-scale 50kW battery module, a reduced-scale 8kW battery module was designed and tested. The results of high-rate pulse power discharge during rated discharge are shown in Figure 3, along with calculated projections of the pulse power capability of a 50kW module. These results provide confidence that scale-up to a full-size module can be successfully accomplished.
3. Design and Testing of a 50kW Super Power Battery Module

Based on data from the 8kW reduced-scale module tests, a full-scale 50kW battery module comprised of 320 T5 cells was built and tested. Figure 4 shows a picture of the prototype 50kW module, along with target specifications. As shown in Figure 5, the test circuit sets the load resistance equal to the internal resistance of the battery (0.37ohm), corresponding to the theoretical maximum power that the battery can produce.

Figure 4. 50kW Super Power NAS Battery Design and Target Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse Power</td>
<td>250kW (30 seconds)</td>
</tr>
<tr>
<td>Rated Power</td>
<td>50kW</td>
</tr>
<tr>
<td>Energy</td>
<td>350kWh</td>
</tr>
<tr>
<td>Dimensions</td>
<td>2200W x 1762D x 640H [mm]</td>
</tr>
<tr>
<td>Weight</td>
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</tr>
</tbody>
</table>

Figure 5. Test Circuit of 50kW Battery Super Power Battery Module
4. Results of 50kW Super Power Battery Module Tests

Tests were conducted to evaluate pulse power delivery capability at different depths of discharge (D.O.D.) during charging and discharging operations of a peak-shaving cycle. Figures 6 and 7 show the capability of the 50kW Super Power battery module to deliver 30-second pulses during constant power discharges of 23kW and 45kW for 14.5 and 6 hours, respectively. At a constant 23kW discharge, the internal temperature does not increase because the rate of heat generation within cells does not exceed the rate of heat rejection by radiation from the thermal enclosure. Accordingly, pulse power discharges can be conducted to full D.O.D., although the pulse magnitude decreases as battery voltage decreases. On the other hand, at a constant 45kW discharge, the internal temperature gradually increases about 40 degrees-C over the 6-hour discharge since the rate of heat generation exceeds the rate of heat rejection; however, pulse power capability is not affected by temperature increase.

Figure 6. 30-sec Pulse Power Capability During 23kW Peak Shaving

Figure 7. 30-sec Pulse Power Capability During 45kW Peak Shaving
Figure 8 shows the variations in 30-second pulse power capability during a 52kW constant power charge operation over 9 hours from full D.O.D. For this test, the internal temperature was maintained at about 310 degrees-C. Near the end of charge, pulse power capability is gradually reduced by polarization resistance induced by charging.

Figure 8. 30-sec Pulse Power Capability During 50kW Charging

Figure 9 shows representative voltage and current profiles during a 30-second pulse power discharge test. Full, high-rate discharge power is achieved in about 0.1msec, demonstrating that there is essentially no difference in rate of response between a single cell and a 50kW module (320 cells connected in series). Also, the rate of response demonstrated for the NAS battery confirms its suitability for power quality applications.

Figure 9. Time Chart of 30-sec Pulse Power Discharge Test
5. Conclusions

Basic performance tests of the prototype 50kW Super Power battery module comprised of 320 T5 cells have been conducted. Test results confirm its capability to deliver 30-second pulses of power at each depth of discharge during both discharging and charging operations of a peak-shaving cycle. It was observed that the magnitude of the power pulse varies for different operating conditions, and is especially dependent on the depth of discharge. The evaluation of the prototype 50kW battery module is ongoing and supports module design optimization and the development of detailed specifications, as well as optimization of the integrated power quality system design.

References