Evaluation results from AC/DC converters for xTCA

Collaboration (CERN PH-ESE-BE)
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Outline

- Considered xTCA powering scheme
- AC-DC rectifier system architecture
- Evaluated AC-DC rectifier systems
- Evaluation parameters
- Evaluation test examples
- Results summary
- Conclusion
Considered xTCA powering scheme
(1/4)

LHC experiments racks and related constraints

- In-rack vertical re-circulating air-flow
- Limited electrical power and cooling capacity available (~10-12 kW /rack)
- Racks housing xTCA equipment might be located away from each other
- Possible (limited) stray magnetic field. (This is the case in some places where experiments plan to install xTCA equipment.)
- Some applications require battery backup; So far implemented with UPS (uninterruptible power supply) on the mains power network
- Power factor must be close to 1 (large number of equipment with important power consumption)
Considered xTCA powering scheme (2/4)

3 main options

Option 1:
Small AC-DC system delivering power to each shelf individually

But:

- Potentially reduced total efficiency (multiplication of AC-DC converters of a certain nominal power)
- Not compatible with in-rack vertical air-flow: Most AC-DC systems are designed for horizontal (front to back) air-flow
- Multiplication of DCS data-points if all AC-DC systems are remotely monitored and controlled
- Space consuming solution: Multiplication of AC-DC rectifiers (each occupies a rack space of 1U typically)
- Modular rectifier systems with little output power are difficult to find on the market (mainly applies to MTCA applications; small DC power per shelf required)
- Redundancy potentially difficult to apply efficiently
Considered xTCA powering scheme (3/4)

3 main options

Option 2:
Large AC-DC system providing power to several racks

But:

- Requires important modifications to the actual mains electrical distribution (to supply power to the large AC-DC rectifier and LV DC distribution to racks).
- Depending on the xTCA rack location, long LV cables have to be installed. Potentially important cable costs and losses.
- Not well suited for racks housing both xTCA and non-xTCA equipment.
- If the desired remote monitoring and control granularity on power distribution is at the rack level, all DC circuit breakers must have monitoring and control capabilities (potentially important cost and complexity increase).
Considered xTCA powering scheme (4/4)

3 main options

Option 3:
Medium AC-DC system providing power to one full xTCA rack

Probably the best compromise

But:

- Internal rack cooling air-flow is an issue as most AC-DC systems are designed for horizontal (front to back) air-flow. The AC-DC system should be placed outside the closed re-circulating air-flow (below the air deflector). Highly efficient AC-DC system preferred.

- AC-DC power system remote monitoring and control granularity is at the rack level. If thinner control granularity (i.e. for each crate) is required, the DC circuit breakers must have monitoring and control capabilities (important cost and complexity increase but can be applied individually for each rack).
AC-DC rectifier system architecture (1/2)

3 options

- Bulk power rectifier system
- Pair of bulk rectifier systems for full redundancy
- Modular hot-swappable rectifier system with a N+1 redundancy
Retained specification

- 19” rackmount system
- -48 Vdc output
- 5 kW minimum total output power (this is for an ATCA crate)
- Europe (230/400 Vac, 50 Hz) input voltage
- Hot-swappable modular system based on AC-DC power bricks
- Optional N+1 redundancy (with hot swap)
- Self cooled system (equipped with fans)
- High efficiency (>90%) and low noise and ripple (< 200 mVpp)
- Limited inrush current (soft-start) and (active) PFC equipped
## Evaluated AC-DC rectifier systems

<table>
<thead>
<tr>
<th>AC-DC system</th>
<th>Main characteristics</th>
<th>Evaluation test status</th>
</tr>
</thead>
</table>
| PowerOne, Aspio                                   | Power (total): 4.8 kW  
Power (/brick): 1200 W  
Size: 2U  
Specified efficiency: > 95% (typ)            | ✓                      |
| PowerOne, Guardian                                | Power (total): 14.5 kW  
Power (/brick): 2900 W  
Size: 3U  
Specified efficiency: > 95% (typ)            | ✓                      |
| Emerson Network Power, NetSure 501                | Power (total): 10 kW  
Power (/brick): 2000 W  
Size: 5U  
Specified efficiency: 96.5 %                  | ✓ (To be finalized)        |
| Lineage Power, CPL (no remote control unit, no output circuit breaker) | Power (total): 11 kW  
Power (/brick): 2750 W  
Size: 1U  
Specified efficiency: 93 %                    | Pending                  |
Evaluation parameters

Technical (electrical characteristics) evaluation
- Sensor accuracy
- Efficiency and PF measurements
- Soak testing (output voltage stability)
- Overvoltage and overcurrent limits
- Hot swap functionality
- Static and dynamic regulation test
- Noise and ripple measurements and EMC compliance (conducted)
- Start-up mains inrush current

Additional evaluated aspects
- User interface (front panel, web server and delivered SW, when available)
- Available technical documentation
- Mechanical robustness and system layout
- Packaging quality

<table>
<thead>
<tr>
<th>Test condition</th>
<th>measured</th>
<th>specified</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor accuracy voltage</td>
<td>&lt; 0.15%</td>
<td>not specified</td>
<td>NA</td>
</tr>
<tr>
<td>Sensor accuracy current</td>
<td>&lt; 1%</td>
<td>not specified</td>
<td>NA</td>
</tr>
<tr>
<td>Soak testing</td>
<td>2 hours @ 75% load voltage fluctuation</td>
<td>&lt; 4mV</td>
<td>not specified</td>
</tr>
<tr>
<td>SW-HW limits voltage</td>
<td>70% load</td>
<td>SW limit &lt; 0.15%</td>
<td>Specified via the GUI</td>
</tr>
<tr>
<td>SW-HW limits current</td>
<td>48V</td>
<td>SW limit &lt; 1%; HW limit: 26.3A</td>
<td>Specified via the GUI</td>
</tr>
<tr>
<td>Static regulation</td>
<td>0 to 100% load output variation</td>
<td>&lt; 1.3%</td>
<td>± 1%</td>
</tr>
<tr>
<td>Dynamic regulation voltage variation recovery time</td>
<td>10-90% and 90-10% load 5.6% (worst case)</td>
<td>3%</td>
<td>accepted</td>
</tr>
<tr>
<td>Dynamic regulation</td>
<td>16 ms</td>
<td>20 ms</td>
<td>pass</td>
</tr>
<tr>
<td>Voltage ripple</td>
<td>90% load</td>
<td>102 mV p-p</td>
<td>&lt; 100mV p-p</td>
</tr>
<tr>
<td>EMC tests input</td>
<td>90% load</td>
<td>within spec</td>
<td>EN61000-6-3</td>
</tr>
<tr>
<td>EMC tests output</td>
<td>90% load</td>
<td>QP: ok, Avg: 2 dBuV out of spec</td>
<td>EN61000-6-4</td>
</tr>
<tr>
<td>Inrush current</td>
<td>few exceptions out of spec.</td>
<td>ETS 300 132-1</td>
<td>accepted</td>
</tr>
<tr>
<td>Efficiency</td>
<td>40-100% load</td>
<td>95%</td>
<td>&gt; 95%</td>
</tr>
<tr>
<td>Power factor</td>
<td>40-100% load</td>
<td>&gt; 0.99</td>
<td>EN61000-3-2 (0.99 typ.)</td>
</tr>
</tbody>
</table>
Evaluation test examples (1/3)

Efficiency and PF (Aspiro)

Performed for each individual brick as well as with the full system
Evaluation test examples (2/3)

Dynamic load regulation (Aspiro)

Performed for each individual brick for a current step of 10-90% of max load with a slew rate of 1MA/s

Transient response to a load variation of 90% to 10% of the maximum power (measured voltage overshoot: 1.4 V, first peak: 2.4 V, recovery time: 11ms)

Transient response to a load variation of 10% to 90% of the maximum power (measured voltage undershoot: 1.4 V, first peak: 3 V, recovery time: 16ms)
Evaluation test examples (3/3)

EMC compliance measurement (Aspiro)

Performed at 90% of max load for each power brick individually.

Limits:
- Input: EN61000-6-3 (QP and AVG)
- Output: EN61000-6-4 (QP and AVG)
## Results summary (electrical) (1/2)

### PowerOne Guardian

<table>
<thead>
<tr>
<th>Sensor accuracy</th>
<th>Test condition</th>
<th>measured</th>
<th>specified</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>voltage</td>
<td>&lt; 0.31%</td>
<td>not specified</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>current</td>
<td>&lt; 3.3%</td>
<td>not specified</td>
<td>NA</td>
<td></td>
</tr>
</tbody>
</table>

- **Soak testing**: 14 hours @ 75% load
  - voltage fluctuation < 12mV
  - not specified
  - NA

- **SW-HW limits**: voltage 70% load
  - SW limit < 0.31%
  - Specified via the GUI
  - pass

- **Static regulation**: voltage 0 to 100% load
  - output variation < 1.8%
  - ± 1%
  - pass

- **Dynamic regulation**: voltage variation 10-90% and 90-10% load
  - 7.2% (worst case)
  - 3%
  - fail

- **Voltage ripple**: 90% load
  - 20.7 ms
  - < 250 mVpp
  - accepted

- **EMC tests**: input 90% load
  - within spec
  - EN61000-6-3
  - accepted

- **Inrush current**: not specified
  - 95% (max)
  - > 95%
  - accepted

- **Power factor**: > 25% load
  - > 0.99
  - EN61000-3-2 (0.995 @ > 25% load)
  - pass

### PowerOne Aspiro

<table>
<thead>
<tr>
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<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>voltage</td>
<td>&lt; 0.15%</td>
<td>not specified</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>current</td>
<td>&lt; 1%</td>
<td>not specified</td>
<td>NA</td>
<td></td>
</tr>
</tbody>
</table>

- **Soak testing**: 2 hours @ 75% load
  - voltage fluctuation < 4mV
  - not specified
  - NA

- **SW-HW limits**: voltage 70% load
  - SW limit <0.15%
  - Specified via the GUI
  - pass

- **Static regulation**: 0 to 100% load
  - output variation < 1.3%
  - ± 1%
  - pass

- **Dynamic regulation**: voltage variation 10-90% and 90-10% load
  - 5.6% (worst case)
  - 3%
  - accepted

- **Voltage ripple**: 90% load
  - 176 mVpp
  - < 250 mVpp
  - accepted

- **EMC tests**: input 90% load
  - within spec
  - EN61000-6-3
  - accepted

- **Inrush current**: not specified
  - few exceptions out of spec
  - ETS 300 132-1
  - accepted

- **Efficiency**: 40-100% load
  - 95%
  - > 95%
  - accepted

- **Power factor**: 40-100% load
  - > 0.99
  - EN61000-3-2 (0.99 typ.)
  - pass

### Emerson Power NetSure 501

<table>
<thead>
<tr>
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<th>measured</th>
<th>specified</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>voltage</td>
<td>&lt; 0.15%</td>
<td>not specified</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>current</td>
<td>&lt; 3.33%</td>
<td>not specified</td>
<td>NA</td>
<td></td>
</tr>
</tbody>
</table>

- **Soak testing**: 22 hours @ 50% load
  - voltage fluctuation < 46mV
  - ± 0.1 V
  - pass

- **Static regulation**: 0 to 100% load
  - output variation < 0.42%
  - 1%
  - pass

- **Dynamic regulation**: voltage variation 10-90% and 90-10% load
  - 5.56% (worst case)
  - 5%
  - accepted

- **Voltage ripple**: 90% load
  - 20.7 ms
  - 4 ms
  - pass

- **EMC tests**: input 90% load
  - within spec
  - EN61000-6-3
  - accepted

- **Inrush current**: not specified
  - few exceptions out of spec
  - ETS 300 132-1
  - accepted

- **Efficiency**: 40-100% load
  - 95%
  - > 95%
  - accepted

- **Power factor**: 40-100% load
  - > 0.99
  - EN61000-3-2 (0.99 typ.)
  - pass

### Lineage Power CPL 2750

- **Power factor**: 0-98% power
  - 95.6% peak at 37.4% power
  - 96.5% peak
  - fail

- **Power factor**: 0-98% power
  - > 0.99 from 49% to 98% power
  - 0.99
  - pass

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**Pending...**
All systems evaluated so far offer:

- Different interface possibilities (front panel, web server, proprietary SW and SNMP)
- Intuitive and comprehensive GUIs
- Clear graphical representation
- No compatibility problems observed on the tested OS and web browsers
Conclusion

- AC-DC systems fulfilling the predefined requirements exists and are mostly compliant to specification
- So far no vertically cooled AC-DC system was found on the market
- However, tested systems show very satisfactory efficiency
- Price of selected equipment is relatively reasonable

To be tested further and checked:

- Remaining evaluation tests to be finalized
- Real case application test (integration with xTCA system(s))
- MTBF and long term availability of spares to be checked

- What additional parameters should be considered ??

Link to full and up coming test reports