Best Practice
for Achieving High Reliability With PV Systems

Questions to Consider

- How can a maturing industry benefit from application of reliability engineering?
- What are some of the best practices from other industries?
- What are some of the techniques / approaches that will likely be applicable in PV
- Can reliability engineering be cost-effective?
- Can service life predictions ever be made without enormous amounts of testing?

Achieving High Reliability is a Business Necessity

Achieving high Reliability requires **FOCUS**

1. Set well written Reliability requirements
2. Understand the entire system
3. Design in Reliability to products and processes
4. Properly use Accelerated Life Testing as part of overall test plan
5. Ensure supplier parts are reliable
6. Ensure manufacturing processes are free of defects that impact Reliability
7. Execute all tasks through a Best Practice Reliability Program Plan, aligned to Product Development Stages and staying within cost and timing requirements

Link to ALT

All of these Reliability tasks are necessary for successful Accelerated Life Testing

First - What is Reliability?

Reliability is the probability that an item will perform its intended function for a designated period of time without "failure" under specified conditions.

- Statistical measure
- Intended function
- Designated time
- Specified conditions
- Requires precise definition of failure

Traditional "Quality Control" assures that the product will work after assembly and as designed. Reliability looks at *how long* the product will work as designed.

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Always begin with a good definition of Reliability!

“Experience is the name everyone gives to their mistakes”

Oscar Wilde, Irish Playwright

At each stage of the presentation we’ll look at some of the major lessons learned from industry

Concept Stage

During the Concept Stage of Product Development it is important to develop and agree on Best Practice Reliability Requirements and get them properly incorporated into Technical specifications and flowed down (allocated) to subsystems and components. Properly specifying reliability at system and component levels can drive the right tasks both internally and with suppliers in order to achieve high system reliability.

Vital Few Reliability Tasks That Support *Concept Stage*

1. Generate System Conditions of Use Operating Profile
2. Develop System Level Reliability Requirements
3. Flow Down Reliability Requirements to Subsystems and Components
4. Generate a System Reliability Model (also called Reliability Block Diagram, RBD)
5. Identify "Reliability Critical" Components and Subsystems
6. Perform System FMEA

Concept Stage Task Example

Set Well Written Reliability Requirements

1. Reliability requirements are more than numbers
2. Good reliability requirements include certain key elements, such as
   a. Probability statements that are measurable by testing
   b. Linked to functional product requirements
   c. Clear statement of time
   d. Defined customer usage and operating environment
   e. Definition of product failure
3. They must be based on correct statistical models and included in technical specifications
4. One of the best ways to flow down system reliability to components is with a System Reliability Model (Reliability Block Diagram)

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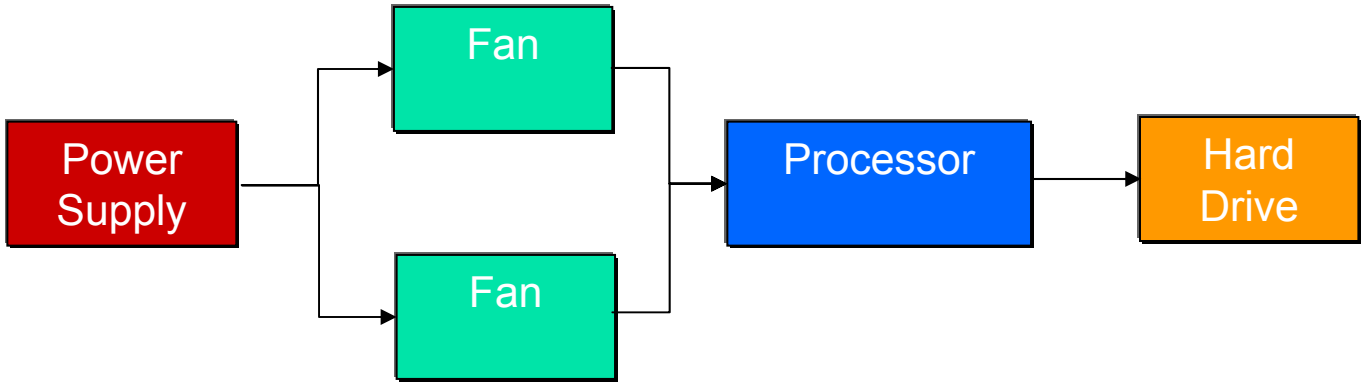
The information from Reliability requirements is a primary input to Accelerated Life Testing procedures

Concept Stage Task Example

Reliability Block Diagrams
What Are They?

1. A system is made up of subsystems and components that are called "Blocks".
2. Once the block's reliability characteristics have been determined, they can then be connected in a reliability-wise manner to create a Reliability Block Diagram for the system.
3. Each "Block" has its own Reliability distribution and RBD software can integrate into one system level distribution.



Concept Stage Task Example

Reliability Block Diagrams
How Are They Used?

There are 3 uses for RBDs with PV systems

1. Flowing down system Reliability requirements to subsystems and components so that the overall system meets it's objectives
2. Making system reliability predictions based on individual component life predictions and/or actual test results.
3. Showing areas of highest risk and where to get the most benefit from investing in reliability improvements

Link to ALT

The RBD can be used to set Reliability requirements that become input to ALT and to help with system Reliability predictions based on results from ALT

3 Lessons Learned
Concept Stage

1. Assuming that failures are exponentially distributed and using metrics such as MTBF without data that supports that assumption.
2. Treating all parts as equally important rather than doing risk assessment to identify the "vital few" that are critical for special handling.
3. Failing to properly define the environment and stresses that a product is expected to see as part of Reliability requirements, which can result in lack of robust design or improper test procedures.

Design Stage

During the Design Stage of Product Development, the vital few tools that support Design for Reliability will be identified for implementation. It is usually not possible to focus only on Reliability testing as the primary way to achieve reliability objectives. It is important to focus on achieving reliability in design, when there are greater opportunities from a cost and feasibility basis. Many of these methods and tools are variously called Robust Design or Design for Six Sigma.

Vital Few Reliability Tasks That Support *Design Stage*

1. Perform Design Margin Analysis
2. Perform Design and Process FMEAs
3. Address Root Cause of Known Reliability Problems
4. Develop and Use Product Design Guides
5. Incorporate Reliability Input Into Design Reviews
6. Identify and Execute Specific Robust Design Tasks, such as Design of Experiments (DOE), Physics of Failure Modeling and Highly Accelerated Life Testing (HALT)

Perform Design Margin Analysis

1. Review the risk assessment for the list of safety and performance critical areas
2. Best Practice is to provide design margin for safety and performance critical design parameters such that these issues do not show up within the system target life.
3. Establish and implement adequate design margins for each critical area. Many companies use a design margin of 2 as a "rule of thumb".

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ALT can verify that adequate design margins have been achieved thus ensuring that serious problems do not show up during product life

Perform Design FMEAs

1. Design FMEAs should begin as soon as subsystem concepts are identified and complete before design freeze.
2. For each FMEA, use best practice procedure
3. Require FMEA to meet FMEA Quality Objectives
4. Include FMEA status and recommendations as part of ongoing management reviews
5. FMEAs that are to be performed by suppliers for reliability critical parts must be reviewed and approved by project core team .

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Results of Design FMEAs are a key input to ALT procedures, helping to ensure that testing discovers all failure modes of concern

FMEA Quality Objectives

DESIGN IMPROVEMENTS *FMEA adequately drives Design Improvements*

HIGH RISK FAILURE MODES *FMEA addresses all high risk Failure Modes*

DVP&R PLAN *Comprehends failure modes from the Design FMEA*

INTERFACES *FMEA scope includes integration and interface failure modes*

LESSONS LEARNED *Warranty, Campaigns, Hardy Perennials included*

KCDS CONNECTION *The FMEA identifies appropriate KPC candidates*

TIMING *The FMEA is completed during the "Window of opportunity"*

TEAM *The right people participate as part of the FMEA team*

DOCUMENTATION *FMEA document is completely filled out "by the book"*

TIME USAGE *Effective & efficient use of time by FMEA Team*

3 Lessons Learned
Design Stage

1. Waiting for testing to discover design weaknesses; the result is too many problems that have to be fixed with program delays and cost overruns.
2. Using FMEA as a "check-off" rather than doing them properly and reducing risk to an acceptable level (reference FMEA Quality Objectives)
3. Inadequate Design Margins for safety or performance critical parameters, resulting in field problems due to product or process variation.

Assurance Stage

Improving the effectiveness of reliability assurance and testing will ensure your company develops and launches products with the highest possible system reliability. Properly analyzing test data will markedly increase the effectiveness of all forms of testing to improve product and process reliability. With Product Development times getting shorter and shorter it is essential to accelerate test methods. Doing this properly will not only yield more effective test results but will also facilitate buy in from customers.

Vital Few Reliability Tasks That Support *Assurance Stage*

1. Develop Improved Reliability Testing Methods, including ALT
2. Develop and Get Approved Reliability Test Plan
3. Conduct Reliability Component and Module Level Testing
4. Conduct System Reliability Growth Testing
5. Verify that Suppliers Meet Supplier Reliability Requirements
6. Implement Ongoing Management Reviews to include test failure data

Understand Different Types of Reliability Tests

Many types of testing can be used in a Reliability program

1. Qualitative Accelerated Life Testing quickly discovers product weaknesses
2. Quantitative Accelerated Life Testing determines product life using accelerated stresses
3. Reliability Growth Testing can be used to find and fix problems and estimate the eventual product reliability
4. Reliability Demonstration Testing is used to ensure product reliability is demonstrated
5. Etc.

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Accelerated Life Testing is one of many types of testing and it is important to understand when and where it is used

Assurance Stage Task Example

Develop Improved Reliability Testing Methods

Reliability test procedures should be well researched

1. With direct input from
   a. Technical Specifications
   b. System & Design FMEAs
   c. Field history knowledge transfer
   d. Conditions of use profiles, etc.
2. Based on correct statistical models
   a. Note: Be careful when assuming constant failure rate as this is often incorrect
3. Ideally there is no gap between test results and actual field results and testing reveals actual failure modes

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Use the earlier Reliability tasks to ensure that ALT procedures are correct

Perform Accelerated Life Testing

Accelerated Life Testing typically includes steps such as

1. Set up test regimens for both normal conditions of use and accelerated stresses, with the appropriate sample sizes.
   a. Remove non-damaging time and events.
   b. Increase stresses such as temperature, humidity and/or vibration, as appropriate.
2. Determine appropriate Life-Stress Models
3. Perform tests at both normal and higher stress profiles
4. Correlate results back to conditions of use operating profile.
5. Publish upgraded Accelerated Life Test protocol.

Link to ALT

The key to planning ALT is a thorough understanding of Life-Stress models and Reliability statistics

Ensure Supplier Parts are Reliable

1. Select suppliers who are capable of achieving reliability objectives
2. Ensure that reliability requirements are understood and agreed upon by suppliers.
3. For Reliability Critical parts:
   a. Require suppliers to demonstrate that reliability requirements are met
   b. Require project core team review and approve all supplier FMEAs and supplier testing
4. Best Practice is to require these approvals before parts are shipped

Link to ALT

Ideally system testing is performed with reliable components, therefore it is important that suppliers properly use ALT

3 Lessons Learned
Assurance Stage

1. Not modifying test procedures based on expected environments, conditions of use, field histories or FMEAs.
2. Doing system testing with parts that have not been reliability tested by suppliers, which prevents system testing from discovering interface and integration problems.
3. Lack of understanding of Life-Stress models before doing Accelerated Life Testing.

Manufacturing and Launch Stage

Well done Design for Reliability tasks still need to be supported by Manufacturing and Field Support tasks to ensure that the inherent design reliability is not degraded or unstable. The following are minimum tasks that need to be done to support Manufacturing Reliability.

Vital Few Reliability Tasks That Support *Manufacturing and Field Support Stage*

1. Develop Preventative Maintenance Plan (advanced application would be Reliability Centered Maintenance)
2. Develop Manufacturing Control Strategies
3. Develop Screening & Monitoring Plans
4. Develop and Implement Field Test Plan
5. Verify All Requirements Met Before Launch
6. Document Field Lessons Learned

Ensure Manufacturing Reliability

Manufacturing processes can be improved and controlled to ensure maximum reliability

1. Use Process FMEA and Process Control Plans
   a. Identify specific reliability Key Characteristics and control them through a manufacturing control plan
2. identify appropriate stress tests to screen or monitor component or batch fitness, as needed
   a. Environmental Stress Screening (ESS)
   b. Highly Accelerated Stress Screening (HASS)

Link to ALT

Manufacturing processes can reduce inherent design Reliability, therefore it is important to implement proper manufacturing controls and screening

3 Lessons Learned
Manufacturing and Launch Stage

1. Assuming that the inherent design reliability demonstrated during testing will be equivalent to field reliability, and not understanding how manufacturing processes can degrade design reliability.
2. Not taking advantage of preventative or predictive maintenance methods.
3. Using costly 100% screening when other techniques may suffice.

Program Management

The objective of the Reliability Program Plan is to focus on the significant few tasks that are most effective and applicable to the business of providing highly reliable equipment. The plan specifically avoids a long list of tasks that may exceed company resources and capabilities. In other words, the effort is to stretch and do the right things to achieve high reliability, but to avoid the unrealistic goal of too many tasks requiring too many resources.

Pull It All Together With a **Reliability Program Plan**

Develop and execute a comprehensive Reliability Program Plan

1. Pulls together all necessary resources and tasks
   a. Uses the "Vital Few" Best Practice Methods
   b. Addresses high risk areas
   c. Closes gaps
   d. Strengthens organizational shortfalls
   e. Detailed: What, who, when, where, how
2. Must be approved by management and supported through regular reviews

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Execution of many Reliability tasks are necessary for successful Accelerated Life Testing

Heroes

"Heard at a seminar. One gets a good rating for fighting a fire. The result is visible; can be quantified. If you do it right the first time, you are invisible. You satisfied the requirements. That is your job. Mess it up, and correct it later, you become a hero."

W. Edwards Deming

Out of the Crisis

Management Role is to create the environment that encourages and supports the correct behaviors to prevent problems and achieve world class reliability.

3 Lessons Learned
Program Management

1. Lack of management support for reliability tasks, including staffing, software and training.
2. Failure to write and get approved a Best Practice Reliability Program Plan.
3. Not executing the Reliability Plan with regular oversight, debugs and support.

Biography – Carl Carlson (page 1 of 2)

- Currently Senior Consultant and instructor in areas of FMEA, reliability program planning and other reliability engineering and management disciplines, supporting ReliaSoft clients.
- 20 years experience in reliability engineering and management positions at General Motors, with responsibilities including
  - Senior Manager for the Advanced Reliability Group.
  - Design and Process FMEAs for North American operations
  - Developing and implementing advanced reliability methods to achieve/demonstrate reliability requirements
  - Managing teams of reliability engineers.
- Previous to General Motors, worked as a Research and Development Engineer for Litton Systems, Inertial Navigation Division.
- Co-chaired the cross-industry team to develop the Society of Automotive Engineers (SAE) J1739 for Design and Process FMEA

Biography – Carl Carlson (page 2 of 2)

- Participated in the development of the SAE JA 1000/1 *Reliability Program Standard Implementation Guide*.
- Chaired technical sessions for the Reliability Track of the Annual SAE Reliability, Maintainability, Supportability and Logistics (RMSL) Symposium
- Member of the Reliability and Maintainability Symposium (RAMS) Advisory Board for 4 years; received Best Tutorial Award
- Vice Chair for the SAE's G-11 Reliability Division for 5 years
- B.S. in Mechanical Engineering from the University of Michigan
- Completed the Reliability Engineering sequence from the University of Maryland's Masters in Reliability Engineering program.
- Completed more than two dozen short courses in Quality & Reliability tools
- ASQ Certified Reliability Engineer and Senior Member of ASQ