Introduction

UPS solutions in detail - AC and DC

Industrial UPS markets

Q&A and wrap-up

Wednesday, October 21st 2015
6:00 – 8:50 PM

Agenda

• Follow-up day 1
• UPS technology
• Operating and monitoring of UPS
• UPS for nuclear applications
• Batteries
• Standards
• Maintenance
• Q&A and wrap-up

Tuesday, October 20th 2015
6:00 – 8:50 PM

Agenda

• Introduction
• Basic functions of UPS
• Industrial UPS markets
• Find the best UPS solution
• UPS configurations
• UPS solutions in detail - AC and DC
• Q&A and wrap-up

Follow-up Day 1: Any questions?
UPS technology

UPS technology
- Thyristor rectifier
  - 6-Pulse
  - 12-Pulse
- PFC Rectifier (Power Factor Corrected)
- Relation Harmonic Current and Voltage
- IEEE 519 Harmonic Considerations
- How can the Harmonic Current be reduced
- IGBT PWM Inverter
  - Inverter Performance
  - Inverter Short Circuit Considerations
- Heavy overload / short circuit on AC safe-bus / load

UPS and Battery Systems
Rectifier 6-Pulse Configuration

Characteristics
- Input isolation transformer with 30° phase shift
- Full wave 6-pulse thyristor bridge
- LC smoothing filter
- Up driven control loop
UPS and Battery Systems
Rectifier 6-Pulse Harmonics

<table>
<thead>
<tr>
<th>Order of Harmonics</th>
<th>Harm. Current % of total load</th>
<th>Order of Harmonics</th>
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3 0 29 2.2

UPS and Battery Systems
Rectifier 6-Pulse Harmonics

6-pulse Thyristor Controlled
UPS and Battery Systems
Rectifier 6-Pulse Harmonics

- Voltage L1 to L2
- Current L1
- Current L2
- Current L3

Mains current THD distortion ~28%
Check Generator rating: approx. 3 x Rectifier rating

UPS and Battery Systems
Rectifier 6-Pulse Diesel Generator Sizing

Load factor vs distortion for 6-pulse loads

Voltage distortion %

40%  35%  30%  25%  20%  18%  16%  14%  12%  10%  8%  6%  4%  2%  0%

Generator load %

+/- 30%  50%  100%
UPS and Battery Systems
Rectifier 12-Pulse Configurator

Characteristics
- Input isolation transformer with 0° and 30° phase shift
- 2 x full wave 6-pulse thyristor bridges coupled with 30° phase shift
- LC smoothing filter
- Up driven control loop with active load sharing

<table>
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<tr>
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Harm. Current ~12%
Order of total load
DC-Load

UPS and Battery Systems
Rectifier 12-Pulse Configurator

DC-Load
Inverter
Voltage L1 to L2
Current L1
Current L2
Current L3

Mains current THD distortion ~12%
Check Generator rating:
1,5 - 2,0 x Rectifier rating

Preferred Solution for harmonic current reduction
UPS and Battery Systems
Rectifier 12-Pulse Diesel Generator Sizing

Load factor vs distortion for 12-pulse loads

Voltage distortion %
- 5%
- 10%
- 15%
- 20%
- 25%

Current distortion %
- +/− 70%
- +/- 70%

Generator load %
0 50 100

UPS and Battery Systems
Rectifier with PFC

Reduction of harmonics
- PFC rectifier drastically reduces level of input harmonics (<5% THDi)
- No distortion of upstream equipment
- No need for 12-pulse thyristor bridge or additional harmonic filters
UPS and Battery Systems
THDi Thyristor rectifier compare with PFC rectifier

THDi 6-pulse Thyristor rectifier ~27%
THDi PFC rectifier ~5%

UPS and Battery Systems
Relation Harmonic Current and Voltage

50MVA
$U_k=10\%$

2.5MVA
$U_k=6\%$

EMG
200kVA
$U_k=10\%$

Other Load

Other Load
### UPS and Battery Systems

#### Relation Harmonic Current and Voltage

![Diagram of UPS and Battery Systems](image)

- **G**: Generator
- **X1 ~ 0.15 Ohm**
- **132kV**
- **50MVA**
- **Uk=10%**

- **X2 ~ 0.01 Ohm**
  - **6.6kV**
  - **2.5MVA**
  - **Uk=6%**

- **X3 ~ 0.2 Ohm**
  - **480V**
  - **EMG**
  - **200kVA**
  - **Uk=10%**

- **Load**

- **I_HARMrec = 100A**

#### IEEE 519 Harmonic Considerations

**Table 19.8**

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<th>L2k</th>
<th>L1k+1</th>
<th>L1k+2</th>
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</table>

*Note: harmonic are limited to 8% of the odd harmonic levels shown.*

*Current distortion that result in a decrease, e.g., harmonic variances, are not added.*

*All power quantities measured are limited to those values of current distortion, summation of odd, e.g.,

$$\Delta I = \text{maximum short-circuit current at PCC}$$

$$X_c = \text{maximum short-circuit current fundamental frequency component at PCC}$$

- **Load**

**Location of PCC (Point of Common Coupling) is difficult to determine and may vary depending on Power Generation topology.**

**IEEE 519 harmonic limits must be considered for the whole plant power distribution scheme.**

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**Extract from IEEE 519-1992**

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**UPS and Battery Systems**

**How can the Harmonic Current be reduced?**

1. From 6-pulse to 12-pulse Rectifier
   - From 28% down to 10-12%

2. Additional filter for the 11th and 13th harmonics for 12-pulse Rectifier
   - Down to ~5%

3. Additional active harmonic filters
   - or
   - Power Factor Corrected (PFC)
   - Rectifiers with IGBT Transistors
   - Down below 5%

**UPS and Battery Systems**

**PWM IGBT Inverter**

- DC Input from Rectifier and/or Battery
- Output

**Characteristics**
- Pulse Width Modulation (PWM) with >2kHz carrier frequency
- IGBT Insulated Gate Bipolar Transistor switching-bridges
- Linear inverter isolation transformer with connected sine wave filter
- Fast control loop and digital monitoring
UPS and Battery Systems
Inverter Performance

Inverter Loadprofile

- kVA [%]
- Full rating

UPS and Battery Systems
Inverter Performance

Inverter I/U Diagram with short circuit

- Constant Current

Confidential Property of Schneider Electric (Page 21)
### UPS and Battery Systems

**Inverter Performance**

3ph. Inverter I/U Diagram with single phase short circuit

- **Inverter Output voltage (%)**
- **Inverter Output current (%)**

### AC-Systems

**Heavy overload / short-circuit on AC safebus / load**

1. **Current source Inverter:**
   - 1) Current limitation current/time (for details see following slides)

2. **Bypass:**
   - 2) Short-circuit current depending on upstream impedance and impedance of bypass transformer
In Case 1:
- Wire length = 2 x 100m
- Rwire = 0.9Ohm
- Ishort = 218A
- Unom = 3 x 145A
- Ushort = Rwire x Ishort = 195V
- Ushort = 85% of Unom

Conclusion: MCB will trip within 20-30ms

In Case 2:
- Wire length = 2 x 5m
- Rwire = 0.045Ohm
- Ishort = max. 435A for Ushort < 0.1Unom
- Ushort = Rwire x Ishort = 19.5V
- Ushort = 8.5% of Unom

Conclusion: MCB will trip within 20-30ms

Max. single phase short current without bypass available:
- for 0 < t < 100ms and Ushort < 0.1 x Unom: 435A (300%)
- for t < 5s and 0.1 x Unom < Ushort < 0.9 x Unom: 218A (150%)
- for t < 60s and Ushort > 0.9 x Unom: 218A (150%)

In Case 3:
- Wire length = 2 x 200m
- Rwire = 1.8Ohm
- Ishort = Unom / Rwire = 129A
- Ushort = Unom

Conclusion: MCB will not trip within 20-30ms

AC-Systems
Inverter Short Circuit Considerations

AC-Systems
Inverter Short Circuit Considerations

3ph. Inverter I/U Diagram with single phase short circuit

Case 1: Trip
Case 2: Trip
Case 3: No Trip
Operating and monitoring of UPS

Human Machine Interface | Network / Remote monitoring

Gutor DC UPS

Operating Status indication  Operation  Display Unit

Alarm indication
Operating and monitoring of UPS

Human Machine Interface

Gutor AC UPS

Operating Status indication  Operation  Display Unit

Alarm indication

---

Operating and monitoring of UPS

Operator Access

"Operational" Section

"Calibration" Section

"Genes" Section

Pass-Word protected

"Operational Parameter" Section

User menu

"Alarm" Section

List of present alarms

"Log-Alarm" Section

Event logger with Time Stamps

Factory settings
Operating and monitoring of UPS
Networking / Remote Monitoring

Web/SNMP /VMC Management Card

UPS System

Ethernet, TCP/IP Network (10/100M, RJ45)

Network Client with WEB Browser

UPS for Nuclear Applications

Hardware | Firmware
UPS for Nuclear Applications
Qualification

IEEE 650 (1E)
- Classify Components
  - Safety / Non-safety related
- Significant Aging
- Assemble Components in Equipment
- Testing before Seismic Test
- Seismic Test
  - Qualification by testing, full scale test according to IEEE344
  - Qualification by analogy
  - Qualification by combination of testing and analysis
- Testing after Seismic Test
- Conclusion

GUTOR Standard Spectras (TRS)
UPS for Nuclear Applications

UPS Seismic Design

Seismic Qualification of systems and parts

• By Full System Test
• By Combined Method
  (structure analysis / parts tests)
### Batteries

#### Lead Acid

**Lead Acid**
- VRLA (Valve Regulated Lead Acid)/Sealed
  - Medium Lifetime
  - No topping up
  - Low Maintenance
- VLA (Vented Lead Acid)
  - Long Lifetime
  - Topping up required
  - Low / Normal Maintenance

- Electrolyte (filled in liquid) for Lead Acid Batteries is Sulphuric Acid (caustic)
- Each cell has a nominal voltage of 2.0 VDC
- Cells must be connected in Series to achieve the required DC Level
Batteries

Lead Acid

Batteries are used to store the energy that is required to feed the load, for example inverter, during a mains failure.

VRLA Lead Acid Batteries

- Medium Lifetime
- No topping up
- Low Maintenance

Vented Lead Acid Batteries

- Long Lifetime
- Topping up required
- Low / Normal Maintenance

Batteries

NiCd

- Vented Nickel Cadmium (Ni-Cd) Batteries
  - Long Lifetime
  - High Performance
  - Low / Normal Maintenance

- The alkaline Electrolyte for Ni-Cd Batteries is a solution of Potassium Hydroxide (KOH) and Lithium Hydroxide (LiOH) and is highly caustic
- Each cell has a nominal voltage of 1.2 VDC
- Cells must be connected in Series to achieve the required DC Level
Vented Nickel Cadmium (NiCd) Batteries

- Long Lifetime
- Topping up required
- Low / Normal Maintenance

Battery installation on rack

Typically Industrial Battery Installation on Racks, alternative in Battery Cubicles.

2 x 108 cells x 2.0 V/cell = 216 VDC
2 x 120 cells x 2.0 V/cell = 240 VDC

One or more strings parallel depending on capacity
**Batteries**

**DC-Voltage Range & applicable number of cells (c)**

<table>
<thead>
<tr>
<th>Battery Nominal Voltage (VDC)</th>
<th>UPS Voltage Range for standard applications with AC output voltage in tolerance +/-1% (minimum values)</th>
<th>Battery Type</th>
<th>NiCd</th>
<th>Lead-Acid</th>
<th>Sealed</th>
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</table>

Possible numbers of cells

The voltage is limited on the downside due to the end-discharge voltage: 1.1V/c for NiCd & 1.75V/c for Lead Acid

The voltage is limited on the upside due to max. voltage range & boost charging: 1.6V/c (1.7V/c) for NiCd & 2.4V/c for Lead-Acid.

**Batteries**

**Nominal Capacity 1/2**

The nominal capacity is defined as follows

- Lead acid batteries
  - at 10 hours discharge time, a discharge end voltage of 1.80V/cell and at 20°C
- NiCd batteries
  - at 5 hours discharge time, a discharge end voltage of 1.00V/cell and at 20°C

**Performance**

- The battery capacity cannot be recalculated linear over the respective discharging time
- If the discharging time is lower, then the capacity to be drawn from a battery is also lower
- If the discharge end voltage is lower, then the capacity to be drawn from a battery is higher
- Higher temperatures on lead acid batteries will result in higher capacities to be available from the battery, but will significantly reduce the lifetime of lead acid batteries
Batteries
Nominal Capacity 2/2

Performance
- The available capacity and the aging of a lead acid battery are mainly influenced by the battery temperature.
- Generally, the lifetime reduces by 50% if the battery temperature of lead acid batteries increases by 10°C (taken from the reference temperature of 20°C).
- For lead acid batteries, the tested capacity must be at least 95% of the nominal capacity for the 1st cycle test and must be 100% after a maximum number of 5 cycle tests.
- For NiCd batteries, the tested capacity must be 95% of the nominal capacity after the 5th cycle test.
- The factory test procedures are given in the applicable standards IEC 60896 for lead acid batteries, and IEC 60623 for NiCd batteries.

Batteries
VRLA life / temperature

Valve Regulated Lead Acid Batteries (sealed) are very sensitive to temperature.

Temperature compensated charging helps to minimize the negative impact of elevated temperatures.
Batteries
Capacity of Lead-Acid and NiCd-Batteries in relationship to the temperature

NiCd-Batteries do have a higher capacity at lower temperatures in comparison to Lead-Acid batteries.

At higher temperatures, the capacity of NiCd-Batteries will decrease, and will also be lower than compared to Lead-Acid batteries.
Batteries
Configuration

Individual Batteries

Mains $\rightarrow$ Load

Short-circuit in the DC-circuit in one unit has no influence in the DC-circuit of the second unit.

Mains $\rightarrow$ Load

Short-circuit

Batteries

Built-in Battery Capacity Test

Features:
- Full discharge cycle
- Rectifier is kept on stand-by for safety reason
- Automatic recharge (float- or boost charge)

U_{BAT}

Boost Charge Voltage Level

Float Charge Voltage Level

Nominal Battery Voltage Level

Discharge End Voltage Level

Battery Backup Time

Recharge Time on Boost

Recharge Time on Float Charge

Time
**Batteries**

**Built-in Battery Monitoring and Testing Advances Battery Monitor**

- Expected discharge curves
- $V_{BAT}$ at 25% of expected Battery back-up time
- $V_{BAT}$ at 50% of expected Battery back-up time
- $V_{BAT}$ at 75% of expected Battery back-up time
- At 10% load

**Features:**
- Monitored discharge with reference data
- Displaying actual backup time
- Automated periodical partial battery test

**Example 1.: Battery weak:** $V_{BAT}$ falls below $V_{BAT} \cdot 25\%$ time before 25% of the time is reached

**Example 2.: Battery defective:** $V_{BAT}$ falls below $V_{BAT} \cdot 50\%$ time before 25% of the time is reached

---

**Batteries**

**Single Cell Battery Management System GBMS**

**Features**
- Single Cell Voltage / Resistance Monitoring and recording
- WEB Based Front End for remote monitoring
- Single Cell Equalize Charging
- Monitored Discharge Testing
Standards

Overview

Standards
- IEC
- UL

Quality
- ISO 9001

Conformity
- IEC - VFI
## Standards

### Certificates

<table>
<thead>
<tr>
<th>Certificate</th>
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<td>ISO 9001</td>
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<td>IEC 62040 - 1</td>
<td>Uninterruptible Power Systems (UPS) - General and safety requirements</td>
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<td>IEC 62040 – 2</td>
<td>Uninterruptible Power Systems (UPS) - EMC Requirements</td>
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<td>Graphical Symbols for Diagrams</td>
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### Standards for Industrial UPS UL / FCC

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## Standards

### Standards for Industrial UPS IEEE / NEMA

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<td>IEEE 519</td>
<td>Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems</td>
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<td>Graphics Symbols for Electrical and Electronics Diagrams</td>
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<td>Edition 1992: Input current total harmonic distortion</td>
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<td>- 0 - 20kVA 30% THD</td>
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<td>- 20 - 200kVA 15% THD</td>
</tr>
<tr>
<td></td>
<td>- &gt;200kVA 10% THD</td>
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<tr>
<td>NEMA PE5</td>
<td>Utility Type Battery Chargers</td>
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<tr>
<td>NEMA ST20</td>
<td>Dry Type Transformers for General Applications</td>
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<tr>
<td>NEMA 250</td>
<td>Enclosures for Electrical Equipment</td>
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## Standards

### Conformity

<table>
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<tr>
<th>Standard</th>
<th>Description</th>
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<tbody>
<tr>
<td>IEC 62040 – 1</td>
<td>Uninterruptible Power Systems (UPS) - General and safety requirements</td>
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<td>CE Label</td>
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<tr>
<td>IEC 62040 – 2</td>
<td>Uninterruptible Power Systems (UPS) – EMC Requirements</td>
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<td>IEC 62040 – 3</td>
<td>Uninterruptible Power Systems (UPS) - Method of specifying the</td>
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<td>performance and test requirements</td>
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<td>Performance Code VFI-SS-111</td>
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Maintenance
Onshore and Offshore Installations

Onshore Installation
• Easy to get maintenance staff on site
• Availability of spare parts typically higher

Offshore Installation
• More difficult to get maintenance staff on site
  – Travel restriction
  – Certificates
• Consider
  – Remote monitoring
  – Single cell battery monitoring
  – Improve on site availability of spare parts

Maintenance
UPS

Maintenance is important; to secure long time reliable operation of the secured power system.

• UPS part
  – Visual inspection
  – IR check (Infrared camera)
  – Regular functionality check
  – Maintenance according to supplier specification
    – Components with limited lifetime
  – Parallel Redundant and Dual UPS; UPS power is available during maintenance
  – Single UPS; UPS power is not available during maintenance
Maintenance
Battery

Maintenance is important; to secure long time reliable operation of the secured power system.

- Battery
  - Visual inspection
  - Check connection/termination - IR check (infrared camera)
  - Cleaning and greasing
  - VLA and NiCd requires check of level of electrolyte, how often is depending on type of battery and temperature of electrolyte (not ambient temperature)
  - Further maintenance requirements are depending on type of batteries
  - Discharge test preferable; only a real discharge test can give evidence of healthiness of the battery

Maintenance
UPS Downstream distribution and loads

Maintenance is important; to secure long time reliable operation of the secured power system.

- UPS downstream distribution and loads
  - Dual configuration
    - If individual power supplies in the load is not monitored, it's important to check that both power supplies are working correct, other ways the duality of the DUAL system is not guarantee.
Questions?

THANK YOU.