Rotary UPS Systems
with
Frictionless Bearings

Presented by
Liebert Products & Services, San Francisco
A district sales & service office of Emerson Network Power

Pentadyne Power Corp
A leading manufacturer of flywheel energy storage systems
Traditional Power Quality Configuration

- Utility feed
- ATs
- UPS
- Protected load
- Back-up genset
- Batteries

*The Weakest Link*
**A better way**

<table>
<thead>
<tr>
<th>Lifecycle Cost</th>
<th>Flywheel Batteries</th>
<th>Lead-Acid Batteries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installation cost</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Footprint</td>
<td>Small</td>
<td>Medium to large</td>
</tr>
<tr>
<td>Maintenance</td>
<td>infrequent</td>
<td>Frequent</td>
</tr>
<tr>
<td>Life expectancy</td>
<td>&gt;20 Years</td>
<td>2 – 4 years</td>
</tr>
<tr>
<td>Standby energy use</td>
<td>Very low to high</td>
<td>Low</td>
</tr>
<tr>
<td>Air conditioning cost</td>
<td>None to low</td>
<td>Medium</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reliability</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Recharge</td>
<td>Rapid</td>
<td>Very slow</td>
</tr>
<tr>
<td>Diagnostics and monitoring</td>
<td>Precise, real-time</td>
<td>Speculative</td>
</tr>
<tr>
<td>Known state of charge</td>
<td>Yes</td>
<td>Unpredictable</td>
</tr>
<tr>
<td>Dropped load MTBF</td>
<td>&gt;350,000 hours</td>
<td>~30,000 hours</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Environment and Safety</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating temperature range</td>
<td>Very broad</td>
<td>Very narrow</td>
</tr>
<tr>
<td>Hazardous materials</td>
<td>None to very few</td>
<td>Yes</td>
</tr>
<tr>
<td>Explosive and toxic gas emissions</td>
<td>None</td>
<td>Yes</td>
</tr>
<tr>
<td>Disposal requirements</td>
<td>None</td>
<td>Yes</td>
</tr>
<tr>
<td>Ventilation requirements</td>
<td>Minimal</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Flywheel/Rotary Systems
High-Reliability Configuration

- Utility feed
- ATS
- Back-up genset
- UPS
- Flywheel
- Optional batteries
- Protected load
Battery “Whiplash” Prevented

- Programmable discharge is set above the battery discharge voltage
- Flywheel isolates the batteries from ALL short-term cycling events
- If event lasts longer that flywheel capacity, flywheel gently rolls down voltage into the battery set; eliminating battery coup de fouet

Diagram:
- Graph showing UPS DC Bus Voltage vs. Time (Seconds)
- Plot of Float Voltage, Grid Disturbance, and w/flywheel
- Coup de fouet = Whiplash
- 99% of disturbances < 10 sec. --EPRI
Storage: Critical to Every Event

The 1st 10 seconds matter 100% of the time
The next 10+ seconds matter less than 1%

- EPRI confirms 99% of power disturbances last less than 10 seconds.
- Energy storage matters 100% of the time; backup genset power is needed <1%.
- IEEE data confirms outages >60 sec. occurred an average of only 1.5 times per utility customer over the last decade.
IEEE Gold Book 493-2007 Annex L, Table XII:

- Circa-1980 studies encompassing >26,000 genset starts
- Starting reliability was proven to average 99.5%
- These studies involved gensets made in the 1980s or earlier
  - Starting reliability of modern gensets, properly maintained and exercised, would arguably show higher first-attempt reliability
“15 Minutes” of Ridethrough

- In reality: 60 seconds or less with 10-kW racks
  - If genset(s) aren’t up and driving cooling within 60 seconds, servers will crash on thermal overload*
  - Higher rack power = even less time
  - Advantage of 15 min. of batteries?
    - One data center operator said: “So I’ll have 15 minutes to update my resume.”

* Source: Aperture Research Institute 2007
One Line

To UPS Battery Input

IGBT Power Converter

Soft Start

DC Monitoring

Motor Generator Controls

Power Conversion Module Controller

AC Aux Backup

Remote Monitoring & Controls (Optional)

Flywheel Module

Speed Sensors

Temperature Sensors

Position Sensors

Magnetic Levitation Module
Flywheel Technology Evolution

KE = m(v^2)

- "Low-speed" 7,800 rpm
- More mass means more energy
- Double mass = energy doubled
  - Heavy (600 lbs)
  - Large puck
  - Mechanical bearings
  - Minor service every 12 months, major service every 30 months
  - High standby power consumption: 2,500W

- "High-speed" 52,000 rpm
- More speed means more energy
- Double rpm = energy quadrupled
  - Light (52 lbs)
  - Compact cylinder
  - Full magnetic levitation
  - Minor service in first 6 months, then moderate service every 6 yrs
  - Very low standby power consumption: 250W
Full MagLev = No Mechanical Bearings

- Magnetic levitation system fully floats the spinning mass
  - No bearings, no contact
  - No wear, no friction, no heat
  - No costly maintenance
  - Strong and robust
Aerodynamic Drag

Maintaining Vacuum

- Spinning mass is always throwing off gas molecules
- Almost all flywheels have a constantly operating mechanical pump to maintain vacuum level
  - Unpredictable single point of failure
  - System will fault out within 1 hr
- One model uses a grooved sleeve and high velocity to evacuate stray molecules
  - Eliminates unpredictable failure
  - Cuts energy consumption and noise
Footprint Comparison

- Floorspace needed by 5-minute VRLA cabinets for a 400-kVA UPS is nearly double that of a similar capacity pair of flywheels (green). Compared to a one megawatt set of wet cells, the flywheel footprint is nearly 80% less (orange).
Floor-Loading

- Lightest flywheel cabinet: 1,300 lbs
- Comparable VRLA battery cabinet: ~5,000 lbs
Green Technology

- Elimination of Hazardous Materials
  - No lead mining, smelting, transport, disposal etc.
  - No sulfuric acid disposal
  - No toxic, explosive or greenhouse gas emissions
  - No disposal/replacement after only a few years of service

- Energy Use Reduction
  - Most efficient flywheel uses only 250 watts “float” charge
    - About ½ or less than that of batteries
    - About 1/10th that of other flywheels
      - Annual savings per unit deployed
        - 20,000 kWh
        - 26,000 lbs of utility carbon emissions
        - Only 850 Btu/hr of heat vs. >8,500 Btu/hr of steel flywheel
        - No cooling requirements for Pentadyne flywheels
  - Ultra-efficient rapid recharge from full discharge in seconds
    - Batteries need weeks of energy use to do a full recharge
During its 20-year life, each flywheel deployed mitigates the use of at least 15,000 pounds of virgin lead and hundreds of gallons of sulfuric acid.

Lead-acid batteries also emit ozone-depleting gases, contributing to global warming.

The mining, smelting, refining, transporting and disposal of so much virgin lead requires an enormous use of low-efficiency energy and its resulting carbon footprint.

“Lead is ranked 2nd in US for all hazardous materials and requires proper disposal” - EPA
The OTHER Green Advantage
Relatively New, But Well Proven

• >3,000 flywheel energy storage systems sold
• >50M hours of total commercial fleet runtime
• Compared to battery strings deployed over the same time periods, >1,000% greater proven reliability

NASA Tech Scott Marabito checks runtime hours on their flywheel that’s been operating since 2004.
Example – Small Colocation

NetAlliant: Tennessee

- 150-kVA UPS
- 1 flywheel
- No batteries
- Protecting server loads
- Ride-through to gensets

Drivers:
- Short battery life
- Batteries had dropped load
- Other bad experiences with batteries
- Reliability
Example – Research Data Center

Technology Center: Nebraska

• Six 750-kVA UPSs
• 24 flywheel systems (4.5 MW)
• Protecting data center loads
• No batteries
• Drivers:
  • Increase total system reliability
  • Eliminate batteries & maintenance
  • Green, sustainable solution
  • Reduce O&O costs
  • Minimize footprint
  • Saved $180,000 in construction costs that would have been needed to for wet cells
Example – Utility

Southern California Edison: California

- 300-kVA UPS
- Two flywheels
- Protecting data and other loads
- Drivers:
  - Battery reliability issues
  - Battery maintenance issues
  - Wanted green, high-tech solution
  - Reduce O&O costs

President Obama visited this SCE facility in ’09; the UPS and part of one of the flywheels are visible behind him.
Example - Transportation

Mineta San José International Airport: California

- 50kVA UPS
- 1 flywheel
- Protecting radar and other critical loads
- Battery parallel
  - Flywheel is first line of defense
- Ride-through to genset
- Drivers:
  - Reliability issues
  - Maintenance issues

Now in “The OC” too!
Example – Military

Missile Silos: Hundreds of Sites Nationwide

- VFD energy recycling
- ICBM modernization program
- High inrush power needs
- Poor utility conditions at remote sites
- >500 flywheel systems are being deployed around the nation