



Energy 2003:

What? Me vulnerable?

Highly Reliable Power Systems: Myth or Legend?

August 18, 2003

Wyndham Palace Resort and Spa

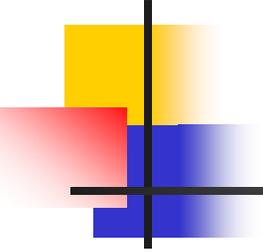
Lake Buena Vista, Florida

Stephen Fairfax
President, MTechnology, Inc.

Copyright © 2003 MTechnology, Inc.

MTechnology, Inc. 2 Central Street Saxonville, MA 01701

(508) 778-6260; fax (508) 788-6233 fairfax@mtechnology.net



Outline

Introduction

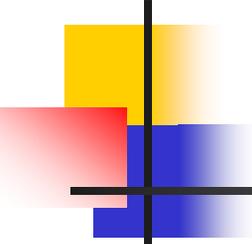
Electric power reliability

Probabilistic Risk Assessment

Case Studies

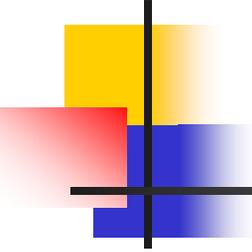


Power system engineering for the 21st Century.



Introduction to MTechnology

- Consulting Engineers
- Founded 1996
- Applied Probabilistic Risk Assessment:
 - Enterprise Data Centers
 - Hospitals, Bio-Medical Research Facilities
 - Distributed Generation for Reliability
 - First National Bank of Omaha
 - Harvard Medical School / Merck & Co.
 - Fidelity (in progress)
 - OEMs, A&E firms, end users

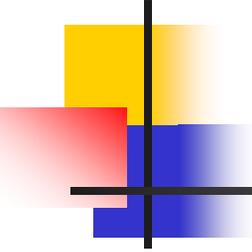


Electric Power Reliability

- Reliability: The probability that a system or component will operate for a given time
 - Can be function of time, events, environment
 - Reliability tends towards 0 (all things fail)
 - $R = 1 - P_f$ (Probability of Failure)
- What constitutes a power failure?
 - Most electric utilities: no power for >1 minute
 - Most computers: no power for > 0.08 seconds
 - Heart/lung machine, ventilator: ?

Definitions of Power Outage

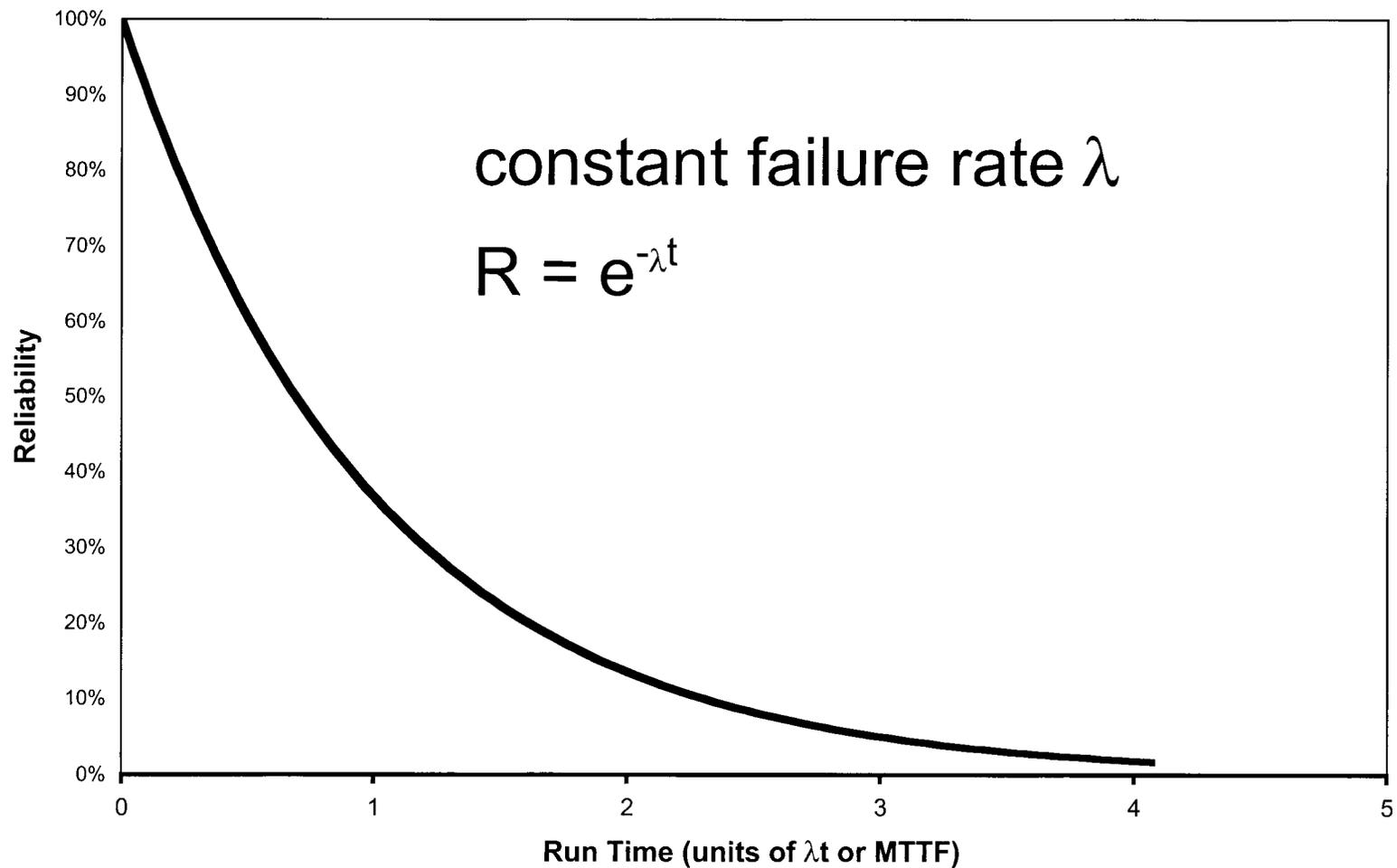
- Computer Power:
 - At device level: sub-nanosecond
 - At system level: 1/2 cycle, 0.008 seconds
 - CBEMA and ANSI/IEEE C62.41-1991
- Utility power
 - Most utilities don't log interruptions <1 minute,
 - some start at 5 minutes
 - Many don't count outages in bad storms in published availability figures
 - Routine switch and fault-clearing cause 1/2 to 10-cycle upsets, reclosers deliberately interrupt for seconds



Electric Power Reliability

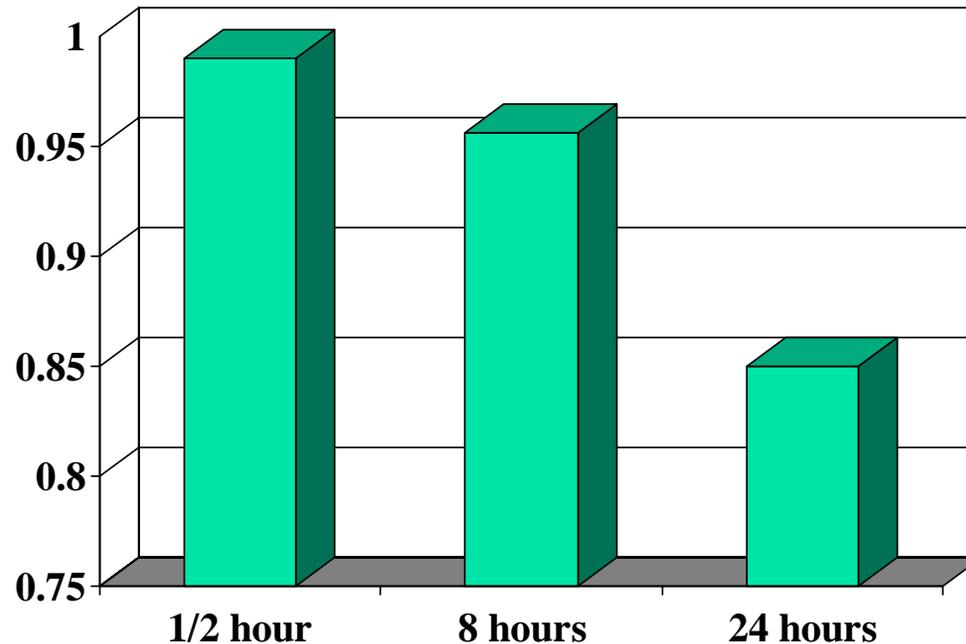
- Reliability varies widely
 - Electric utility to utility
 - Within one utility territory
 - From year to year at one location
- “Good” utility reliability
 - 2-3 outages > 1 minute, total ~ 60 minutes/year
 - 12-20 momentary outages < 1 minute / year
 - 30-40 sags, surges, other “power quality events”

Chart of Reliability(t)

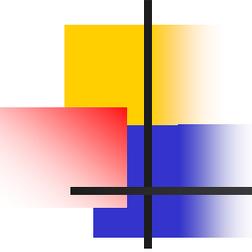


Reliability Example

Reliability (Start, Load and Run) of Emergency Diesel Generators

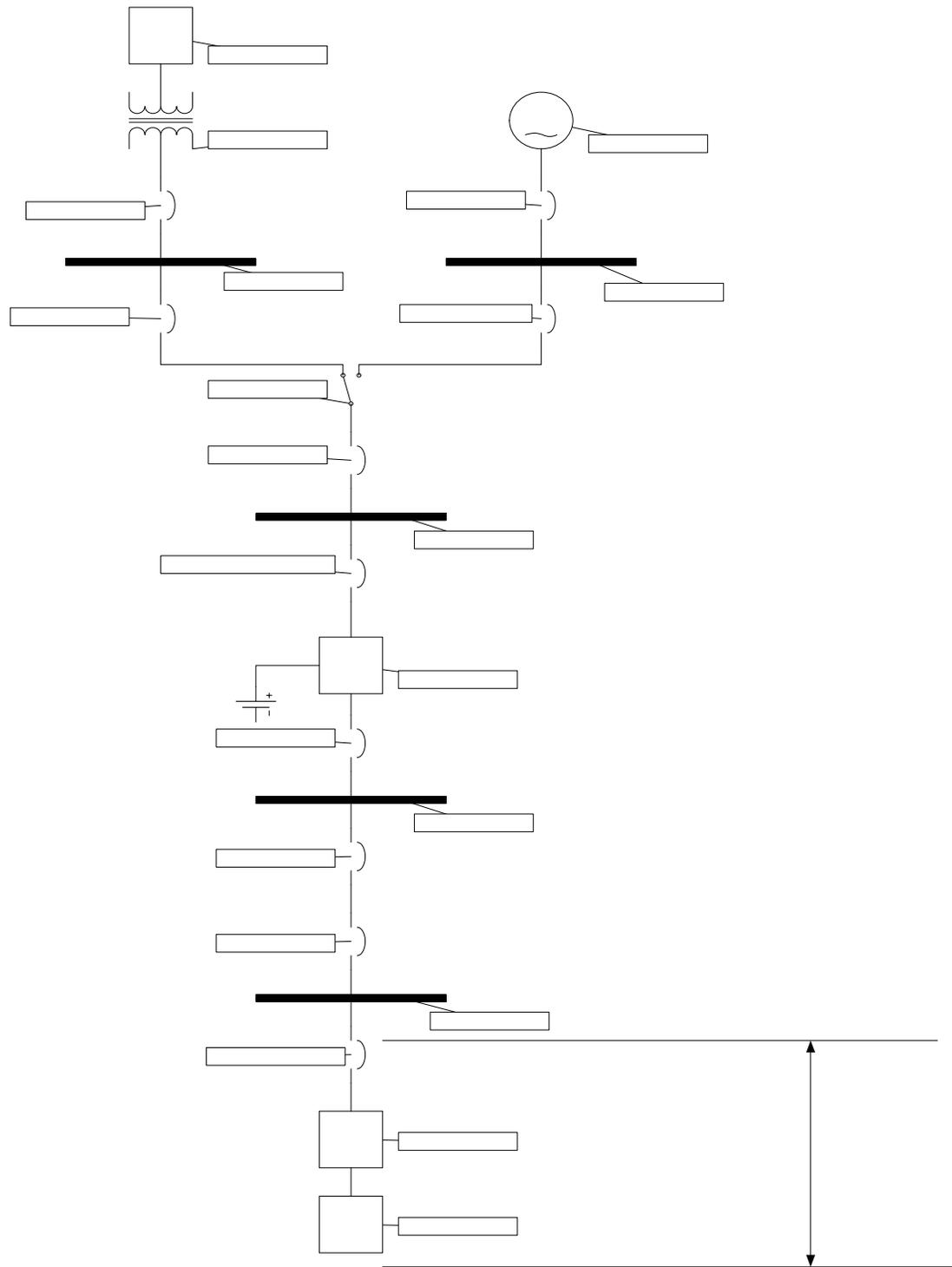


Emergency Diesel Engine Generator Power System Reliability 1987-1993 Grant, G.M., et al., Idaho National Engineering Laboratory, INEL-95/0035, February 1996



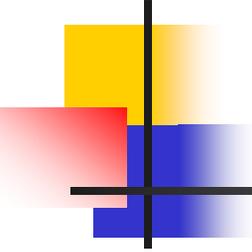
“Premium Power” Protection

- Utility (sometimes 2 feeders)
- Standby diesel engine/generator(s)
- Uninterruptible Power Supply (UPS)
- Battery bank rated 10-40 minutes
- Automatic Transfer Switch (ATS)
- Fuel
- People to operate, maintain, repair



MAIN-B

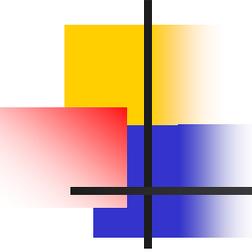
SERV-BKR



Summary of PRA Analysis of Example Power System

Mission Duration	1 Year	5 Years	10 Years
Probability of Failure	9.6%	41%	66%

Failure = Loss of Power for > 0.08 seconds



Probabilistic Risk Assessment

- Origins in understanding rocket failures
- Developed by military, aerospace, civilian nuclear power
- Constructs mathematical models of complex systems
 - Use knowledge of component failures to predict system failures
 - Can be applied to systems under design, compare proposed upgrades
 - Extended to risk-informed maintenance, effects of management policies, human error

Characteristics of PRA

- Basis in science, engineering, fact. Defensible. Falsifiable.
- Demands scrutiny of the entire life-cycle
 - design (logic, math, knowledge, review)
 - manufacture
 - operation
 - maintenance and repair
 - data gathering, review, publication
- Extreme care with definitions, assumptions, language
- Constant pursuit of root causes, common-cause failures, and relevant data

Why PRA?

- Difficult, dangerous to determine reliability by measuring failures
 - Highly reliable systems rarely fail
 - Results of failure increasingly unacceptable
- Evaluation of new and existing systems, alternatives
 - Risk/reward ratios, component sensitivity
 - Unintended interactions in complex systems
- Science-based approach avoids pitfalls
 - Answers appeals to anecdote, experience
 - Avoids excessive reliance on “worst-case” scenarios
- Human Reliability Analysis (HRA) evaluates operability, quantifies risk of human error, estimates effects of improved training, aids, design
- Provides rich, quantitative, useful results
 - Component contributions to risk
 - Confidence limits, best and worst cases
 - Effects of human error, aging equipment, test policy
 - Graphical aids to understanding complex systems

Why PRA?

- 7x24 Industry standard practice is to characterize systems by redundancy:
 $N, N+1, 2N, 2N+2$
- Redundancy provides no guidance as to relative contribution of each component to overall risk
- Impossible to allocate limited resources optimally, rationally, or defensibly
- PRA quantifies risks, focuses capital and operating resources where ROI is greatest

Typical Data Center Failure Profile

- Based on recent data center PRA w/1200 kW critical load, dual-cord equipment
- Fraction of failures caused by:
 - ATS, sensors, cables: 30%
 - Circuit breakers: 40%
 - UPS Failure: 20%
 - Balance of System: 10%
- Probability of failure exceeds 70% in 20 years

PRA is an Engineering Tool

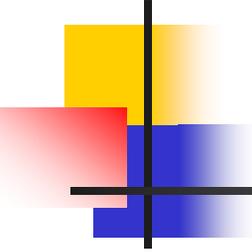
- Quantifies probability of failure, availability
- Identifies most critical systems
- Estimates improvement possible via
 - Additional equipment e.g. $N+1$ vs $2N$
 - Premium components
 - Targeted maintenance/surveillance

PRA is a Management Tool

- Provides guidance for review, decisions
- Quantifies risk (probability & consequences)
- Quantitative confidence limits/worst-case results
- Measures effectiveness of proposed solutions
- Focuses attention, resources on critical areas
- Guidance for least-harmful reductions, cuts
- Graphical aids for presentation of complex relationships

PRA Adds Value

- Choosing the best design is always less expensive than changing installed systems.
- Reduce redundancy where it contributes least: no need for rigid $2N$ vs $N+1$ rule.
- Focus commissioning and maintenance activities where they do the most good and least harm.
- Place facility decisions on same quantitative base as other business process decisions.
- Powerful tool for communication to management, stakeholders, designers, and operators.



Case Studies

- Effects of Power Failure
 - Integrated Circuit factory
 - Biomedical research facility
 - Hospitals
- PRA results
 - First National Bank of Omaha
 - Harvard Medical School/Merck & Co.

Consequences of Electric Power Failure

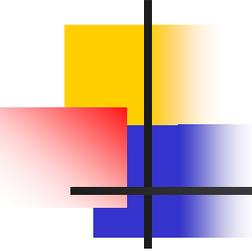
- Integrated Circuit Fabrication Facility
 - Chandler, AZ
 - Utility switches capacitor bank
 - standard practice on transmission system
 - Facility power protection apparatus failed
 - 4-second outage on 1/2 of plant systems
 - 34 hours to resume production

Consequences of Electric Power Failure

- Columbia Presbyterian Medical Center
 - 19-hour Manhattan blackout summer 1999
 - 3 of 4 diesels started, all failed in less than 4 hours
 - Freezers of irreplaceable tissue samples, research materials, 20-year collections lost
 - Short outages reset all computers, computerized instruments with unpredictable effects

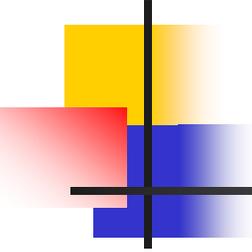
Consequences of Electric Power Failure

- Houston Hospitals, Medical Center, Medical School
 - June 5-12 2001: Tropical Storm Allison: torrential rains, flooding, \$2+ billion damages
 - Memorial Hermann Hospital lost all power, evacuated 540 patients, 4 died
 - Generators moved from basement after previous flood
 - Transfer switches, controls remain in basement
 - June 14: emergency rooms remain closed at Methodist Hospital and St. Luke's Episcopal Hospital, lack of power
 - Texas Medical Center, Baylor College of Medicine
 - 30,000 genetically engineered animals lost
 - Years of research data, cultures, specimens lost due to loss of refrigeration power



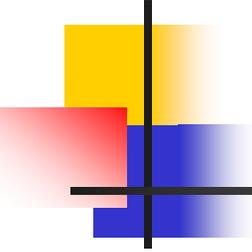
First National Bank of Omaha

- Major credit card processing center
 - Real-time processing for VISA
- Multiple failures of standard UPS systems
 - \$ millions in damages to FBNO, customers
- Retained MTech for evaluation of on-site distributed generation proposal



First National Bank of Omaha

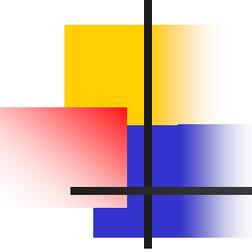
- Unique contract provisions specified minimum 99.999% availability
 - Equivalent to 10% probability of failure in 20 year operating life
- Primary power: 4 fuel cells, any 2 of 4
- Backup 1: 2 diesel generators
- Backup 2: 2 utility feeds
- 2 flywheel batteries, 2 rotary UPS



First National Bank of Omaha

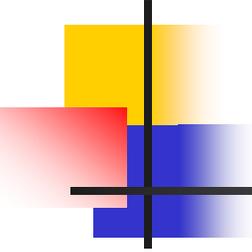
■ Results

- PRA calculated availability ~ 99.9999%
 - Unavailability $< 10^{-6}$
- Identified most sensitive component
 - Not obvious
 - On-site spare decreases risk of failure 10x
- Quantified risk/reward of operating policies
- Operating since May 1999
 - All components have failed, no system failures



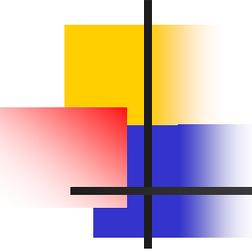
Harvard Medical School Merck & Co.

- Side-by-side 400,000 sq. ft. biomedical research facilities under construction in Boston's Longwood Medical Area
- Massachusetts Renewable Energy Trust awarded planning grant
- MTechnology performed economic, feasibility, PRA analysis of proposed 1 MW fuel-cell based facility
- Unique opportunity for public, private, and academic collaboration



HMS/Merck results

- 2 fixed-price proposals by qualified vendors
- Each suggested at least 2 alternatives
- All alternatives utilized fuel cells
- Best case: <1% risk of failure in 10 years
- Worst case: >90% risk of failure
- Same fuel cells, different architecture
- High site-specific costs, reduced subsidies
- Construction not likely



Summary

- Review of electric power reliability
- Benefits of PRA
 - Rational resource allocation
 - Informed risk management
- Case studies
 - Effects of power outages
 - \$ millions in damages, injuries, deaths
 - FBNO and HMS/Merck distributed generation