Component Reliability in Photovoltaic Inverter Design

2013 Inverter Reliability Workshop
Sandia National Laboratories
Electric Power Research Institute (EPRI)

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Agenda

➢ Schneider Electric Solar Business introduction – 3min

➢ Component Reliability in PV Inverter Design – 15min
  ✓ A inverter standard usage model study
  ✓ Critical component stress level and useful life analysis
  ✓ Design for Reliability/ Maintainability and preventive service plan

➢ Q&A – 2min
Schneider Electric – the global specialist in energy management

24
billion € sales
(last twelve months)

41%
of sales in new economies
(last twelve months)

140,000+
people in 100+ countries

4–5%
of sales devoted to R&D

Balanced geographies – FY 2012 sales

North America 25%
Western Europe 30%
Asia Pacific 27%
Rest of World 18%

Diversified end markets – FY 2012 sales

Utilities & Infrastructure 25%
Industrial & machines 22%
Data centres 15%
Non-residential buildings 29%
Residential 9%
Solutions for solar energy

**PV power plant**
Our solution:
- Switch gear and circuit protection
- Power conversion substation
- Grid connection substation
- Tracking systems
- Inverters and array boxes
- Security
- Supervision and monitoring

**Off-grid / Backup solar**
Our solution:
- Multi-source management
- Inverters and chargers
- Circuit protection

**Residential grid-tie solar**
Our solution:
- Supervision and monitoring
- Maintenance and operation
- Inverters
- Distribution panels
- Circuit protection

**Commercial and industrial buildings**
Our solution:
- Switch gear and circuit protection
- Power conversion substation
- Grid connection substation
- Tracking systems
- Inverters and array boxes
- Security
Ottawa, Canada

Solution: GT500
System Size: 19 MW
Energy Production: 21,850 MWh/Year
Installation Type: Ground Mounted
Senftenberg, Germany

Solution: 62 PV Box (109 x GT630E)
System Size: 82MW
Installation Type: Ground Mounted
A Standard Usage Model of the PV Inverter

Inverter full power operation hours estimated at daily peak sun hours (average 6~8 hours)

The U.S. daily Peak Sun Hour / states

Source: Photovoltaic Design and Installation manual, 2003
A Standard Usage Model of the PV Inverter

Ambient temp varies from -60°C to +50°C (-76°F, +122°F)

Source: Photovoltaic Design and Installation manual, 2003
A Standard Usage Model of the PV Inverter

An example of a typical harsh location:

Peak sun hours > 11 hours  Temperature > 40°C (104°F)

Source: Photovoltaics Design and Installation manual, 2003
## A Standard Usage Model of the PV Inverter

An example of inverter operating ambient temperature range and inverter full power operating hours/day range:

<table>
<thead>
<tr>
<th>Item</th>
<th>Product Spec.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Temp Limit (Full power)</td>
<td>-20 °C (-4°F)</td>
</tr>
<tr>
<td>High Temp Limit (Full power)</td>
<td>50 °C (+122°F)</td>
</tr>
<tr>
<td>Operating hour in power path</td>
<td>8 hrs/day</td>
</tr>
<tr>
<td>Operating hour in control/communication path</td>
<td>24 hrs/day</td>
</tr>
</tbody>
</table>
Large Commercial & Solar Farms Offer

PV Power plant application (> 1MW)
Inverter Function Blocks & Critical Components

Diagram of 3-phase inverter

- DC, AC and Power Conversion Blocks
  - IGBT power module, Main AC/DC breakers
  - DC Buss Caps, AC filter Caps
- Control & Communication Boards
- Auxiliaries
  - Cooling / Circulation fans, Heaters
- Customer interface
  - Display, keypad
Check Component Design Margin!

Component Stress Level Guideline

**SL**: Stress Level

Ensure enough design margin for long-term reliability
## Optimizing Component Design Margin

### Long-term reliability?

### Cost?

### Component Stress Level Examples

<table>
<thead>
<tr>
<th>Component</th>
<th>Maximum Stress Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>IGBT</td>
<td>$T_{jR\text{max}} -25°C$, 75% of $V_{DSR}$, 80% of $V_{GSR}$</td>
</tr>
<tr>
<td>Aluminum electrolytic capacitor</td>
<td>80% of $V_R$</td>
</tr>
<tr>
<td>Resistors (&lt;2W)</td>
<td>50% of $P_R$, 75% of $V_R$</td>
</tr>
<tr>
<td>Power inductors</td>
<td>$T_{maxR} -20°C$</td>
</tr>
</tbody>
</table>
Inverter Requirements vs. Component Reliability

- Inverter useful life >20 years

Solution:
- Analyze component useful life & enforce DFS
- Implement preventive maintenance plan

- Harsh inverter application environment
  - Temperature / Humidity
  - Dust / UV

Solution:
- Using fans, heaters, filters, … etc and control logic to create a local environment to ensure component design margin for long term reliability

- Component relatively short life expectance

- Component spec not directly meeting harsh application
Critical Component Useful Life Prediction

IGBT power module

- Life expectancy of the solder joint:
  - 40,000 cycles at $\Delta T_c=50^\circ C$,
  (Typical worst $\Delta T_c =45^\circ C$ in our application)

- Useful life prediction:
  - $\frac{40,000}{5 \text{ (cycle/day)}/365} = 21.9 \text{ (years)} > PV \text{ inverter service life (20 years)}$
Critical Component Useful Life Prediction

DC Buss Capacitor

- Life expectancy:
  100,000 hours
  @ nominal voltage and specified internal hotspot temperature.
  40,000 hours
  When temperature is 10°C higher than spec

Useful life prediction:
  100,000/8/365=34 (years)
  When use it in the spec.
  40,000/8/365=13.7 (years)
  When temp is 10°C higher
Critical Component Useful Life Prediction

Main DC contactor

• Electrical durability spec.
  30,000 operations at 2050 A maximum and 1000 V

• DVT (Design Verification Test)
  Typical application:
  (310V, 1652.3A) to (480V, 1070A), one operation per day

• Life expectancy:
  30,000/2/365=41 years at Typical application
  Life expectancy > Product service life (20 years)

• Don’t need to replace it during the product service life.
Critical Component Useful Life Prediction

Cooling Fans for power bridge

• Spec.
  • Operating ambient temperature @ max. voltage: -25°C+60°C
  • Service life (L10): 57323h @40°C, 36591h @60°C
  • FIT:313

• DVT (Design Verification Test)
  • Typical application temperature 45.8°C
  • Worst application temperature 56.5°C

• Life expectancy: 8hrs usage/day @60°C
  36591/8/365=12.5 (years) @60°C < Product service life (20 years)

• Replace it at year 10.
Critical Component Useful Life Prediction

Fiber Optic Transmitter and Receivers

- **Estimated life expectancy:**
  > 10 years at 40°C and 60 mA
  Operating temp: - 40°C to +85°C

- **DVT (Design Verification Test)**
  Typical application: 70.6°C and 13.6mA

- Life expectancy < Product service life (20 years)

- Expected to be replaced before year 10.
DFS and Preventive Maintenance

- Design for Serviceability (DFS) to reduce Mean Time To Repair
- Preventive maintenance plan based on the useful life analysis of the critical components

A Example of PM parts list

<table>
<thead>
<tr>
<th>Replacement parts</th>
<th>At year 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling and circulating fans</td>
<td>X</td>
</tr>
<tr>
<td>DC Buss Cap Assemblies</td>
<td>X</td>
</tr>
<tr>
<td>Gate Driver boards</td>
<td>X</td>
</tr>
<tr>
<td>Front panel, control board</td>
<td>X</td>
</tr>
</tbody>
</table>
Designing robust solar products

Key aspects of design for quality & reliability

- WCA (Worst Case Analysis)
- Useful life analysis
- Design standard check
- D-FMEA (Design Failure Modes, Effects Analysis)
- A-FMEA (Application Failure Modes, Effects Analysis)
- FIT/MTBF (Failure In Time/Mean Time Between Failures) prediction
- List of preventive maintenance parts for field serviceable products
- Reliability testing

Types of reliability testing during product development cycle

- THB (Temperature Humidity Bias)
- Salt-fog testing
- HALT (Highly Accelerated Life Test)
- MEOST (Multiple Environmental Over Stress Testing)
- Custom reliability testing: Used for our large three phase inverters tested in walk-in chamber

Product life cycle reliability testing

- Qualification of major design improvements
- Continuous reliability monitoring to ensure the same level of reliability throughout the product life cycle
Conclusion

Inverter reliability relies on component reliability

We provide our customers with a reliable 3-ph inverter with 20 years service life by:

- Ensuring design margin in both inverter and components for long term reliability
- Adopting Design for Serviceability (DFS) to reduce down time
- Implementing preventive maintenance plan based on the useful life analysis of the critical components