Component Reliability in Photovoltaic Inverter Design

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

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Schneider Electric

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)

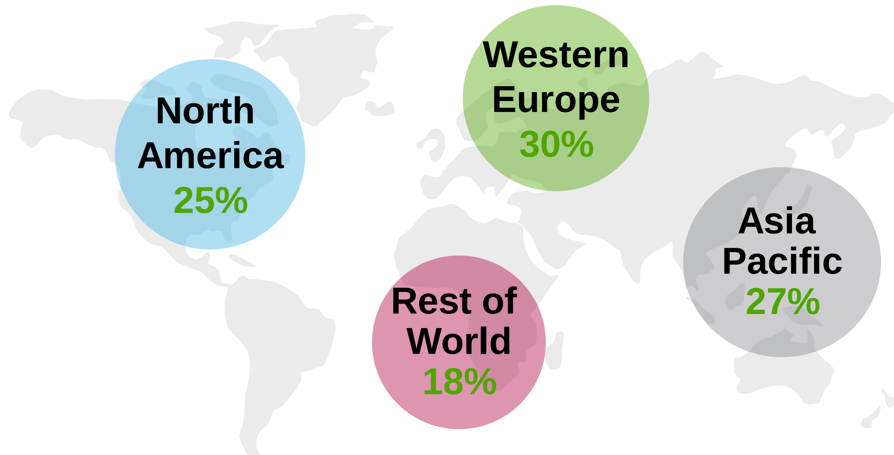
140000+

people in 100+ countries

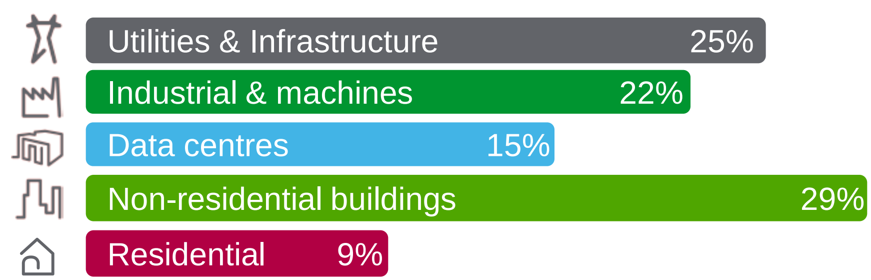
4–5%

of sales devoted to R&D

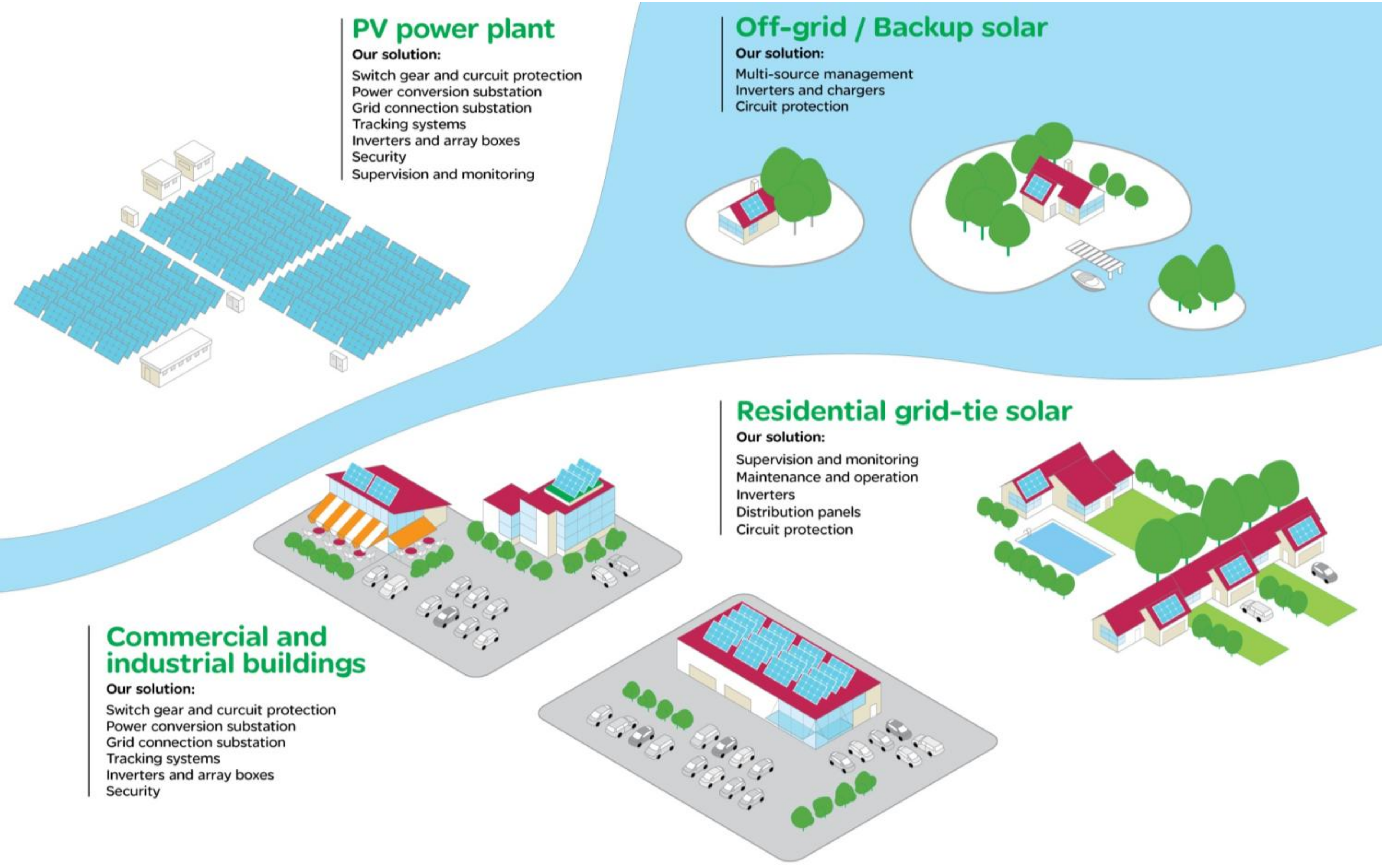
Balanced geographies – FY 2012 sales



Diversified end markets – FY 2012 sales



Solutions for solar energy



Ottawa, Canada

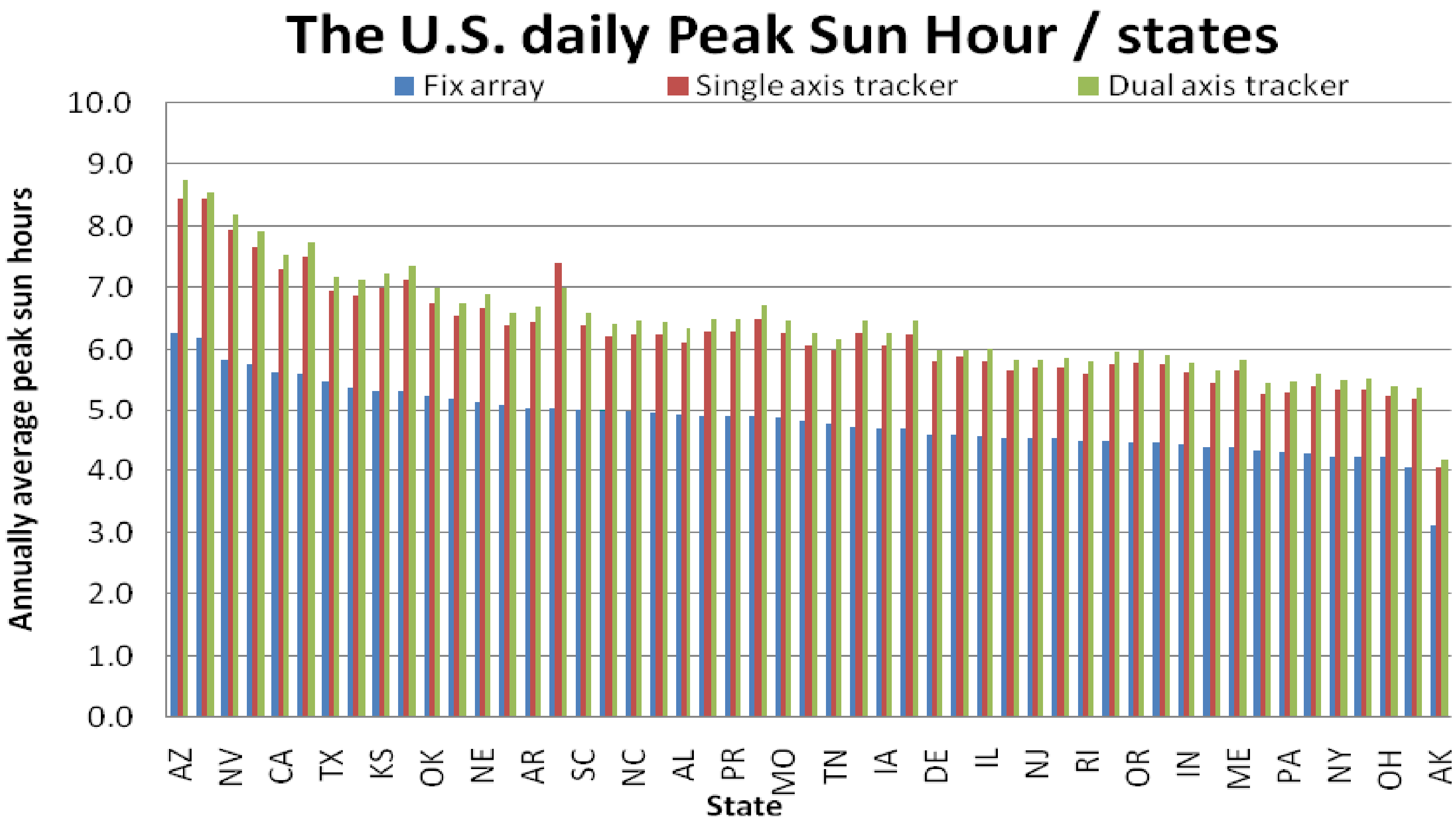
Solution: GT500
System Size: 19 MW
Energy Production:
21,850 MWh/Year
Installation Type: Ground
Mounted

Senftenberg, Germany

Solution: 62 PV Box (109 x GT630E)
System Size: 82MW
Installation Type: Ground Mounted

A Standard Usage Model of the PV Inverter

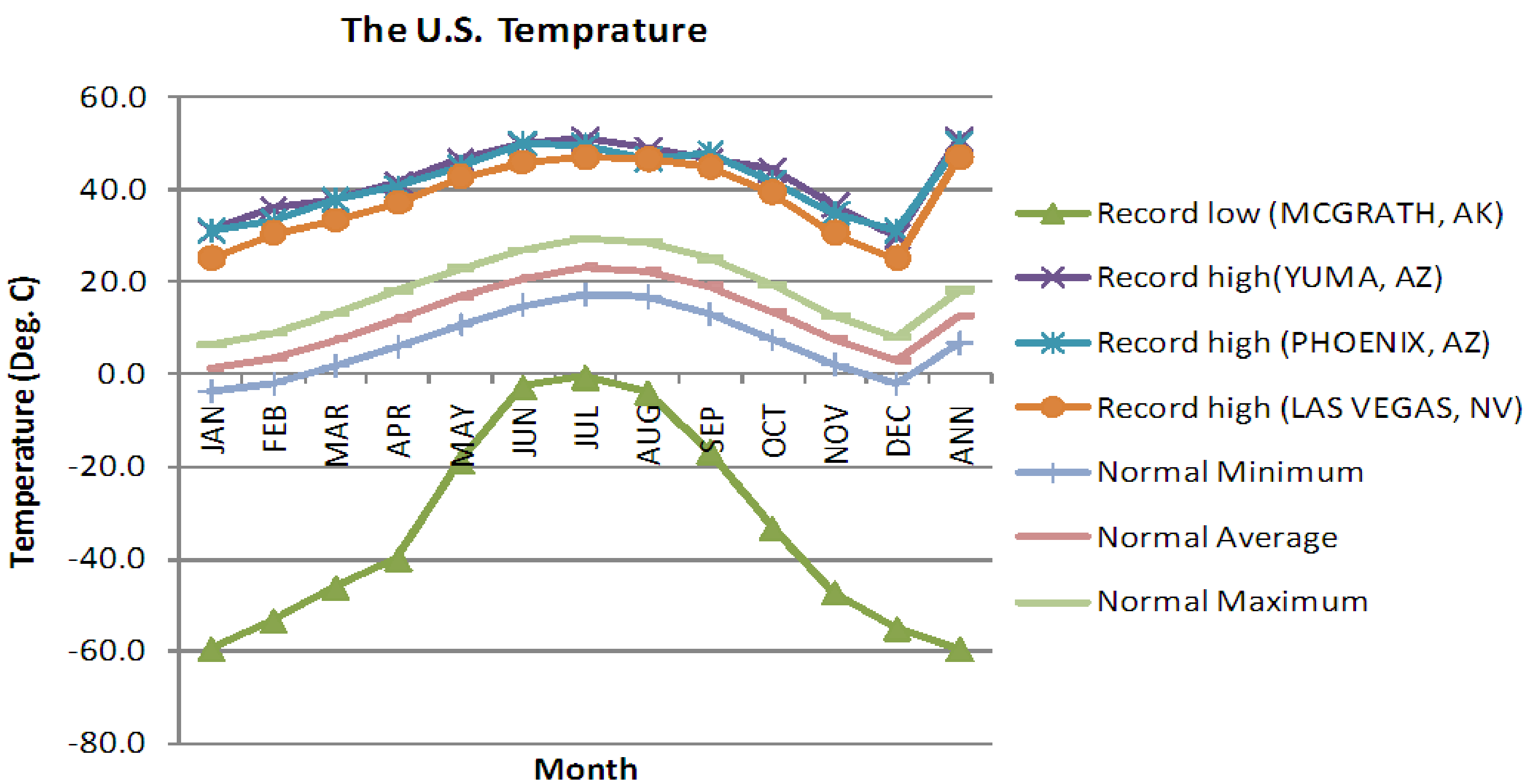
Inverter full power operation hours estimated at daily peak sun hours (average 6~8 hours)



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)

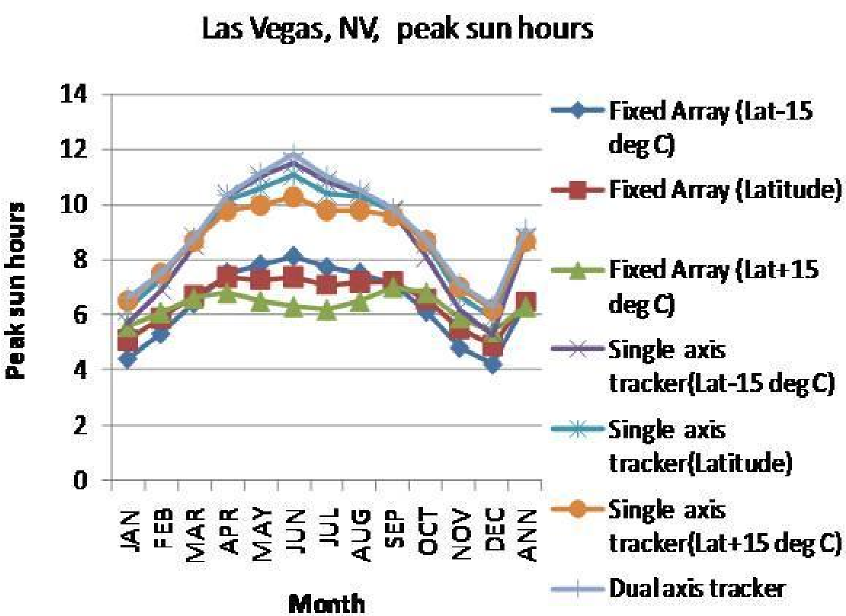


Source: Photovoltaic Design and Installation manual, 2003

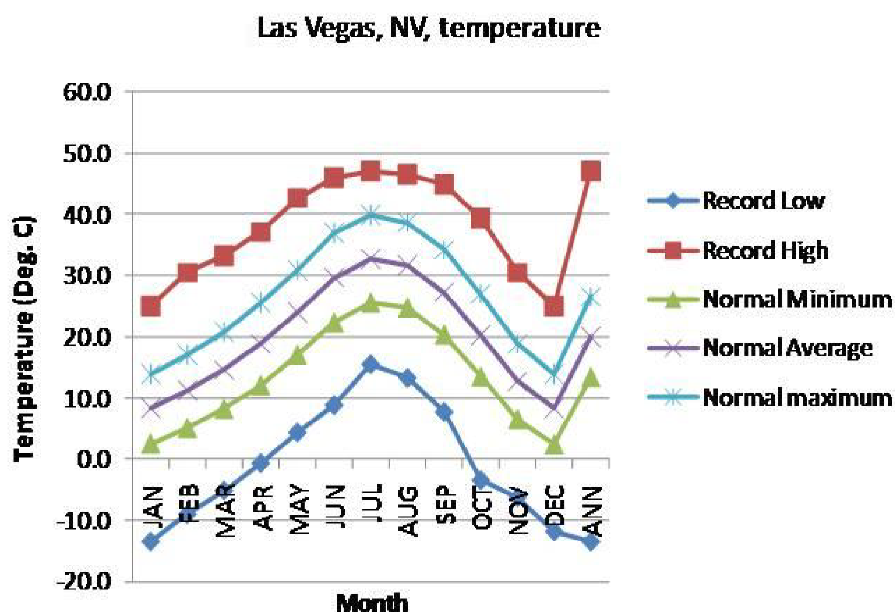
A Standard Usage Model of the PV Inverter

An example of a typical harsh location:

Peak sun hours > 11hours



Temperature > 40°C (104°F)



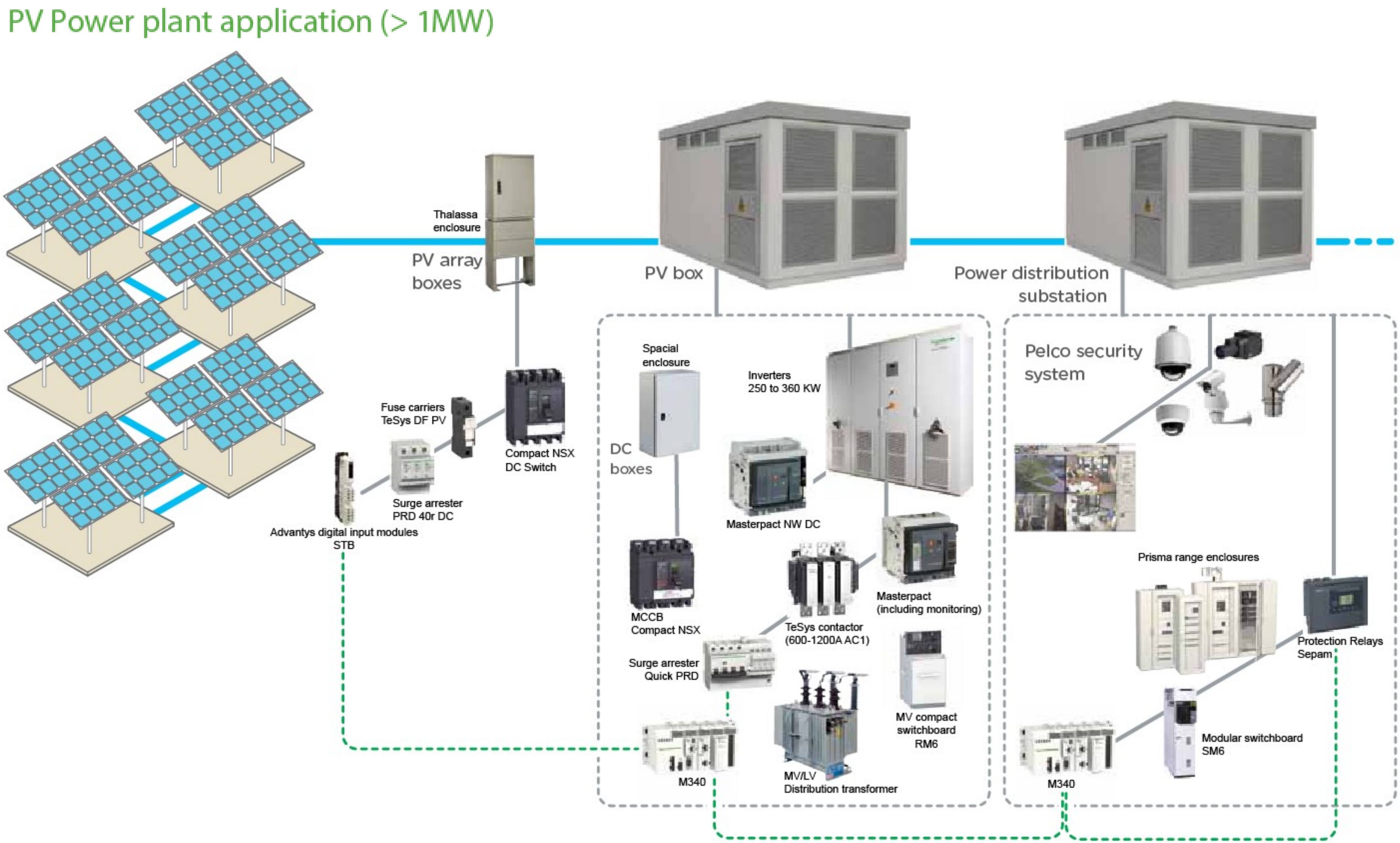
Source: Photovoltaics Design and Installation manual, 2003

A Standard Usage Model of the PV Inverter

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

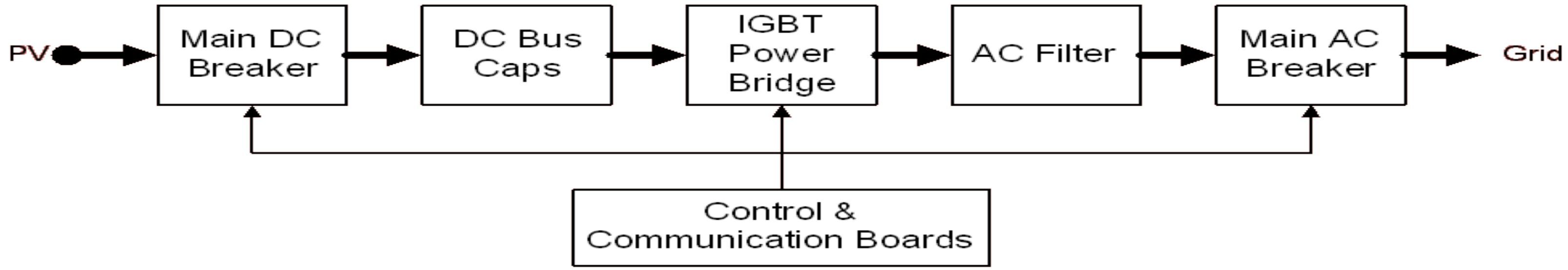
Item	Product Spec.
Low Temp Limit (Full power)	-20℃ (-4°F)
High Temp Limit (Full power)	50℃ (+122°F)
Operating hour in power path	8 hrs/day
Operating hour in control/communication path	24 hrs/day

Large Commercial & Solar Farms Offer



Inverter Function Blocks & Critical Components

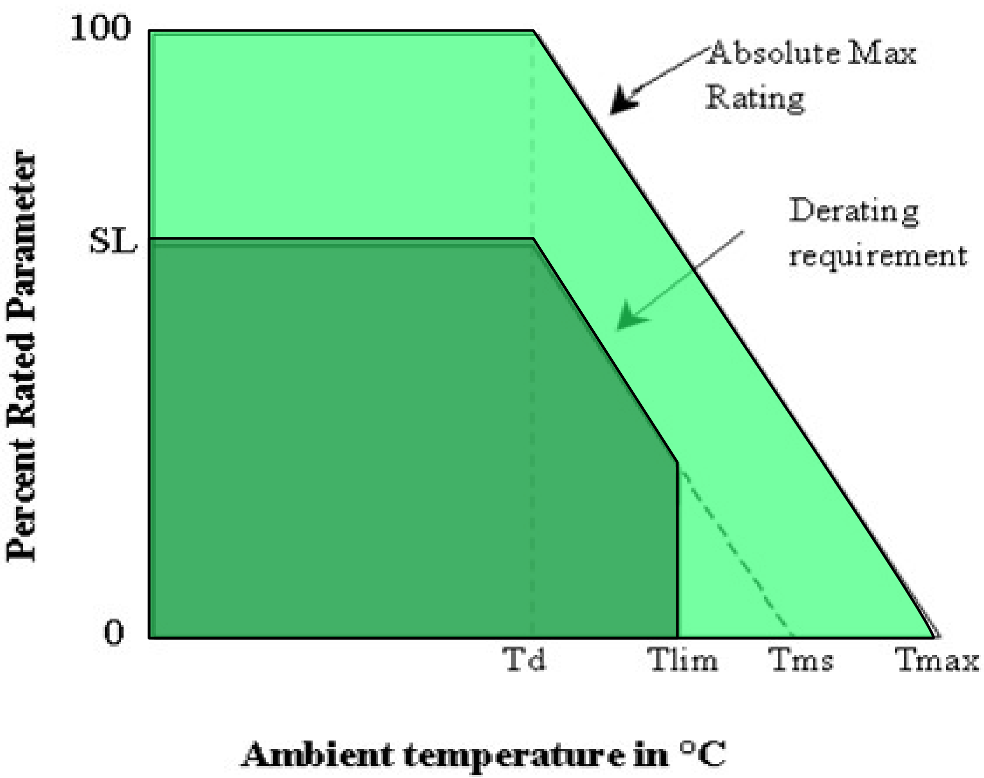
Diagram of 3-phase inverter



- **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

Component	Maximum Stress Level
IGBT	Tj_Rmax -25°C, 75% of VDS_R 80% of VGS_R
Aluminum electrolytic capacitor	80% of V_R
Resistors (<2W)	50% of $P_{R,}$ 75% of V_R
Power inductors	$Tmax_R$ -20°C

Inverter Requirements vs. Component Reliability

- Inverter useful life >20 years
- Component relatively short life expectance

Solution:

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

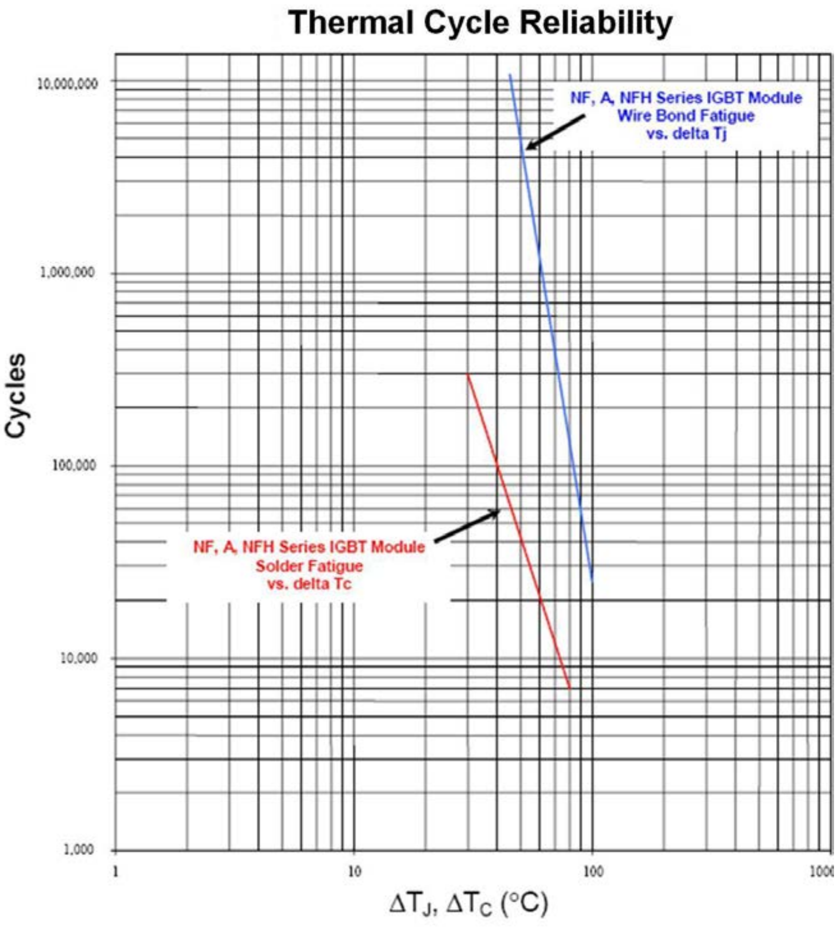
- Harsh inverter application environment
  - Temperature / Humidity
  - Dust /UV
- Component spec not directly meeting harsh application

Solution:

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

Critical Component Useful Life Prediction

IGBT power module



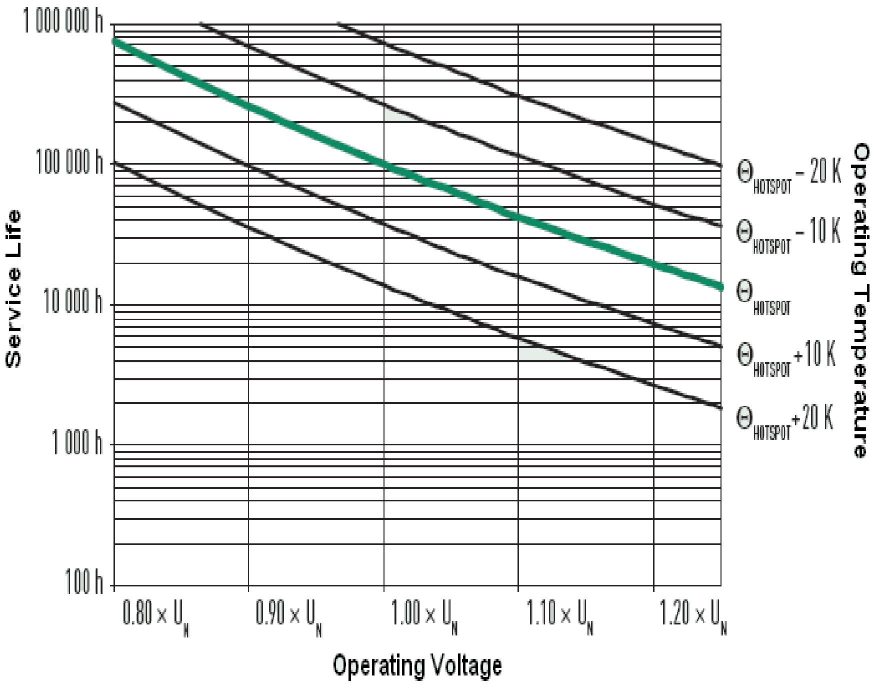
- Life expectancy of the solder joint:

  40,000 cycles at ΔTc=50°C,
  (Typical worst ΔTc =45°C in our application)

- Useful life prediction:
  40,000/5 (cycle/day)/365
  = **21.9 (years) >**
  PV 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

Replacement parts	At year 10
Cooling and circulating fans	X
DC Buss Cap Assemblies	X
Gate Driver boards	X
Front panel, control board	X

Designing robust solar products

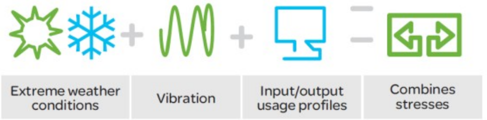
Key aspects of design for quality & reliability

- 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

MEOST Reliability testing is an accelerated stress test that identifies potential weaknesses which may be uncovered during the life span of the product.



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