Agenda

• UPS History
• Current Designs
• Current Market Drivers
• Technology Trends
• Application Trends
A Brief History of Uninterruptible Power Supplies
First UPS Systems

~1950s Double conversion MG set
• Motor (DC or Synchronous AC)
• Flywheel
• Generator

Electrical Energy converted to Mechanical Energy then back to Electrical Energy
• Inefficient
• Reliable
• Simple
• Limited Ride through times
• Still available today (process industry, frequency converters)
First Static UPS Systems

~1960s Static UPS
- SCR based
- Six Step SCR Inverters
- Isolation Transformers

- Low Switching frequency
- Wave form filtering
- Transformers
ALL STATIC
UNINTERRUPTIBLE
POWER SYSTEMS

THIS BULLETIN COVERS

- Complete UPS (Uninterruptible Power Systems) including batteries and battery charger.
- Standard static inverter specifications and optional features.
- Application information.

WHERE TO USE

For military, industrial, utility and other applications including:

- data processing computers
- process control computers
- electronic process instrumentation
- critical communication complexes
- critical process machinery
- emergency lighting
- microwave and crypto equipment
- frequency conversion

FEATURES

- Precise uninterruptible power.
- Super-reliable—field proven with 30,000 KVA of inverters operating today. Conservative design and best quality components.
- Low maintenance—no moving parts, no aging.
- Easy installation—modular design, no special

Figure 1. Typical Rectifier and Inverter Line-up, 185 KVA Output
Traditional North American UPS System

Transformer based with circuit breakers
Current Designs
Line Interactive
Double Conversion

Diagram showing the components and modes of a double conversion system:

- **Bypass AC source**
- **Static Bypass Switch**
- **Inverter**
- **Normal AC source**
- **Rectifier/Charger**
- **Critical Load**
- **Bypass Mode**
- **Normal Mode**
- **Stored Energy Mode**
Parallel UPS with Central Bypass

INPUT SWITCHGEAR

SYSTEM CONTROL

D-CONTROL WIRE & TWISTED SHIELDED PAR
100' MAX DISTANCE

INTERGRATED SYSTEM CONTROL CABINET
“Change is like heaven. Everybody wants to go there, but nobody wants to die.”

Carly Fiorina
Former Chairman and CEO
Hewlett Packard
Current Market Drivers
Technology Advances

- Controls – Analog to digital
- Switching – Breakers to Contactors

- Power Electronics – SCR to IGBT
“No one will remember how much you saved on the utility bill if you drop the load”
-unknown
(it might have been me)

Reliability is still the number one design criteria, but efficiency is starting to move up the list. Efforts by The Green Grid, Green Data Center, and EPA are putting a spotlight on data center efficiency. EPA has expanded the Energy Star program to included Data Centers, Servers, Storage, and UPS modules.
Data Center Energy Efficiency

PUE = \frac{\text{Total Facility}}{\text{IT Equipment}} = \frac{\text{IT+Cooling+UPS+Other}}{\text{Computer/IT}} = \frac{1}{0.65} = 1.53
Data Center Energy Efficiency Regulations?

PUE being adopted as a standard globally

Example:

• Amsterdam requires a PUE of 1.3 or less on new data centers
• Currently operational data centers are required to have a PUE of 1.4 or less, within 5 years.

Amsterdam Regulation – Program to reduce carbon emissions by 40% by 2025 compared to 1990 levels. In 2008 data centers accounted for 6% of total CO2 emissions of the city.
Data Center UPS Operating Costs

**High efficiency up to 96.5%**
- Considerable life cycle cost savings
- Reduction in UPS operating cost
- Reduction in cooling cost

**Assumptions:**
- Power cost = $0.10/kw-hr
- Operating hours/year = 8760
- Cooling factor = 0.35
- Configuration = 500 kW UPS @ 50% load

**UPS Annual Operating Cost**

- **92% Eff UPS**: $6.7 (Losses) + $19.0 (Cooling) = $25.7
- **94% Eff UPS**: $4.9 (Losses) + $14.0 (Cooling) = $18.9
- **95% Eff UPS**: $4.0 (Losses) + $11.5 (Cooling) = $15.5
- **96.5% Eff UPS**: $2.8 (Losses) + $7.9 (Cooling) = $10.7

96.5% efficient UPS annual savings Compared to
- 92% efficiency UPS > $14,980
- 94% efficiency UPS > $8,140
- 95% efficiency UPS > $4,830
Data Center Mission

Cloud Computing

- Redundancy in the software in lieu of physical infrastructure
- Smaller “Zones of Reliability”
- Less infrastructure? – No generators – limited UPS
Data Center Mission

HPC Computing
• N+N UPS on Storage
• N UPS or No UPS on Processing

Internet or Social Media
• UPS at the rack or row
• Energy Storage integral to Power Supply
Customers vote for product designs via Purchase Orders

- Features that customers are not willing to pay for will go away
- Examples:
  - Centralized Bypass
    - Higher cost than distributed bypass
    - Larger footprint
  - Transformer Based UPS
    - Higher cost (not necessarily price)
    - Larger footprint
    - Lower efficiency
Technology Trends
Distributed Bypass

C—CONTROL WIRE
B TWISTED SHIELDED PAIR
100' MAX DISTANCE

480V 3 PHASE 3 WIRE 2500 AMP

LOAD BANK

2500
Centralized Bypass

- Centralized Control
  “Single point of Failure”

- Static Switches Removed
  Units cannot be changed to single module

- Centralized static bypass
  “Single point of Failure”
Distributed Bypass – Cable Lengths

No Inductor – 1A=2A=3A and 1B=2B=3B or max 10% difference

With inductor = allows variation up to 20-25% (depends on UPS rating & cable section)
SCR Rectifiers

6 Pulse & 12 Pulse

SCR Rectifiers
- Harmonic issues
- Capacitive Filters
- Low switching frequency
- Low input power factor
3-Level IGBT Topology

Reduced switching and filter losses improves efficiency

250kW Power Module (480V)

3-Level IGBT Inverter and Rectifier

Three level technology with an Advanced Neutral Point Clamped topology implemented with true Reverse Blocking IGBT.

Reduced switching and filter losses compared to std. two level technology
Transformer-less UPS

Transformer based UPS
• Galvanic isolation (+)
• Large Footprint (-)
• Poor Efficiency <92% (-)
• Higher Mfg Cost (-)

Transformer-less UPS
• High Efficiency (+)
• Low Harmonics (+)
• High Input PF (+)
• Bus Optimization (+)
• Small Footprint (+)
• Less Weight (+)
• Battery Monitoring (?)
• Three Wire Input (?)
• Lower Mfg Cost (+)
Transformer Based /UPS
4 wire input

- Only N-G bond at service entrance
- UPS not separately derived system
- Phase to neutral loads allowed downstream of UPS

• Any open transition 4 pole switching (breaker or ATS) upstream of UPS will result in loss of N-G reference at UPS output during switching. (see appendix for more details)
Transformer Based /UPS
3 wire input

- N-G bond at service entrance & UPS output
- UPS is separately derived system
- Phase to neutral loads not allowed downstream of UPS

N-G bond may be located in UPS module or UPS Output Distribution – typical for both transformer based and transformer-less UPS modules
Transformer-less UPS
4 wire input (Modules with 4 Wire Inverter Output)

Grounding and application identical to transformer based UPS

- Only N-G bond at service entrance
- UPS not separately derived system
- Phase to neutral loads allowed downstream of UPS

- Any open transition 4 pole switching (breaker or ATS) upstream of UPS will result in loss of N-G reference at UPS output during switching (see appendix for more details)
Transformer-less UPS
3 wire input (Modules with 4 Wire Inverter Output)

Service Entrance

- N-G bond at service entrance & UPS output
- UPS is separately derived system
- Phase to neutral loads not allowed downstream of UPS

N-G bond may be located in UPS module or UPS Output Distribution – typical for both transformer based and transformer-less UPS modules

Grounding and application identical to transformer based UPS
Transformer-less UPS
3 wire input (Modules with 3 Wire Inverter Output)

- Only N-G bond at service entrance
- UPS cannot be separately derived system
- Phase to neutral loads not allowed downstream of UPS

• Any open transition switching (breaker or ATS) or loss of voltage upstream of UPS will result in loss of System Ground reference at UPS output
• No System Ground reference at UPS output while UPS is supporting load in Stored Energy mode of operation

Significant Grounding and Application Issues
Eco-mode

Double conversion mode provides the best protection, more protection than is required by the IT equipment, but at the highest operating cost.

Adoption is increasing, especially in N+N configurations where one side is VFI and the other is ecomode.
Ecomode Operation & Impact

Inductor and output filter capacitors provide filtering in eBoost
### The Green Grid Data Center Maturity Model

<table>
<thead>
<tr>
<th>Power</th>
<th>1.2</th>
<th>Architecture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 0</td>
<td>Minimal/No Progress</td>
<td></td>
</tr>
<tr>
<td>Level 1</td>
<td>Part Best Practice</td>
<td></td>
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<tr>
<td>Level 2</td>
<td>Best Practice</td>
<td></td>
</tr>
<tr>
<td>Level 3</td>
<td></td>
<td></td>
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<tr>
<td>Level 4</td>
<td></td>
<td></td>
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<tr>
<td>Level 5</td>
<td>Visionary - 5 Years Away</td>
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</table>

<table>
<thead>
<tr>
<th>1.2</th>
<th>Architecture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Low efficiency power infrastructure and inefficient UPS use</td>
</tr>
<tr>
<td></td>
<td>• Greater redundancy than required</td>
</tr>
<tr>
<td></td>
<td>• Numerous isolation transformers</td>
</tr>
<tr>
<td></td>
<td>• Eco Mode UPS if applicable to business type</td>
</tr>
<tr>
<td></td>
<td>• Fewer and higher efficiency transformers (NEMA TP1 or equivalent)</td>
</tr>
<tr>
<td></td>
<td>• Verify the product's efficiency curve is highest for the load range used vs. highest overall</td>
</tr>
<tr>
<td></td>
<td>• Consolidate transformers (use fewer series isolation transformers, consider autotransformers)</td>
</tr>
<tr>
<td></td>
<td>• Select power (and backup) technologies based on TCO, Materials &amp; Sustainability</td>
</tr>
<tr>
<td></td>
<td>• Eco Mode UPS that works for all business types</td>
</tr>
<tr>
<td></td>
<td>• Scalable power infrastructure</td>
</tr>
<tr>
<td></td>
<td>• Use products with flat, high efficiency at all loads</td>
</tr>
<tr>
<td></td>
<td>• Review and capture waste heat (for example, to augment generator block heaters)</td>
</tr>
<tr>
<td></td>
<td>• Move to higher IT load voltage, either AC or DC</td>
</tr>
</tbody>
</table>
What are the benefits

- Scalable
  - Delay CAPEX cost
- Internal Redundancy
  - Higher Reliability?
- Hot swappable
  - Low Power 208V
  - High Power 480V
  - Arc Flash
  - Human Error
- Lower MTTR
## What is Modular?

### Where do these features make sense?

<table>
<thead>
<tr>
<th>Feature</th>
<th>Monolithic</th>
<th>Modular</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common breakers</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Common Battery</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Common Contactors</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Power Block Construction</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Bolted Power Blocks</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Field upgrade</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Distributed Batteries</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Cold Swap - no FSE?</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Contactors per PB</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>N+1 Block Failover</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Plug-in Power Blocks</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Hot swappable Blocks</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Redundant Static Switches</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Redundant Controls Per PB</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

### Monolithic vs Modular Features

- **Common breakers:** X
- **Common Battery:** X
- **Common Contactors:** X
- **Power Block Construction:** X
- **Bolted Power Blocks:** X
- **Field upgrade:** X
- **Distributed Batteries:** X
- **Cold Swap - no FSE?** X
- **Contactors per PB:** X
- **N+1 Block Failover:** X
- **Plug-in Power Blocks:** X
- **Hot swappable Blocks:** X
- **Redundant Static Switches:** X
- **Redundant Controls Per PB:** X

**Increased Cost**

**Where do these features make sense?**
Application Trends
Elevated Temperatures

- UPS rated 104°F
- Batteries rated 68-77°F
- Air Conditioned Battery Cabinets?
1. Flywheel Energy Storage
2. Lithium Batteries
3. Sodium Batteries
4. Super Capacitors
5. Pure Lead Batteries
Alternative Topologies

- Reduce CAPEX costs
- Reduce stranded assets
- Improve efficiency
- Improve capability to handle “Dynamic Loads”?
- Pressure on Data Centers to be “Competitive”
Changes in Reliability Metrics?

- Uptime Tier System
  - De-facto Metric
  - Relates Topology Characteristics to Reliability
  - Simple

- IEEE P3006.7 Recommended Practice for Determining the Reliability of “7 x 24” Continuous Power Systems in Industrial and Commercial Facilities

- M Technology introducing a new approach at 7X24 June 2015 conference

<table>
<thead>
<tr>
<th>Data Center Tier *</th>
<th>Tier I</th>
<th>Tier II</th>
<th>Tier III</th>
<th>Tier IV</th>
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</thead>
<tbody>
<tr>
<td>System Component Redundancy</td>
<td>N</td>
<td>N+1</td>
<td>N+1 or S+S</td>
<td>Minimum of N+1</td>
</tr>
<tr>
<td>Distribution Paths</td>
<td>1</td>
<td>1</td>
<td>1 Normal 1 alternate</td>
<td>2 Active</td>
</tr>
<tr>
<td>Concurrently Maintainable</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Fault Tolerant</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Staffing</td>
<td>None</td>
<td>1 Shift</td>
<td>1+ Shifts</td>
<td>24 x Forever</td>
</tr>
<tr>
<td>Single Points of Failure</td>
<td>Many + human error</td>
<td>Many + human error</td>
<td>Some + human error</td>
<td>None + fire + EPO</td>
</tr>
<tr>
<td>Annual IT Downtime</td>
<td>28.8 hours</td>
<td>22.0 hours</td>
<td>1.6 hours</td>
<td>0.8 hours</td>
</tr>
<tr>
<td>Site Availability</td>
<td>99.67%</td>
<td>99.75%</td>
<td>99.98%</td>
<td>99.99%</td>
</tr>
</tbody>
</table>
Traditional Topologies – N+1

- Utility Service
- Service Transformer 15 KV Secondary
- MV Main Switchgear
- MV PSG Switchgear
- N+1 Generators
- N+1 UPS Modules
- Mechanical Load
- UPS Input Switchboard
- UPS Output Switchboard
- Critical Load Switchboard
- PDU Transformer (typical)
Traditional Topologies – N+N
Alternative Topologies – Catcher Systems
Traditional Topologies – 4N/3
Alternative Topologies – Isolated Parallel
Alternative Topologies – Isolated Parallel

Diagram showing the flow of power through various switchboards and UPS systems.
480V & 400V Power Chain

North American AC DESIGN

High Efficiency 400V AC DESIGN

Power Transformation
Advantages:

1. Improves server power supply efficiency (from 90% to 92%)
2. Eliminated PDU losses
3. EPA includes multi-mode operation in the Energy Star for UPS standard

Potential Design Issues:

1) Higher Short Circuit currents – Higher Arc Flash
2) Selective Coordination
3) Neutral requirements – 4W design and possible Ground Fault Issues
National Electric Code requires ground fault protection

Data Centers have redundant circuit paths to improve reliability

Redundant neutral paths comprise traditional ground fault protection.

Most data centers are 3 wire to avoid these issues

Only solutions are:

1) Modified differential ground fault protection

2) Four pole breakers to break neutral path – Four pole breakers simplify the process, but does not eliminate the issue (closed transition transfers are still an issue)
Lower Cost driving MV designs

- Less Copper Less PVC conduit
- Less Labor
- Shorter construction cycle
- Equipment costs about the same.
- Overall, total cost is lower (estimate 10-15% on installed cost)
Possible Future Trends
Silicon-carbide IGBT

- Extremely efficient
- Currently very expensive

What premium for 99% efficiency in VFI (double conversion) mode
Questions?