Sodium-Sulfur Batteries for Energy Storage
- Load leveling & Renewable energy -

June 2007
NGK INSULATORS, LTD.
Synopsis

☆ The NAS battery developed by NGK Insulators, Ltd. in conjunction with Tokyo Electric Power Company

☆ The NAS battery is commercially available

☆ Battery energy storage is relevant to power generators, network operators and customers of electricity

☆ The NAS battery is technically proven and suitable for a wide range of energy storage applications

⇒ Scaleable to multi MW and MWh
The development of the NAS battery

Joint Development by TEPCO and NGK

Target: Battery for Large Scale Energy Storage

- 1984 ~ Solid Electrolyte for NAS Battery
- 1989 ~ NAS Cell and Battery Module
- 1997 ~ Field Tests at Substations
- 2000 ~ Field Tests at Customer Sites
- 2002 ~ Commercialization
NAS Battery Attributes

☆ High Energy Density : About 3 times that of Lead-Acid
☆ High Response : Few Second
☆ High Energy Efficiency : 85% (Average DC for Battery)
☆ High Capacity Units : 8 MW System (Installed)
☆ Easy Maintenance : Periodic Inspection
☆ High Cycle life : 2500 Cycles / 15 years (4500 Cycles at 90% DOD)
☆ Short Construction Period : A Few Months -
## Batteries for Energy Storage

<table>
<thead>
<tr>
<th>Items</th>
<th>Battery</th>
<th>NAS</th>
<th>Redox Flow (Vanadium)</th>
<th>Lead-Acid</th>
<th>Zinc-Bromine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>V</td>
<td>2.08</td>
<td>1.4</td>
<td>2.0</td>
<td>1.8</td>
</tr>
<tr>
<td>Theoretical Energy</td>
<td>Wh/kg</td>
<td>780</td>
<td>100</td>
<td>110</td>
<td>430</td>
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<tr>
<td>Density</td>
<td>Wh/l</td>
<td>1000</td>
<td>120</td>
<td>220</td>
<td>600</td>
</tr>
<tr>
<td>Efficiency</td>
<td>%-DC</td>
<td>85</td>
<td>80</td>
<td>85</td>
<td>80</td>
</tr>
<tr>
<td>Temperature</td>
<td>deg. C</td>
<td>280〜350</td>
<td>40〜80</td>
<td>5〜50</td>
<td>20〜50</td>
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<tr>
<td>Electrolyte</td>
<td>β”-Alumina Solid</td>
<td>Vanadium Liquid</td>
<td>H₂SO₄ Liquid</td>
<td>ZnBr₂ Liquid</td>
<td></td>
</tr>
<tr>
<td>Auxiliary</td>
<td>Heater</td>
<td>Pump</td>
<td>Water Addition</td>
<td>Pump</td>
<td></td>
</tr>
<tr>
<td>Side Reaction</td>
<td>None</td>
<td>H₂ Generation</td>
<td>H₂ Generation</td>
<td>H₂ Generation</td>
<td></td>
</tr>
<tr>
<td>Self Discharge</td>
<td>None</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Battery</td>
<td>Manufacturer</td>
<td>Application</td>
<td>Unit</td>
<td>Energy Density</td>
<td></td>
</tr>
<tr>
<td>-----------</td>
<td>----------------------------------</td>
<td>----------------------</td>
<td>----------------------------------------</td>
<td>----------------</td>
<td></td>
</tr>
<tr>
<td>Ni-MH</td>
<td>Panasonic (Panasonic EV)</td>
<td>Hybrid EV (Prius etc)</td>
<td>Battery pack (HEV: 0.05 k Wh)</td>
<td>46, 79</td>
<td></td>
</tr>
<tr>
<td>Li-Ion</td>
<td>Shin-Kobe (Hitachi Vehicle Energy)</td>
<td>Electric Vehicle</td>
<td>Module (PEV: 2.7 k Wh)</td>
<td>93, 114</td>
<td></td>
</tr>
<tr>
<td>Lead-Acid</td>
<td>GS-Yuasa</td>
<td>Stationary</td>
<td>Assembled (SNL-3000-6:12 k Wh)</td>
<td>30, 64</td>
<td></td>
</tr>
<tr>
<td>NAS</td>
<td>NGK</td>
<td>Energy Storage</td>
<td>Module (E50: 420 k Wh)</td>
<td>124, 167</td>
<td></td>
</tr>
</tbody>
</table>
# NAS battery applications

<table>
<thead>
<tr>
<th>applications</th>
<th>objectives</th>
<th>Remarks</th>
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</thead>
<tbody>
<tr>
<td>Load Leveling</td>
<td>Energy shifting</td>
<td>190MW installed</td>
</tr>
<tr>
<td></td>
<td>Peak shaving</td>
<td></td>
</tr>
<tr>
<td>(+Power Quality)</td>
<td>Power outages</td>
<td>Response time</td>
</tr>
<tr>
<td></td>
<td>Momentary outages</td>
<td>1m sec(DC)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20m sec(AC)</td>
</tr>
<tr>
<td>Renewables</td>
<td>Generating flat output power</td>
<td>Demonstrating</td>
</tr>
<tr>
<td></td>
<td></td>
<td>with wind turbine</td>
</tr>
<tr>
<td>Grid Stabilization</td>
<td>Balancing of Supply and demand</td>
<td>Response time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt; 5second</td>
</tr>
</tbody>
</table>
Load Leveling

Power Supply
- Load Leveling
  (Improve Load Factor)
Customer
- Peak Shaving
  (Save Cost)

Leveling of Power

Power Demand

Storage

Discharge

Power

Night Time

Day Time

Time

24

12
Application to Renewable Energy
- Wind Power Stabilization -

Sponsored by NEDO

TEPCO Demonstration at Hachijo-Jima Island (2001-2002)
Deployment history

- By March 2007 -

Cumulative Installed capacity

Annual Installed Capacity

(kW)

(kW)
Customers in Japan

- By March 2007 -

- 34 MW battery system to be combined with wind turbine December 2007 -

Installed Site

(kW)

Factories: 90,000
Shopping malls: 80,000
Substations: 60,000
Water treatment: 50,000
Schools, Hospitals: 40,000
Office buildings: 30,000
Transportations: 20,000

Load Leveling + UPS:
- Renewables: 59%
- Load Leveling: 30%
- Load Leveling + EPS: 10%
- Other: 1%
Overseas installations

☆ **AEP** (American Electric Power Co)
  Columbus, WV
  Capacity : 1000 kW
  Commissioned: July, 2006
  (Substation upgrade deferral)

☆ **NYPA** (New York Power Authority)
  Long Island, NY
  Capacity: 1000 kW
  Installation: Sept, 2006
  (Daily peak shaving)
**NAS Cell structure**

- **Capacity**: 1.2 kWh
- **Voltage**: 2 V (DC)

**Electrochemistry**

- **Negative Electrode**: Sodium (Na)
- **Solid Electrolyte** (β-Alumina)
- **Positive Electrode**: Sulfur (S)

**Chemical Reaction**

\[ 2Na + XS \rightarrow Na_2S_x \] (EMF = 2.08 ~ 1.78 V)

**Diagram Details**

- **Cell Case**: 90 mm
- **Terminal (+)**
- **Terminal (−)**
- **Sodium (Na)**
- **Safety Insert**
- **Solid Electrolyte** (β-Alumina)
- **Sulfur (S)**
- **Discharge**
- **Charge**
- **Load**
- **Electrical Isolation**

**Figure**

- **Diagram Width**: 520 mm
Structure of battery module

Output Power : 50 kW
Storage Capacity : 360 kWh

- Fuses
- Cells
- Thermal Enclosure
- Main Poles
- Cover
- Side Heater
- Connecting Bars
- Sand
- Main Pole
- Bottom Heater
- Cell

Dimensions:
- Width: 2.2 m
- Height: 0.67 m
- Depth: 1.7 m
NAS battery system

TEPCO Ohito Substation

6MW, 48MWh NAS Battery System
(3 blocks, 2 MW each)
Largest NAS Battery System
Hitachi Automotive Systems Factory – Japan

8MW / 57.6MWh

NAS Battery (1 MW)

600 kVA PCS x2

2400 kVA Xfmr

Auxiliaries

NAS Battery (1 MW)

2 MW unit (x 4 sets)

Largest NAS Battery System
Hitachi Automotive Systems Factory – Japan

8MW / 57.6MWh

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2400 kVA Xfmr

Auxiliaries

NAS Battery (1 MW)

2 MW unit (x 4 sets)
## Specifications for NAS Battery

- **1MW / 7.2MWh** -

<table>
<thead>
<tr>
<th>Specification</th>
<th>DC 1.06MW (nominal)</th>
<th>(AC 1MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rated Power</strong></td>
<td>DC 1.28MW for 3Hrs (up to 75% DOD)</td>
<td>(AC 1.2MW)</td>
</tr>
<tr>
<td><strong>Charge</strong></td>
<td>DC 1.13MW</td>
<td>(AC 1.2MW)</td>
</tr>
<tr>
<td><strong>Nominal Voltage</strong></td>
<td>DC 640V</td>
<td></td>
</tr>
<tr>
<td><strong>Stored Energy</strong></td>
<td>DC 7.7MWh</td>
<td>(AC 7.2MWh)</td>
</tr>
<tr>
<td><strong>Voltage Range</strong></td>
<td>Discharge : DC 465V</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Charge             : DC 780V</td>
<td></td>
</tr>
<tr>
<td><strong>Current Range</strong></td>
<td>-1800A to +2800A (“-” Charge, “+” Discharge)</td>
<td></td>
</tr>
<tr>
<td><strong>Site Conditions</strong></td>
<td>Ambient Temp -10 to +40 degree C</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Relative Humidity 20% to 90%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Altitude 1000 m or less</td>
<td></td>
</tr>
</tbody>
</table>
Optional Battery System
Discharge Profiles

Power Ratio to Rated Power

Time of Discharge (Hrs)

Nominal Discharge

3Hrs

5.5Hrs

Power Factor

E-50

0 0.2 0.4 0.6 0.8 1 1.2 1.4

0 2 4 6 8 10 12 14
Characteristics of Battery Module

Discharge / 52kW×7.2hr
Charge / 52kW-39kW-26kW-13kW
Heat Loss / 3700W (from Thermal Enclosure)
1MW Battery Building Block

Plan

Free Space

Space for maintenance

Elevation

1000kW NAS Battery

Control
Monitor
PCS
Tr
CB

Side
A Typical Application of NAS Battery

Load Leveling (Primary) + Emergency Power Supply

Reserved

Load Leveling

Extended Outages

AC Line

SW

Load

Critical Load

PCS

NAS

High Speed SW

负载

Critical Load

PCS

NAS
Japanese wind power Program

- Japan has a Kyoto Protocol target of 3000MW wind power in 2010, 4000MW in 2014.
- Government mediation resulted in agreement to
  - require stabilization via energy storage at the wind source
  - subsidize storage costs ($16.5 million in 2006, $22.7 million in 2007)
- 34MW NAS battery to be installed at wind farm in 2007
Wind Power / Battery Hybrid Application in Japan

Frequency stabilization by energy shifting

- Store Energy during Periods of Low Demand
  (Zero Output is Required by Power Company Previously)
- Deliver The Energy Periods of High Demand

Output power mitigation control
Max-Min < 10% in 20 min

Constant output power control
Max-Min < 2% in 1min
Test facility at Miura-wind park

[Facility]
Wind turbine: 400kW×2
NAS battery system: 500kW

[Operation control]
Remote control by the office at Tohoku area
(Training of 30MW system operation)

[Demonstration]
1) Constant power output (07’ 2-10’)
2) Reduction of power fluctuation (07’ 11-08’ 1)

NAS battery

Housing for PCS
Test result of constant power output

[Charging : 0kW output power control]

[Discharging : 700kW output power control]
NAS Battery Plant

Firing Kiln in Nagoya
Alpha-Beta Alumina Bonding

Komaki Plant
90MW/Year
Production Capacity: 65MW / Year
6000 sq.m Factory
1000 sq.m Warehouse

Robot Welding
500kW NAS Battery
Reference
Safety Design

☆ Multiple Countermeasures

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<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>Cell</strong></td>
<td>High Strength β-Alumina Safety Tube (Suppress Na-S Reaction)</td>
</tr>
<tr>
<td><strong>Module</strong></td>
<td>Current Fuse (Prevent Propagation)</td>
</tr>
<tr>
<td><strong>Battery</strong></td>
<td>Sand (Suppress Fire)</td>
</tr>
<tr>
<td><strong>Battery</strong></td>
<td>Voltage Monitor (Over Voltage Protection)</td>
</tr>
</tbody>
</table>

☆ Certification (Certified by Hazardous Material Safety Techniques Association)

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<table>
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</thead>
<tbody>
<tr>
<td><strong>Test Items</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Cell</strong></td>
<td>Over Voltage, Short Circuit, Freeze-thaw</td>
</tr>
<tr>
<td><strong>Module</strong></td>
<td>Short Circuit, Fire, Drop, Flood, Cell Breach</td>
</tr>
<tr>
<td><strong>Battery</strong></td>
<td></td>
</tr>
</tbody>
</table>
Safety Test of Battery Module

Drop Test

Fire Test

Test Observation:
No cell leakage due to dropping and firing of battery module
Maintenance of NAS Batteries

Continuous Remote Monitoring of Battery Condition

Recommended 3-Year Inspection Interval

<table>
<thead>
<tr>
<th>Inspection</th>
<th>Unusual vibration, noise, odors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Abnormal conditions of cables, enclosure</td>
</tr>
<tr>
<td></td>
<td>Insulation resistance</td>
</tr>
<tr>
<td></td>
<td>Re-torquing terminals</td>
</tr>
<tr>
<td>Confirmation</td>
<td>DC voltage, DC current, temperature sensor</td>
</tr>
<tr>
<td>Data collecting</td>
<td>Battery resistance, open circuit voltage</td>
</tr>
</tbody>
</table>

Consumables

- Equipment fuses, DC power supply, Controller LCD
- Controller memory batteries
Stand-alone Operation

Momentary Outage

Outage

Grid Voltage

Effective Grid Voltage

Load Voltage

Effective Load Voltage

Sec
Recycling of NAS Battery

- 100% of Materials Recycled or Reused -

Used NAS Battery

Parts of Module

Disassembling

Return To Manufacturer

Parts of Cell

Metals - Recycle
- Stainless Steel, Aluminum, etc.

Others - Recycle
- Sand, etc.

Sodium - Reuse

Metals - Recycle
- Stainless Steel, Aluminum, etc.

Others – Eco-cement
- Sulfur, Graphite Felt, Ceramics, etc.