Power Electronics Reliability Analysis

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NNSA National Nuclear Security Administration

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Technologies & Customers

- Complex Systems Modeling & Simulation
- Life Cycle & Total Ownership Costs Analyses
- Design for Reliability/Maintainability
- Prognostics & Health Management (PHM)
- Integrated Logistics Support
- Technology Management Optimization
- Asset Acquisition & Mission Planning
- Risk Assessment & Risk Management

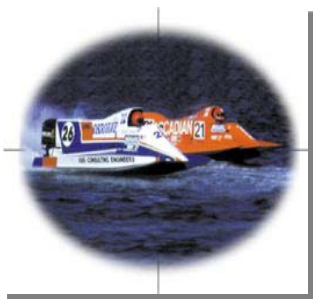
Technologies Support Broad Customer Base

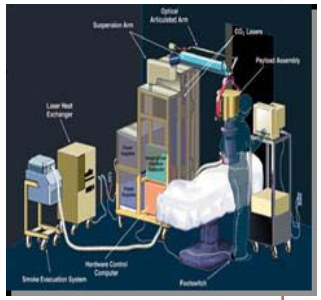

Defense


Machine Tool


Wind Energy

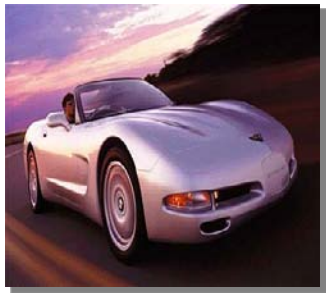

Semiconductors


Boating


Health Care


Petroleum


Aviation


Automotive


Nuclear Power


Coal-Fired Power


Power Electronics

Tools & Technologies Validated Through Broad Use

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Project Goals

- **Better understand the current and future reliability of power electronics:**
  - **Use a rigorous process to create a statistical model to characterize the reliability of power electronics**
  - **Guide reliability improvement efforts, including component, software, and operational improvements**
  - **Explore opportunities for Prognostics and Health Management (PHM)**

Will (initially) focus on equipment that contains high-powered semiconductor switches

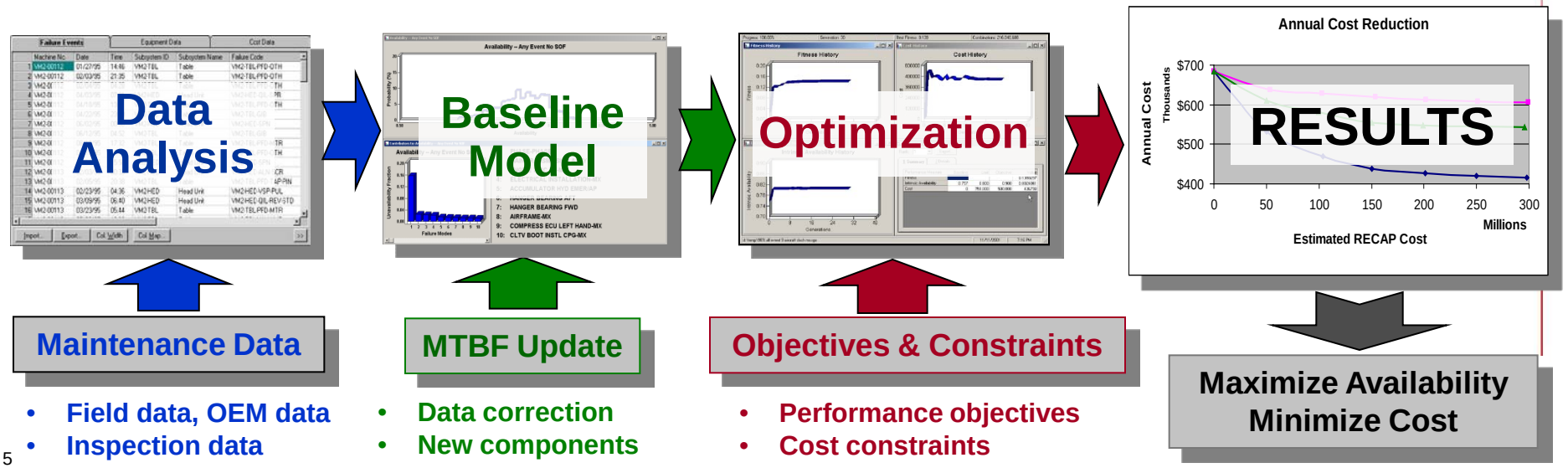
Project Accomplishments

- **Adapted Sandia's reliability analysis tools and processes to power electronics**
  - **Roll up component reliability to a system level**
- **Applied the process to the Solid-State Current Limiter (SSCL) from Silicon Power Corporation (SPCO)**
  - **Created a baseline model using SPCO data**
  - **Updated the baseline model using SPCO feedback**
  - **Performed reliability and cost optimizations**
  - **Identified possible candidates for PHM**

Reliability Analysis Process

Analysis Approach

- **Data Analysis**
  - **Investigate existing failure & maintenance data sources**
- **System Baseline (“as is”) Model**
  - **Populate with existing failure & maintenance data**
  - **Analyze & compare against current system performance**
- **Optimize Plan**
  - **Predict impacts of changes and modifications**
  - **Evaluate cost and availability items identified by the baseline model**

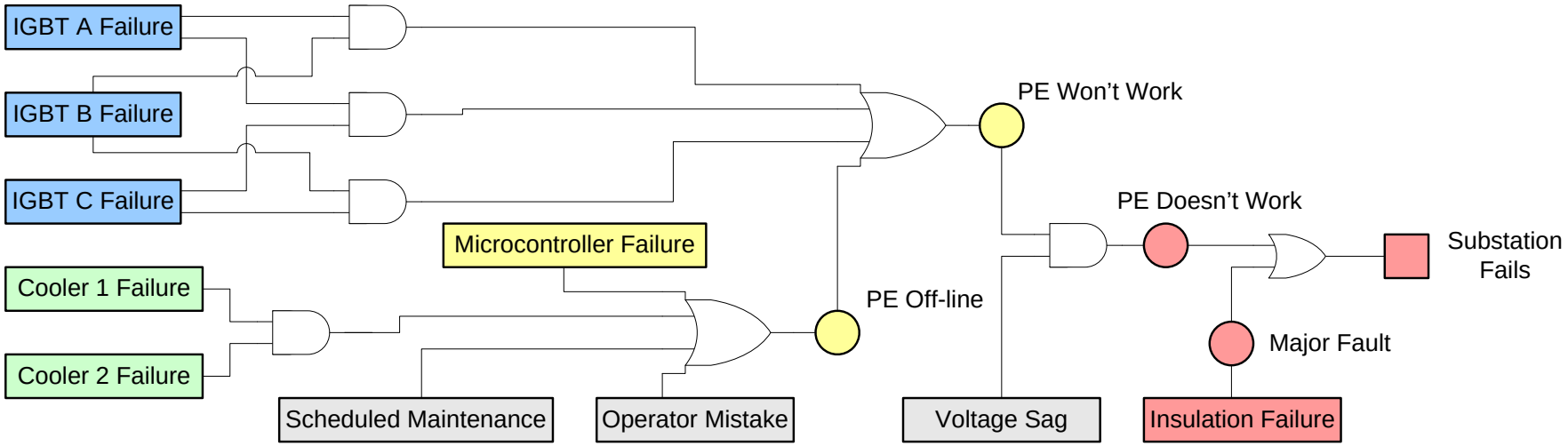


Unique Challenges of Power Electronics

- Establishing a System Boundary
- Deciding on the Failure of Interest; For example, the device:
  - Doesn't alleviate the targeted power system problem
  - Is off-line
  - Becomes the source of a problem
- 24/7 Operation (reliability more important than availability)
- Component Failure Types
  - Random failures
  - External conditions (weather, usage, power events)
  - Human error
- Getting the Data
  - Very application specific: need utility input
  - Sometimes little historical data, especially for novel devices

Illustrative Example: Solid-State SubStation Shunt Sag Suppressor (S7)

- Statistical model is a failure tree (usually called a fault tree)
- Failures modeled as all-or-nothing events
- Failure rates or Mean Time Between Failures (MTBFs) are given at the leaves
- Incorporates downtime and event costs
- Compute overall MTBF (reliability), availability, maintenance cost, etc.



- Also, usually interested in the statistics of intermediate events (circles)

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Reliability Input Data

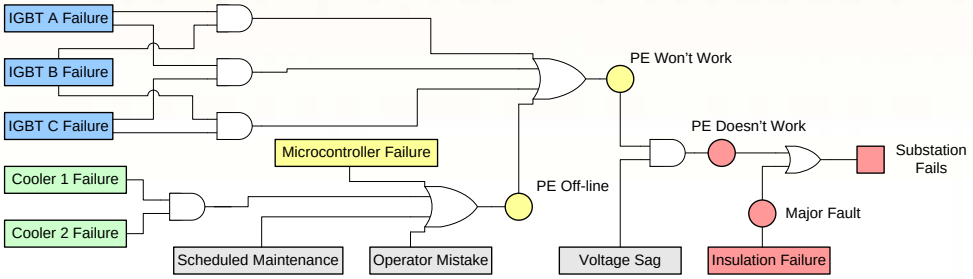
- Product Design, Function, and Principles of Operation
- Concepts of Operations and Maintenance
- Specifications and Application Notes
- Failure Modes or Events of Concern (e.g., scheduled maintenance)
- Component Data
  - Field Data: individual failure/downtime events with costs
  - Summary Data: summary of possible failure modes with costs
- Potential Sources of Component Data
  - Field Maintenance Data
  - Laboratory Testing
  - FMECA (Failure Modes, Effects, and Criticality Analysis)
  - Expert Opinion
  - Warranty Claims
  - Quality Control Information
  - Similar Devices
  - …

Reliability Optimization Modeling

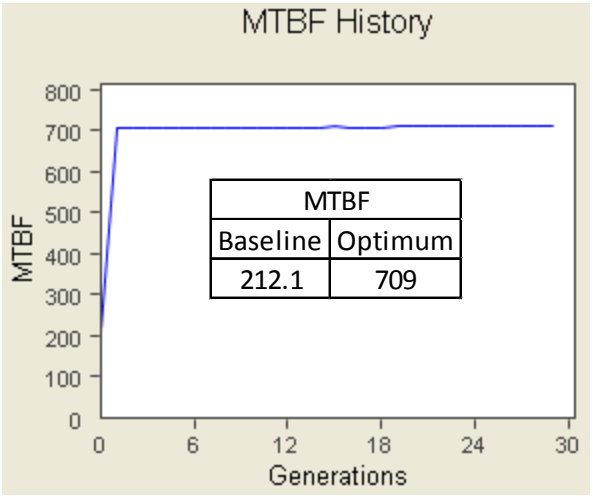
- **Optimization is a unique capability of this methodology**
- **Objectives**
  - **E.g., increase availability, increase MTBFs, reduce costs, reduce size, reduce power losses**
- **Options**
  - **E.g., redesign, technology insertion, improve component reliability**
- **Constraints**
  - **E.g., cost/budget, volume/weight, time**
- **Costs to Whom?—optimality depends on the answer**
  - **Vendor**
    - Cost of design, fabrication, sales losses, warranty claims
  - **Utility**
    - Cost of parts, labor, loss of revenue, liability, fines, increased regulation
  - **Society**
    - Loss of business, spoilage, safety, security, public confidence

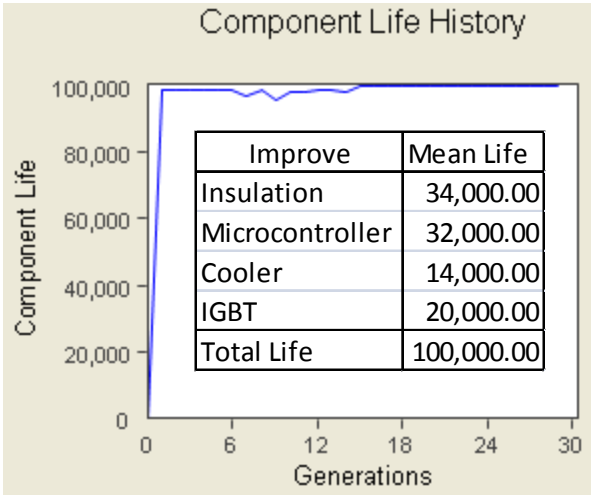
Example: S7 Optimization

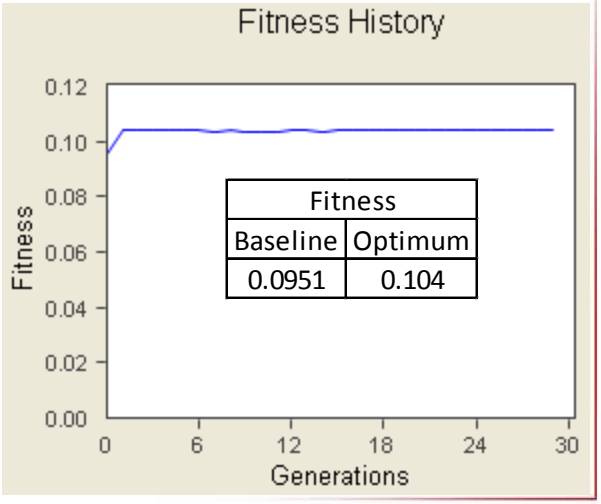
- **Objective is to increase the MTBF of the S7**
- **Options are to increase MTBFs of components starting from 1,000 hours each (with down-times fixed at 1,000 hours each)**



- **Constraint is a total component life of 100,000 hours for the four component types denoted by the colored leaves**
- **Run Genetic Algorithm (GA) to increase "fitness":**







- **Maximum MTBF is limited by the external factor leaves (gray)**

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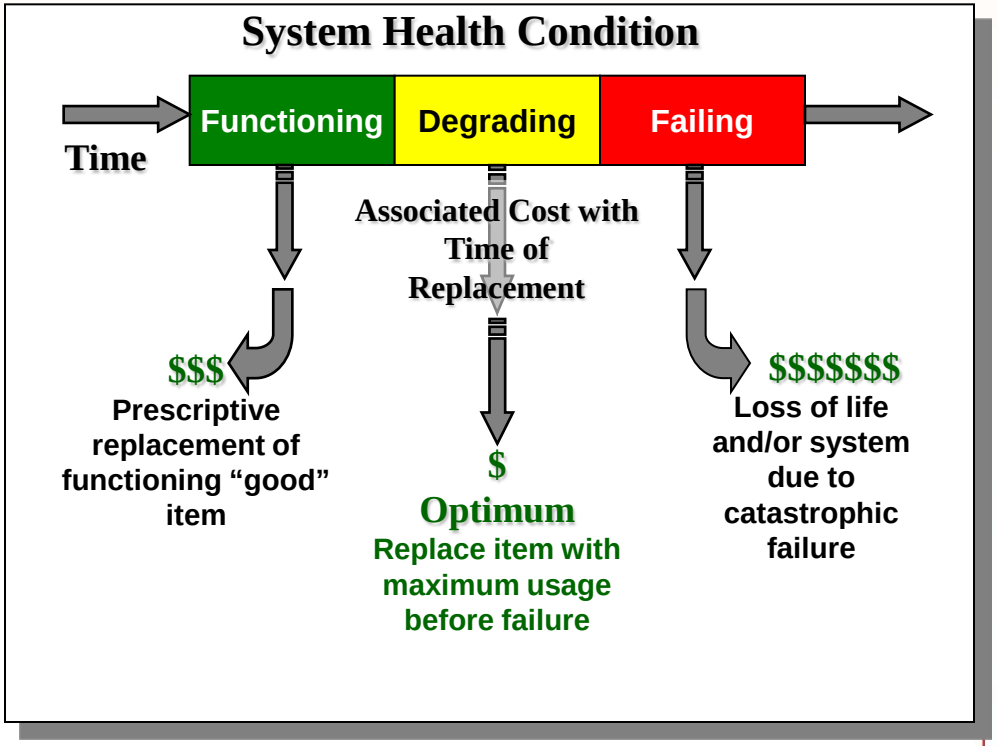
The Future of Power Electronics Reliability and Maintenance

- Run to Failure (Unscheduled Maintenance)
- Schedule-Based Maintenance
  - e.g., once per year
- Reliability-Centered Maintenance (RCM)
- Condition Monitoring (CM)
  - e.g., leakage current has changed
  - sometimes hear the term “health monitoring”
- Condition-Based Maintenance (CBM)
- Prognostics
  - predict time-to-failure or remaining useful life
- Health Management (HM)
  - decide how to schedule maintenance in the context of operations
- CBM+, an approximate synonym with PHM
- Enterprise Health Management (EHM)

Prognostics & Health Management (PHM)

1. **Obtain component's historical and sensor data**
2. **Characterize, interpret, and trend the data to predict future failures**
3. **Combine failure prediction with operations and maintenance schedules to provide *real-time* notification of upcoming maintenance events**



Optimize Operations & Maintenance Actions to Obtain Higher Availability at a Lower Cost

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Data is the Key to Reliability Improvement

- **Data is required to do basic reliability analysis through condition monitoring to advanced PHM**
- **Recommend that vendors of power electronics record and provide data wherever practicable (e.g., through SCADA)**
  - **Operating state, device cycle counts, external event statistics, part failures, temperatures, voltages, currents, etc. (all as functions of time or at least as histograms)**
  - **Maintain a reporting system for data from utilities for continuous improvement**
- **Recommend that utilities warehouse detailed maintenance data along with any data the vendors provide**
  - **Exactly what failed and when, type of failure or event, downtime, part costs, labor cost, other costs**

Questions?

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