Satcon Technology Corporation

Inverter Reliability: Design, Availability, Prognostics

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Satcon

Satcon PowerGate Plus

11 Power Ratings Ranging from 30kW-1MW

PowerGate Plus
30 kW
DC Input Range
305-600V

PowerGate Plus
50kW
DC Input Range
305-600V

S-Type
50kW
DC Input Range
265-600V

PowerGate Plus
75kW
DC Input Range
315-600V

PowerGate Plus
100kW
DC Input Range
315-600V

S-Type
110kW
DC Input Range
265-600V

PowerGate Plus
135kW
DC Input Range
310-600V; 320-600V

PowerGate Plus
150kW
DC Input Range
420-850V

PowerGate Plus
250kW
DC Input Range
320-600V; 333-600V; 420-850V

PowerGate Plus
375kW
DC Input Range
320-600V

PowerGate Plus
500kW
DC Input Range
320-600V; 333-600V; 420-850V

PowerGate Plus
1MW
DC Input Range
420-850V

Satcon Prism

Outdoor Ehouse Enclosure

Two-piece, pre-engineered MV system for grounded or ungrounded (1MW), 1,000V array:

  - 2 x 500kW inverters
  - Corresponding MV transformer
  - Switchgear

- Simplifies installation connection to an MV grid

- Controlled Environment

Satcon Prism

Inside the Ehouse Enclosure

- Low installed cost
- NEMA 3R cabinet
- Customizable transformer
  - Any MV configuration
  - Inside or outside Ehouse options
- Fully controllable switchgear connection/ disconnection
- Inverter, transformer and switchgear covered by Satcon warranty

Equinox Platform

Covered outdoor Inverter

Higher efficiencies

- 98.5% Peak | 97.5% CEC
- IP54/NEMA-3R Electronics Enclosure
- Operational temp range best in class:
  -20°C to +50°C (Optional: +55°C)
- Standard with Equinox:
  - DC combiner fuses
  - CCM Gateway
  - Power factor control
  - Remote start and stop
- Next generation control board
  - Reduced cost and greater availability
- Real and reactive power control
- Low voltage ride-thru per BDEW (German conformance)
- Dynamic VAR capability (CE/ NA utility solution)
- 1000V-rated model has new materials achieves best in class

Hundreds of Millions of Grid Connected kW Hours

1MW Powergate Plus

- **400+ megawatts total PowerGate shipped**
- **220MW of 500 kW since 2005**

Highlighted sites:

- General Motors -12MW
  - Zaragoza Spain
- Southern California Edison - 2MW
  - Fontana California
- GCL - 20MW
  - Xuzhou, China
- First Light - 9MW
  - Ontario Canada
- Energy 21 - 20MW
  - Czech Republic
- CalRENEW – 5MW
  - Fresno, California
- West Pullman - 9MW
  - Chicago, Illinois

Satcon Solstice

Lower Cost, Faster Return on investment

The new standard for large scale solar power plant production

- Increase system yield by 5-12%
- Deliver more kWh per kW peak of installed capacity
- Reduce installed costs
- Minimize and isolate system downtime
- Prevent, quickly manage and solve energy disruptions over the installation's lifespan

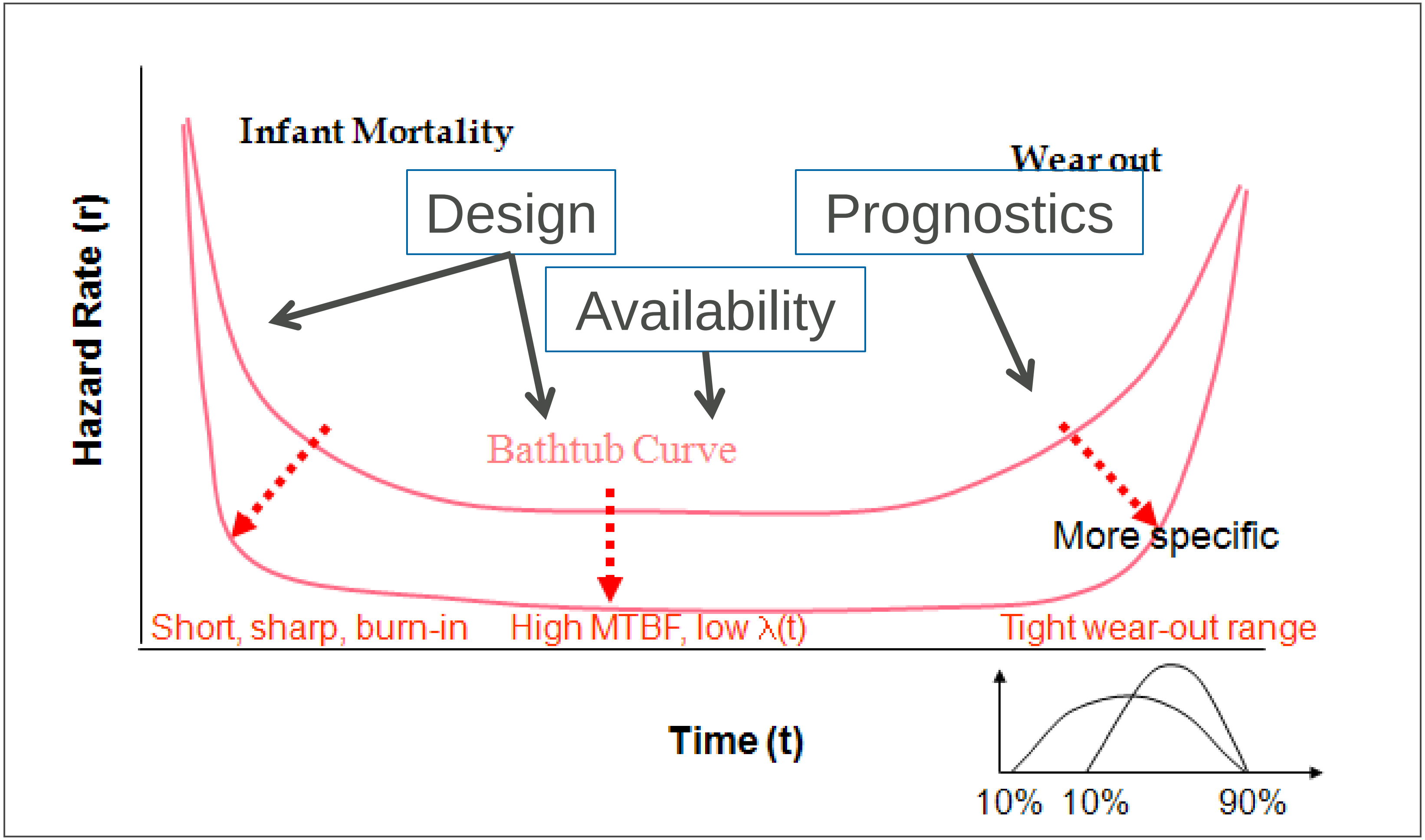
Reliability Design:

Morphs from

•Low Volume – skilled assemblers

•High Volume – streamlined, Repeatable, manufacturing

Bathtub Curve



Reliability from a Design Perspective

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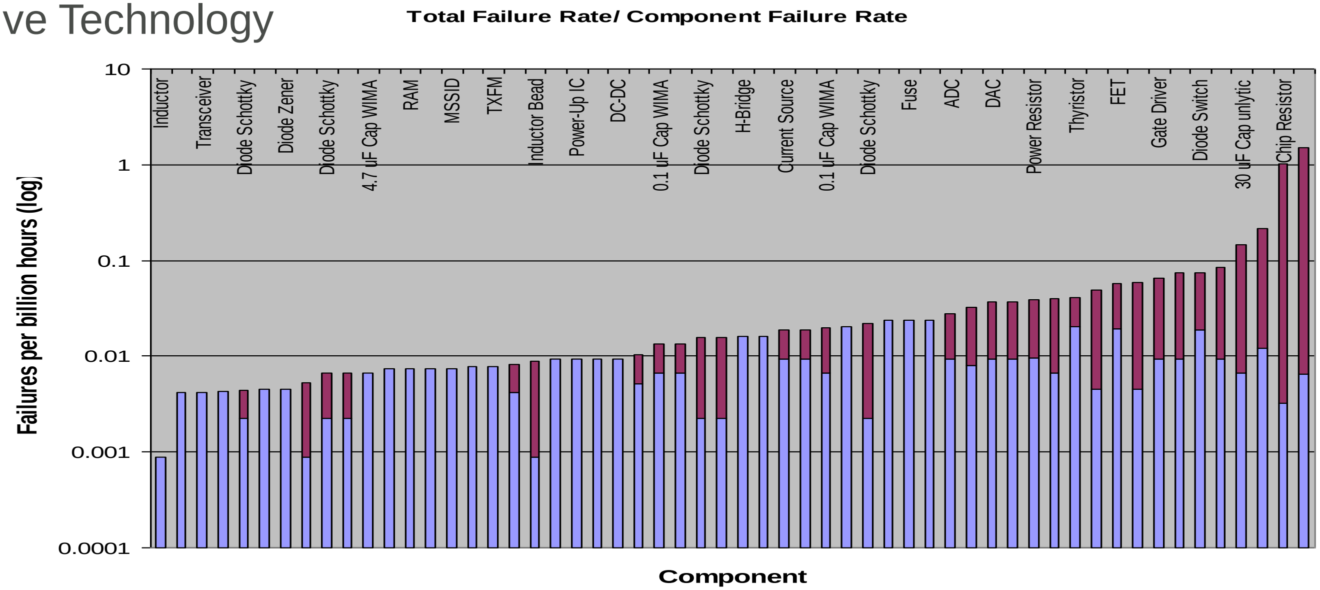
Design: Begins with Component Selection

Squeeze Reliability into Design by Reducing FITs

- Reduce Stresses (derate) [Minimize Dissipation First]
- Reduce Component Count
- Eliminate Components
- Alternative Technology



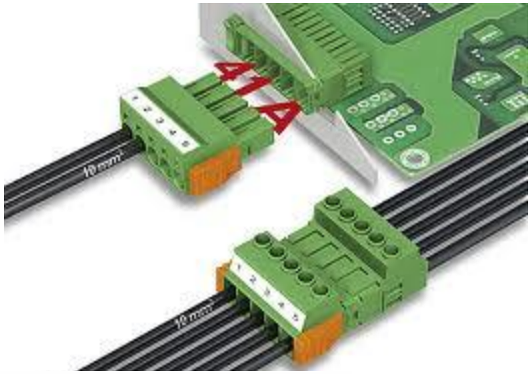
Design: Incorporate intelligent system designs to reduce MTBF

Design Enhancements

- Hermetically sealed
- Modular from 50kW-1MW
- Common components
- Redundant cooling
- High efficiency
- Integrated grid interface & control features
- High reliability

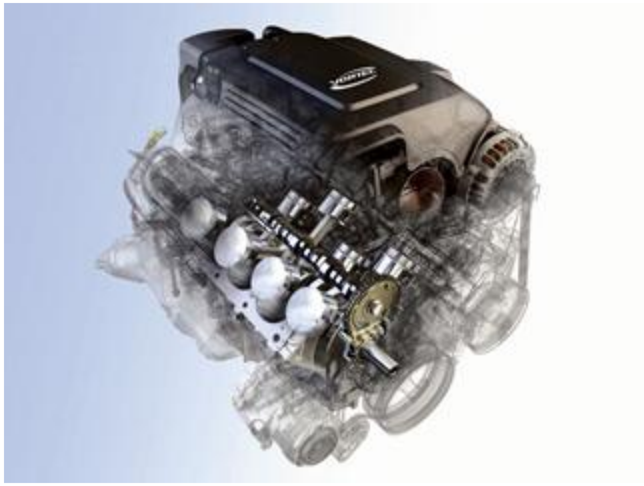
Careful Design of Interconnects – High Infant mortality items

- Interconnects
  - especially between dissimilar items
- Wiring Harnesses
  - Reduce cable assemblies to single parts; testable, replaceable
- Moving Parts
  - Fans, Contactor, Cooling, disconnects, hinges



Load Sharing of high stress devices

- Variable Displacement
  - Shutting down power devices under lower load conditions
- Stress sharing
  - Use history to keep stress equal between redundant power systems



Reliability: Availability

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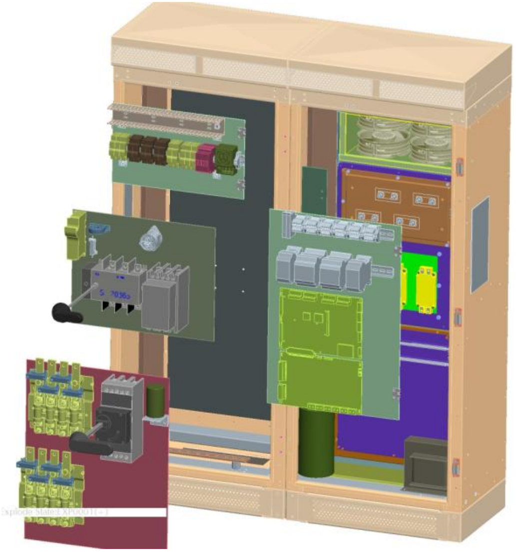
Availability

- Combination of MTTF and MTTR
- MTTF: Constant over time in bottom of bathtub
- MTTR: Establish good service practices
  - Warehouse stocks of common components (Identification)
  - Modular design allows for quick unskilled field replacement



Availability

- Internet connected devices
  - Quick fault reporting
  - Diagnostic information
  - Logging of system parameters prior to fault
- Remote debugging and repair capabilities
- Redundant systems
- Ability to run ‘hobbled’

Availability

- Most Importantly:
  - Able Service Technicians
  - Arrive quickly
  - With knowledge of Exact Problem
  - Parts on Hand

Reliability: Prognostics

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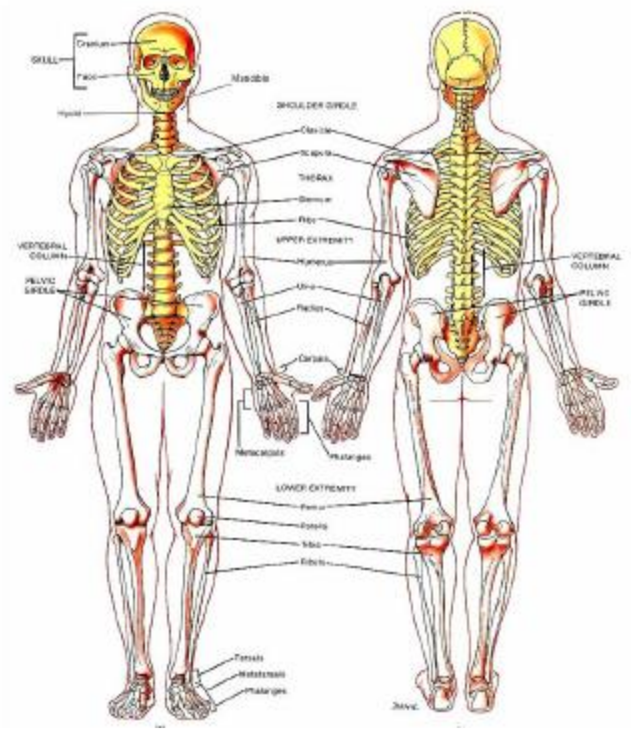
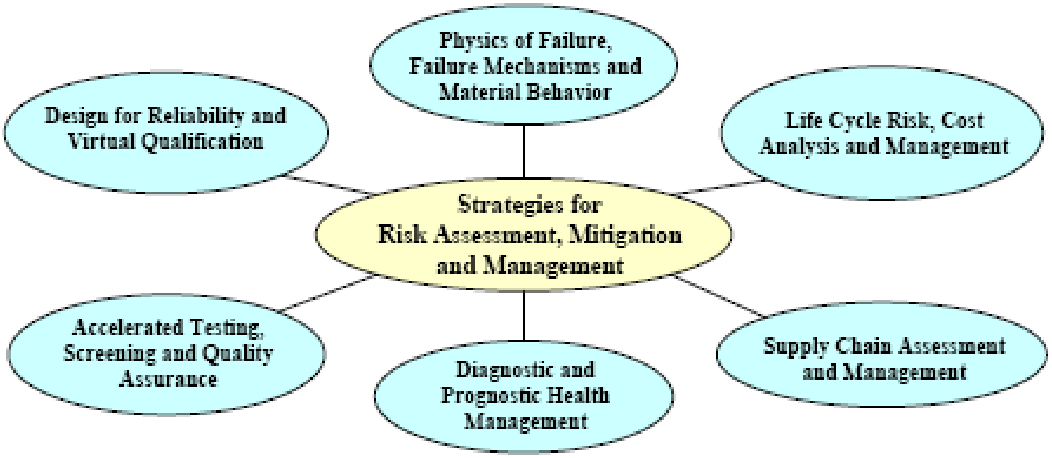
Where does this fit?

Prognostics/Diagnostics/Health Monitoring/End of Life Prediction

Insurance vs Assurance?





Physics of Failure, Failure Mechanisms and Material Behavior

Design for Reliability and Virtual Qualification

Life Cycle Risk, Cost Analysis and Management

Strategies for Risk Assessment, Mitigation and Management

Accelerated Testing, Screening and Quality Assurance

Diagnostic and Prognostic Health Management

Supply Chain Assessment and Management

Historically, Diagnostics & Prognostics have been particularly valuable for Mechanical & Electromechanical

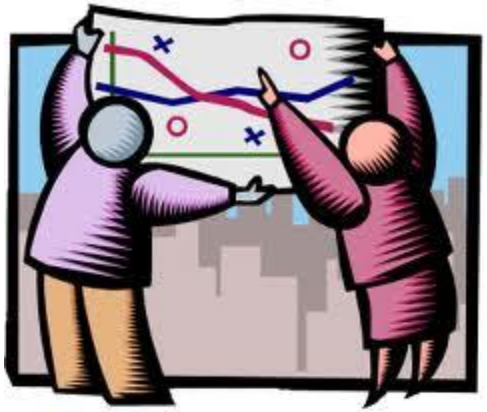
Systems (long time scales), based on symptoms, early warning,

- Motors - Brush arcing, bearing vibration, HF vibration
- Power Transformers - Charge, Vibration, Moisture,

Fundamentally, defects + stress => degradation, our focus is wearout, critical assumptions need to hold

Prognostics

- Relative prediction of critical component usage
- Devices (Thermal): IGBT’s, Capacitors, Reactors
- Mechanical Devices (usage): Breakers, Contactors
- Provide a meaningful metric for preventative maintenance.



Thermal Algorithm for IGBT’s

- Limit sensing (estimation based on models and reduced sensing)
- Monitor life history of the converter with an awareness of the typical aging and wear out mechanisms.
- Insight into failure mechanisms is critical (e.g. sudden ΔT)
- Diffusion related processes vs thermal cycling (fatigue). Accelerated by temperature T, change in temperature ΔT, and thermal shock dT/dt.

Reliable/Long Life/Rugged

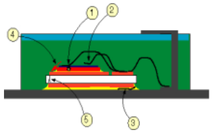
- Inherent Weaknesses
  - Defects
  - Aging (FITs)
  - Wearout
- External Forces
  - Temperature
  - Air density
  - Humidity
  - Ultra-Violet
  - Line and Array
    - Spikes
    - Surges
    - Sags
  - Shock/Vibration
- Internal Forces
  - Power→Temperature
  - dP/dt (thermal shock)
  - V, I
  - dI/dt, dV/dt
  - Aging Mechanisms

Examples

- ➢ µCracks
- ➢ Metal Migration
- ➢ Diffusion, Filamentation
- ➢ Crystallization
- ➢ Trapped Moisture
- ➢ Plasticizers
- ➢ Conductive Condensation
- ➢ Device Stress
- ➢ Fatigue due to Cycling
- ➢ Thermal Shock → Cracks

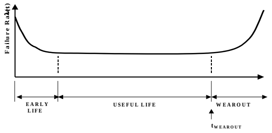
Wearout can be Modeled

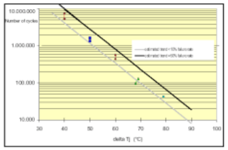
Primary Failure Modes in Si-IGBT Power Modules

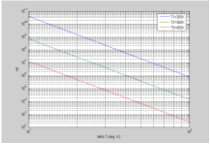


1) Silicon Failure
2) Wirebond Failure
3) Solder/Attachment Failure
4) Encapsulant Failure
5) Substrate Failure

Most Failure Mechanisms are Thermally Activated or Enhanced



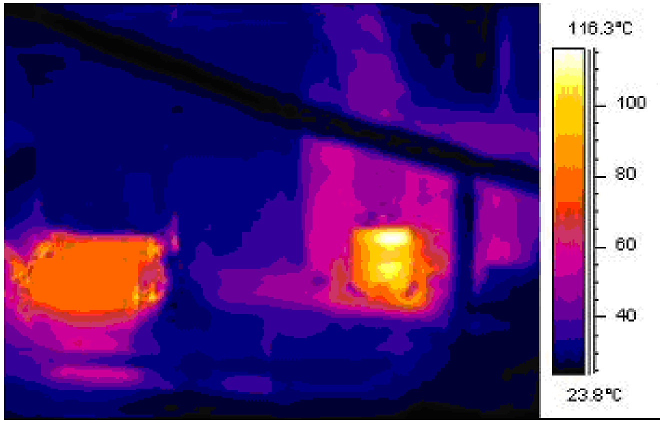




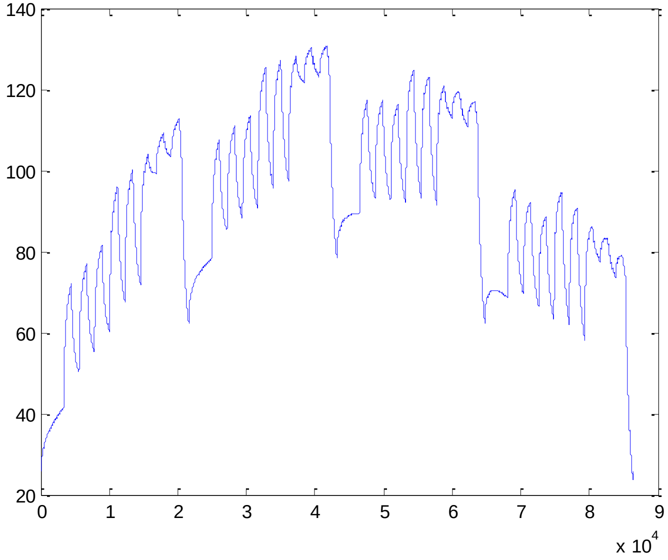
$$N_f = \frac{10^{24} \times (0.9354)^{T_{abs|}}}{(\Delta T_{abs})^{4.696}}$$

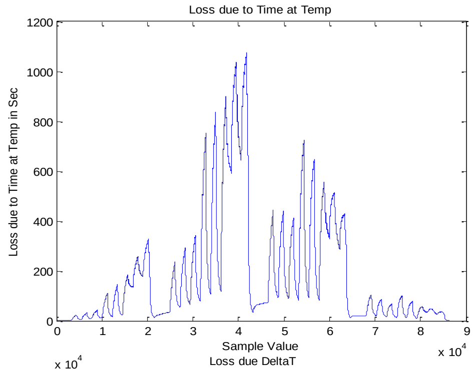
Thermal Algorithm for IGBT's

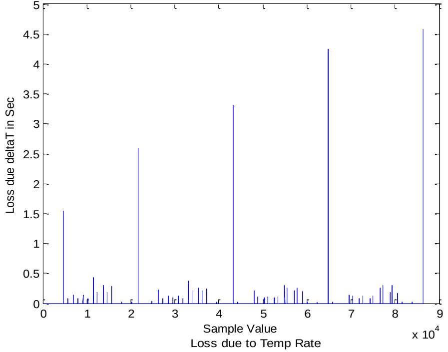
- Temperature is the all important variable!
- Quick, no history storage for embedded processors (cheap)
- All about mismatches and stress
- Three independent thermal factors:
  - Time at Temp
  - Rate of Temp Change
  - Delta Temp (Cycling)

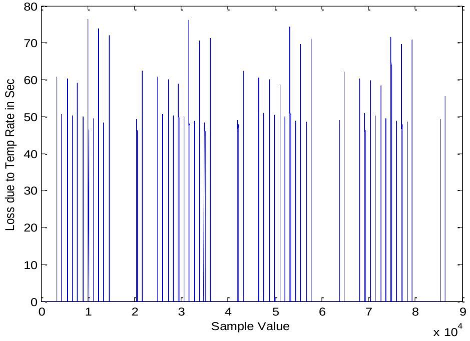


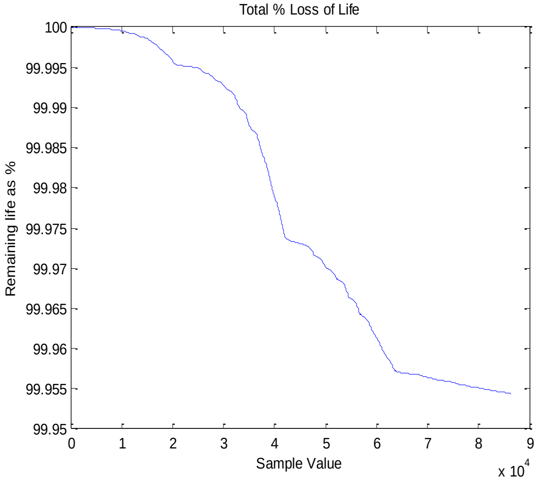
Predicting “real-usage” life acceleration



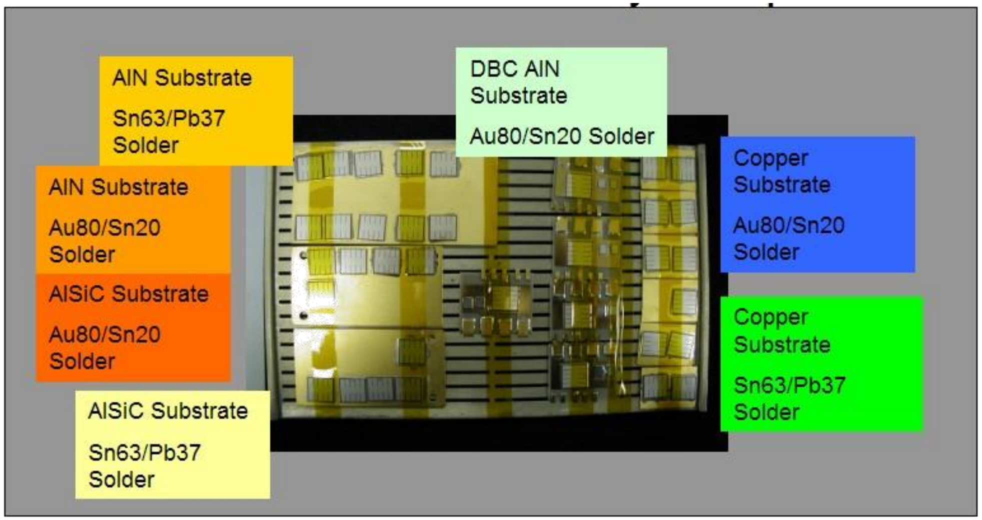


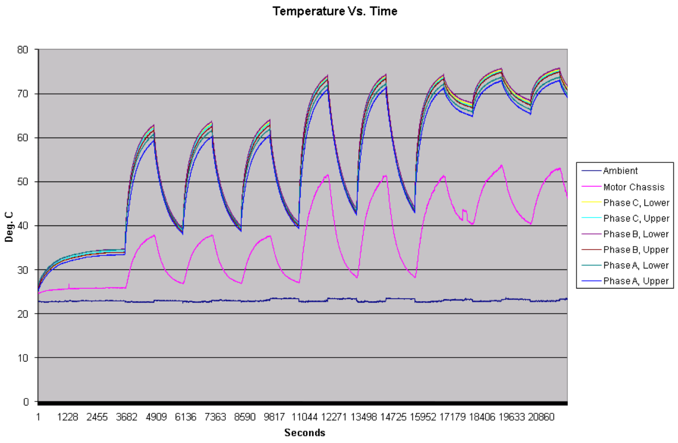


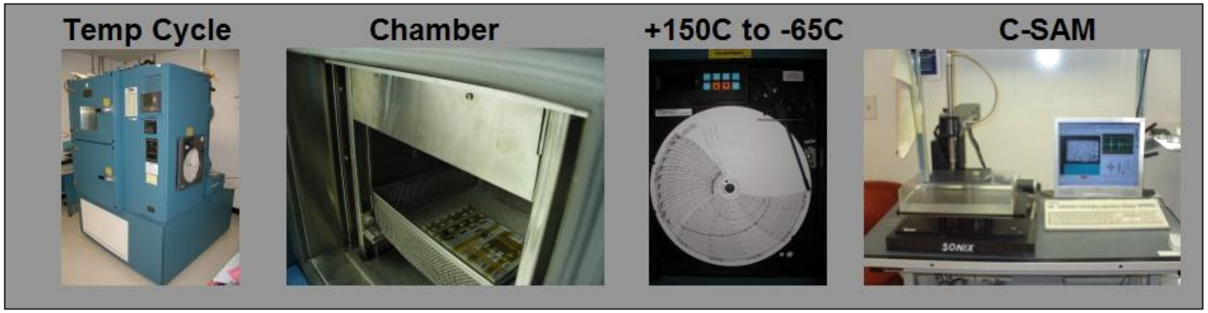




Real Life thermal cycling – Refine Results





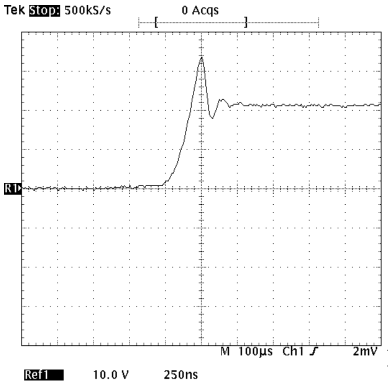


Estimation: Where Cannot Measure, Inference

- Given a known device stack up, Junction temperatures can be determined.

- Sensors placed on a Baseplate give an average thermal picture BUT they don't capture fast moving events.

- Transients cause significant degradation but are un-measurable except through inference.



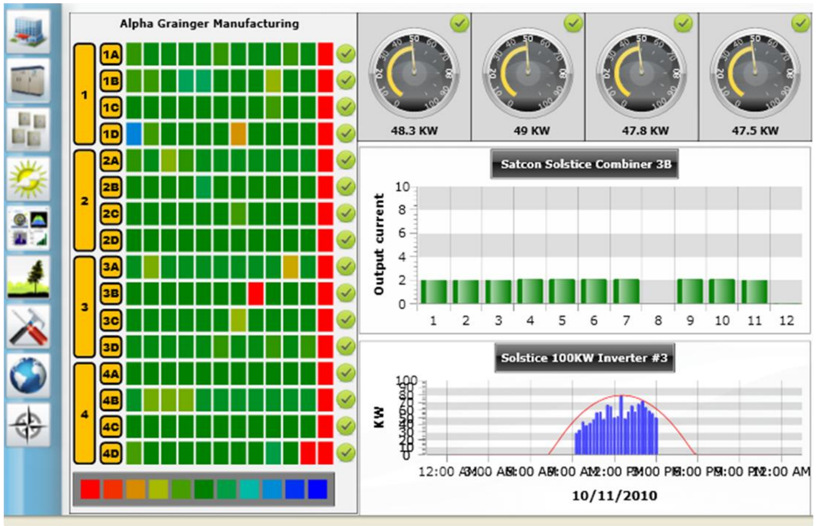
Mechanical Prognostics

- Simple indicators can help provide immense help in maintain product line.

- Contactors:
  - Total Number of cycles
  - Rapid Cycling
- System Usage Information
  - System uptime/cycles
  - System Thermal history

Goal- Comparative Results

- On a single system, comparative results are as effective as absolute results when it comes to PM and system failure analysis
- Given a large enough sample size and intelligent accelerated life testing; comparative results can morph into absolute results.



Environmental Issues- Wild card factors