Improvements in DC Power System Availability and Reliability

Sept.26, 2006

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C&D TECHNOLOGIES® POWER SYSTEMS

Availability vs. Reliability

- **Reliability: "the probability that a device will perform its intended function." (1)**

  $$R(t)_{t \Rightarrow \infty} = 0$$

- **Availability: "the probability that a device is successful at time t." (2)**

  $$A(t)_{t \Rightarrow \infty} = C,\ C > 0$$

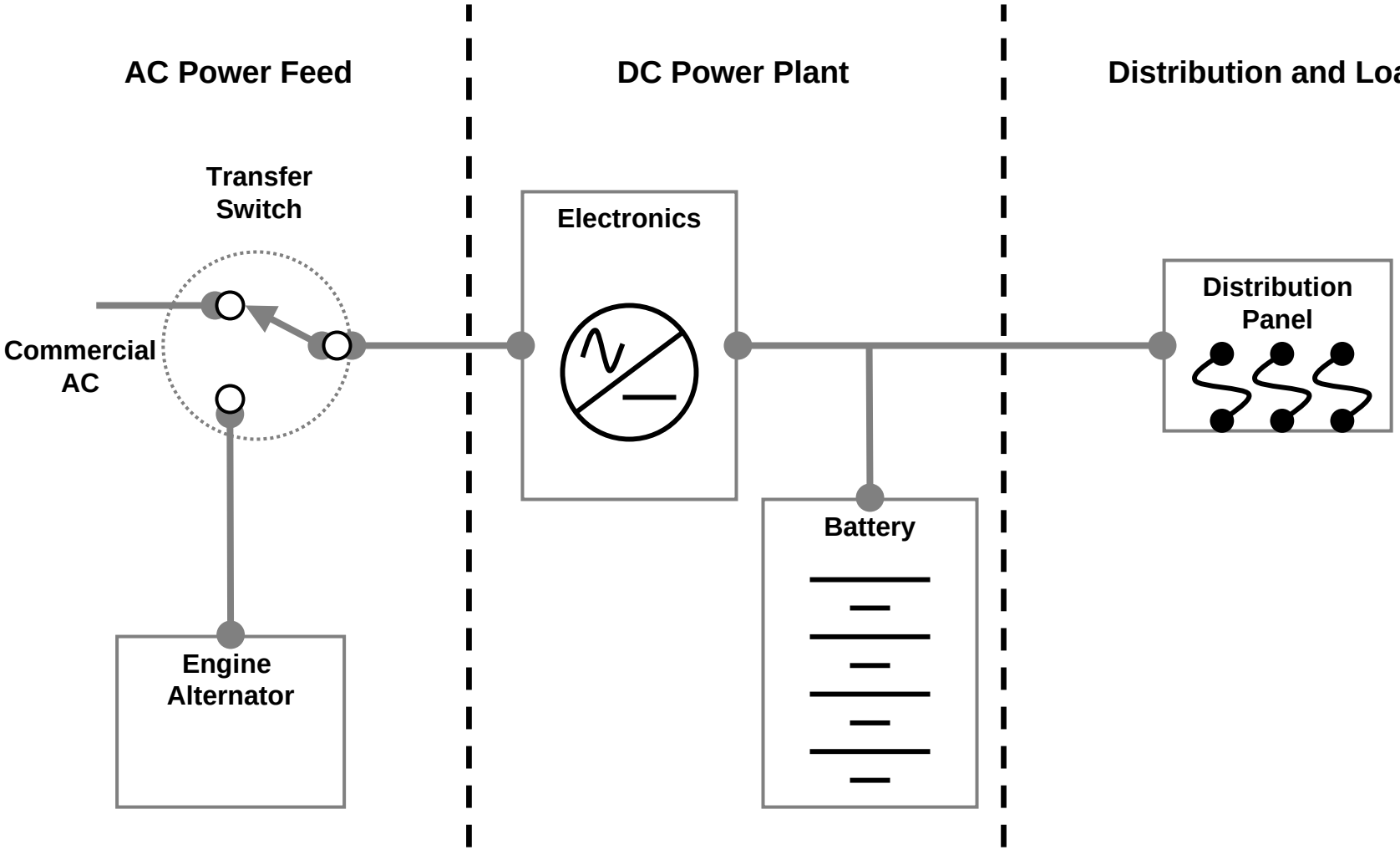
1. Goble, W, "*Control System Safety Evaluation and Reliability*," pp 60, The Instrumentation, Systems, and Automation Society, North Carolina, 1998.
2. Goble, W, "*Control System Safety Evaluation and Reliability*," pp 61.

Availability

- **Availability is a function of:**
  - **Original equipment**
  - **Operating conditions**
  - **Maintenance practices**
  - **Time to repair**

- **The availability of a DC power system can be maximized by analyzing the entire system.**

System Elements

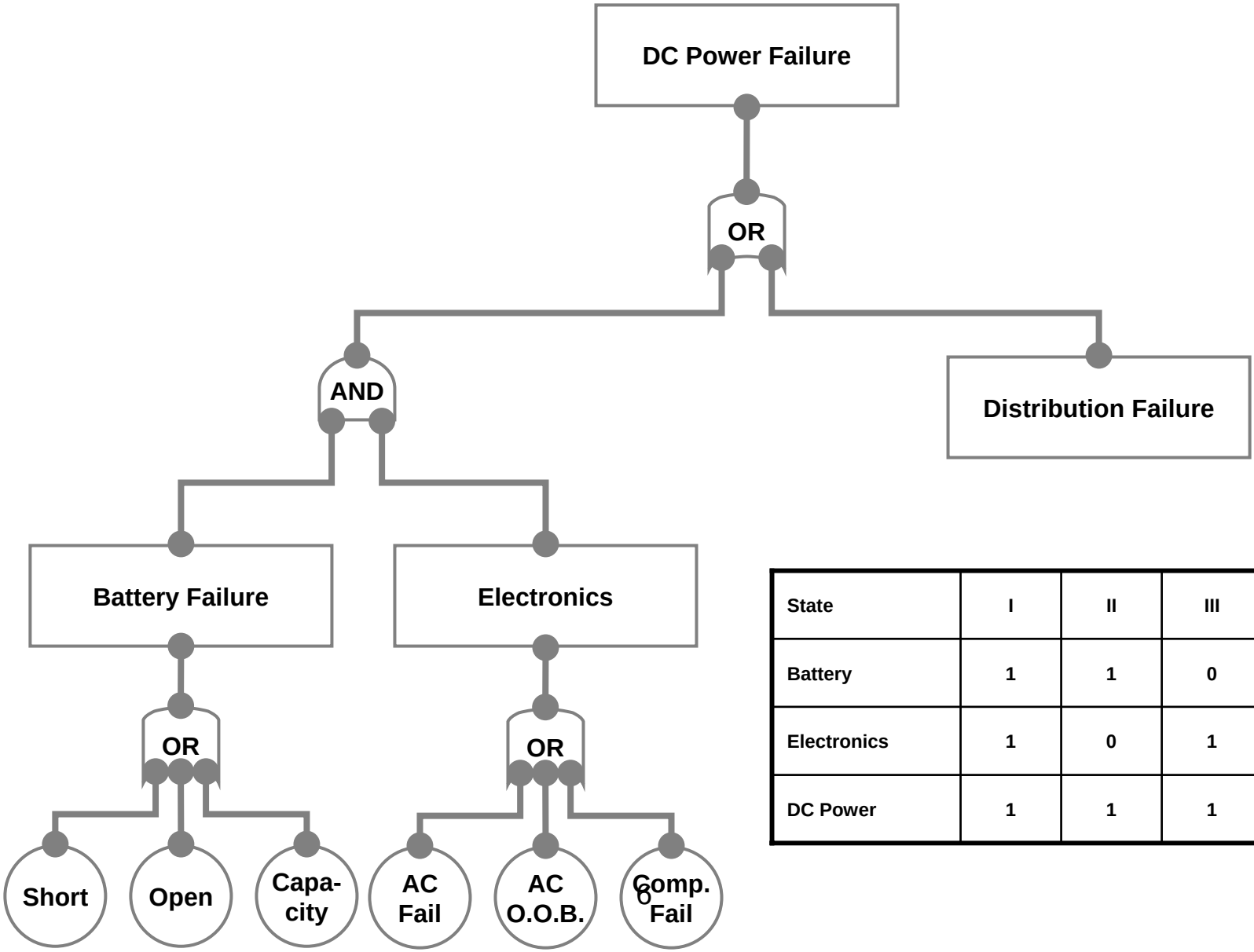


Failure by Area and Equipment Type [3]

AC Power Feed		**DC Plant**		**Distribution and Load**	
Commercial power	70	Battery	63	DC Breakers	63
Engine / Alternator	23	Rectifier	32	DC Fuses	60
AC Fuse / Breaker	20	DC / DC Converter	21		
AC Transfer Switch	10	Alarms	9		
Sub total	123		125		123
Total					**371**
Percentage by Area	**33.2%**		**33.6%**		**33.2%**

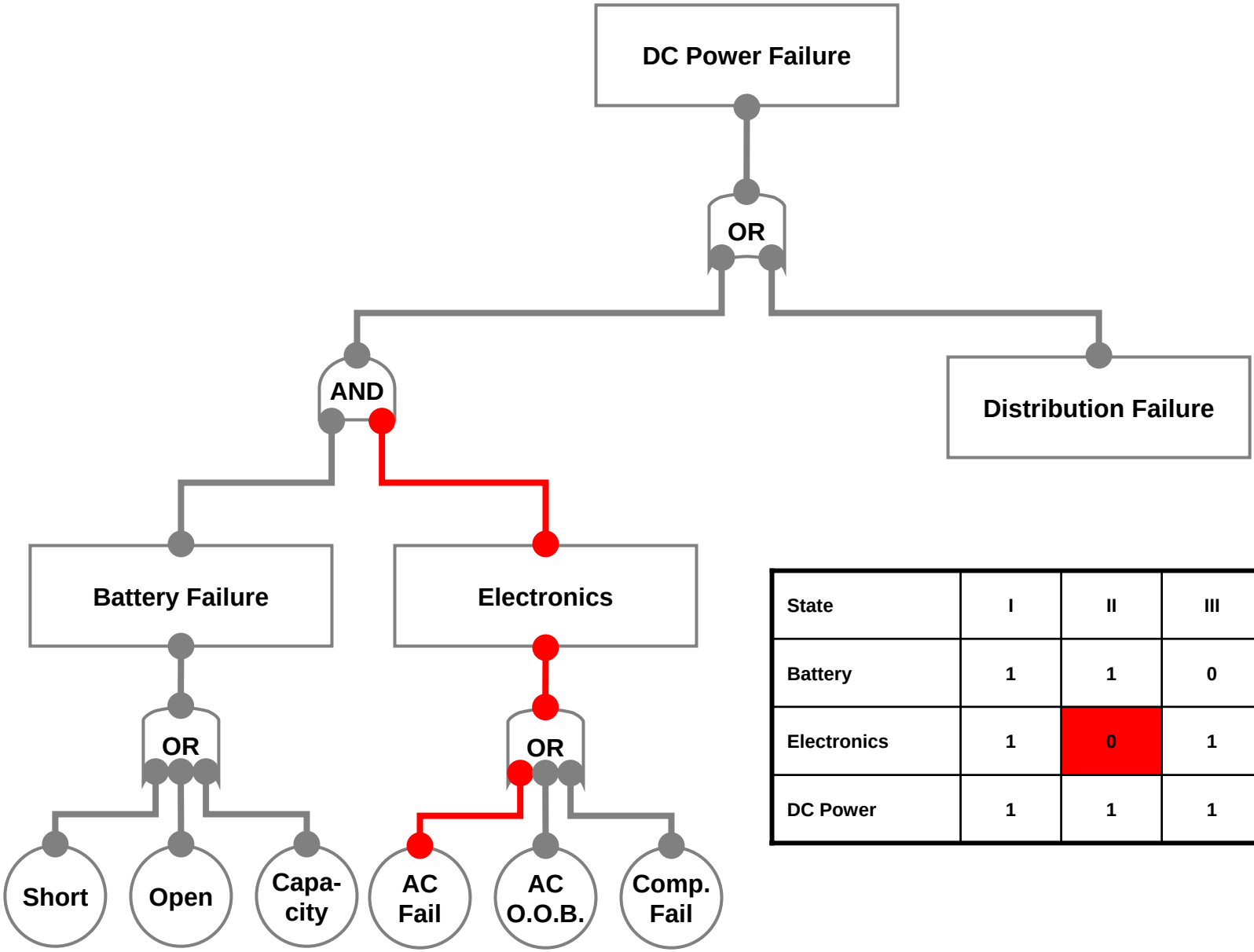
3. Jones, D, "Power Focus Team Analysis," pp 5, Network Reliability: A Report to the Nation, National Engineering Consortium, Illinois, 1993.

Fault Tree Analysis – State I



State	I	II	III	IV
Battery	1	1	0	0
Electronics	1	0	1	0
DC Power	1	1	1	0

Fault Tree Analysis – State II

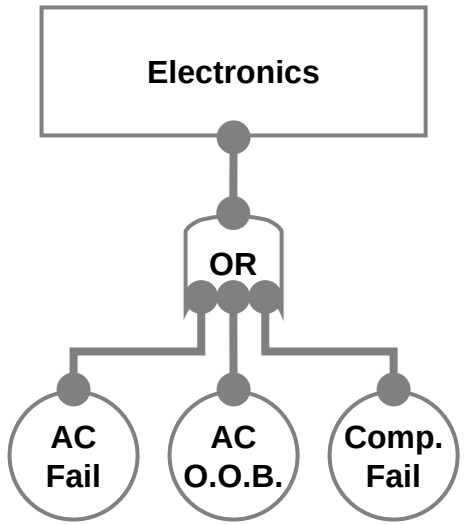


State	I	II	III	IV
Battery	1	1	0	0
Electronics	1	0	1	0
DC Power	1	1	1	0

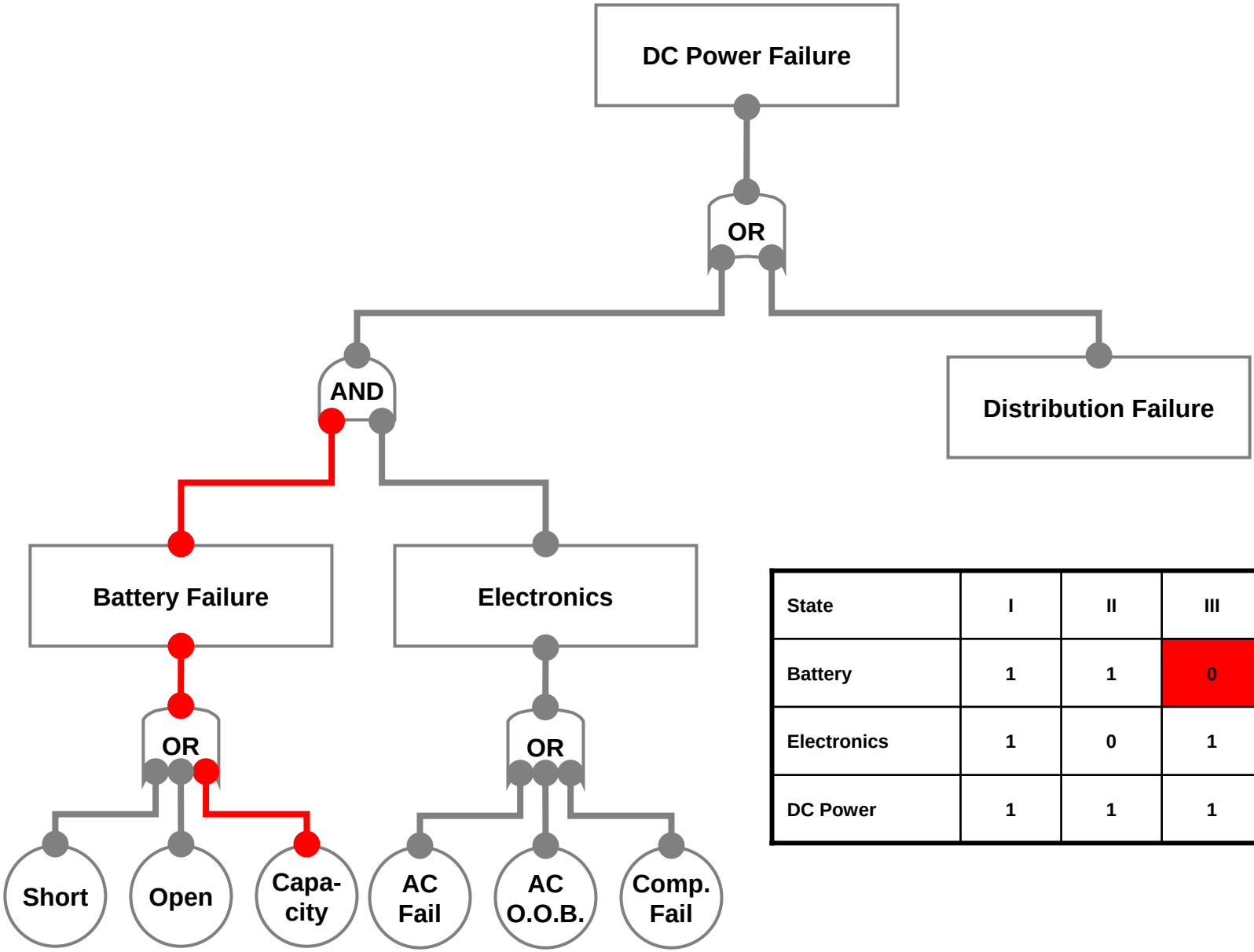
Causes of Power Plant Failure

Stresses

- **AC Fail**
- **AC Out of Bounds**
- **Component Failure**



Fault Tree Analysis – State III

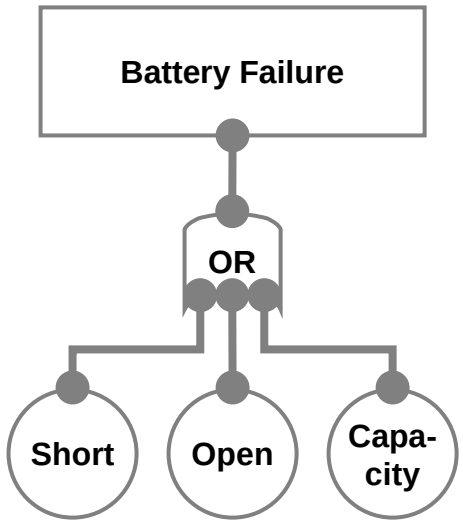


State	I	II	III	IV
Battery	1	1	0	0
Electronics	1	0	1	0
DC Power	1	1	1	0

Causes of Battery Failure

Stresses

- **Positive plate growth**
- **Dry-out**
  - **Float current**
  - **Recharge current**
  - **Evaporation**



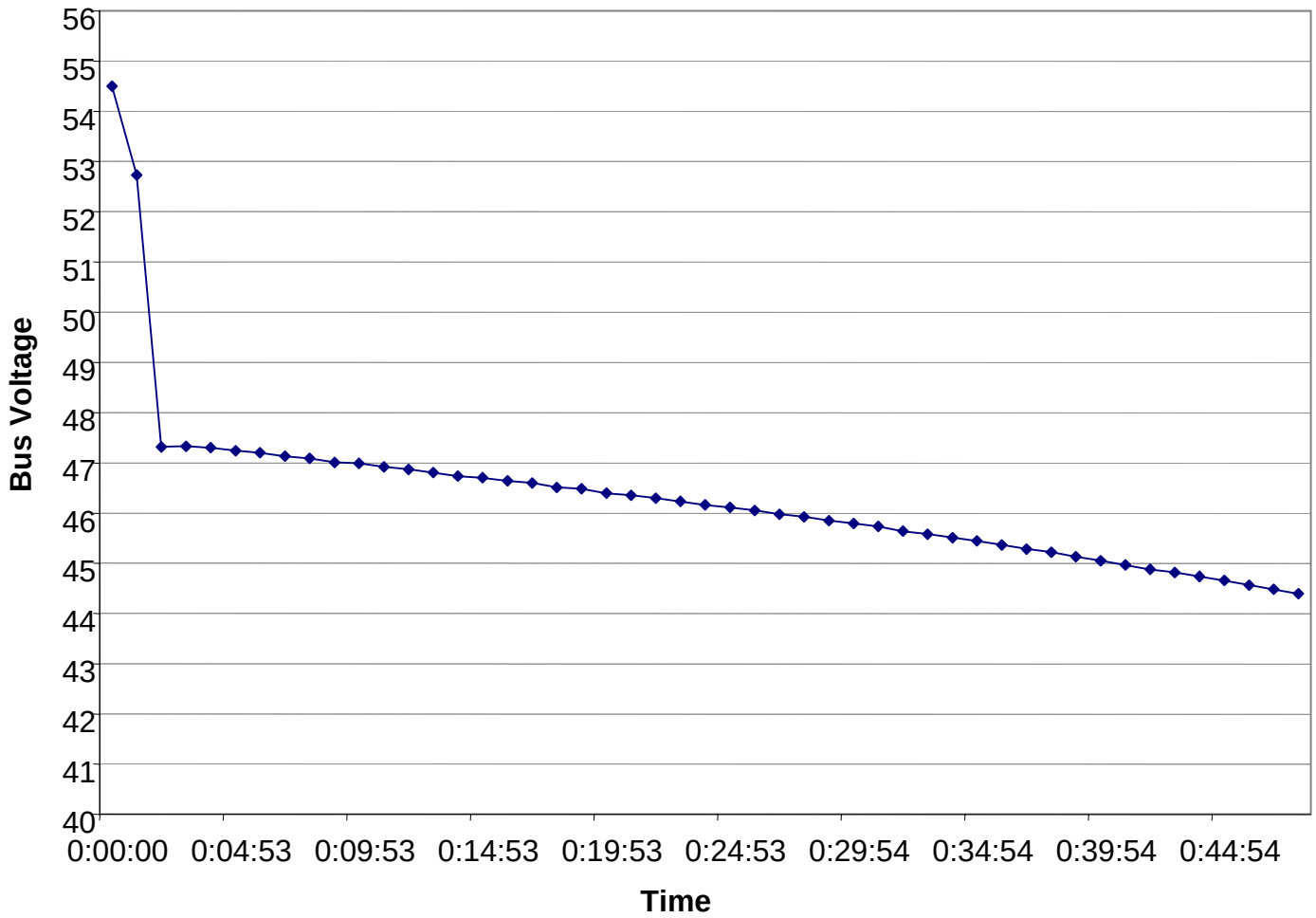
Loss of capacity is usually not known until its too late!

Battery Testing Technologies

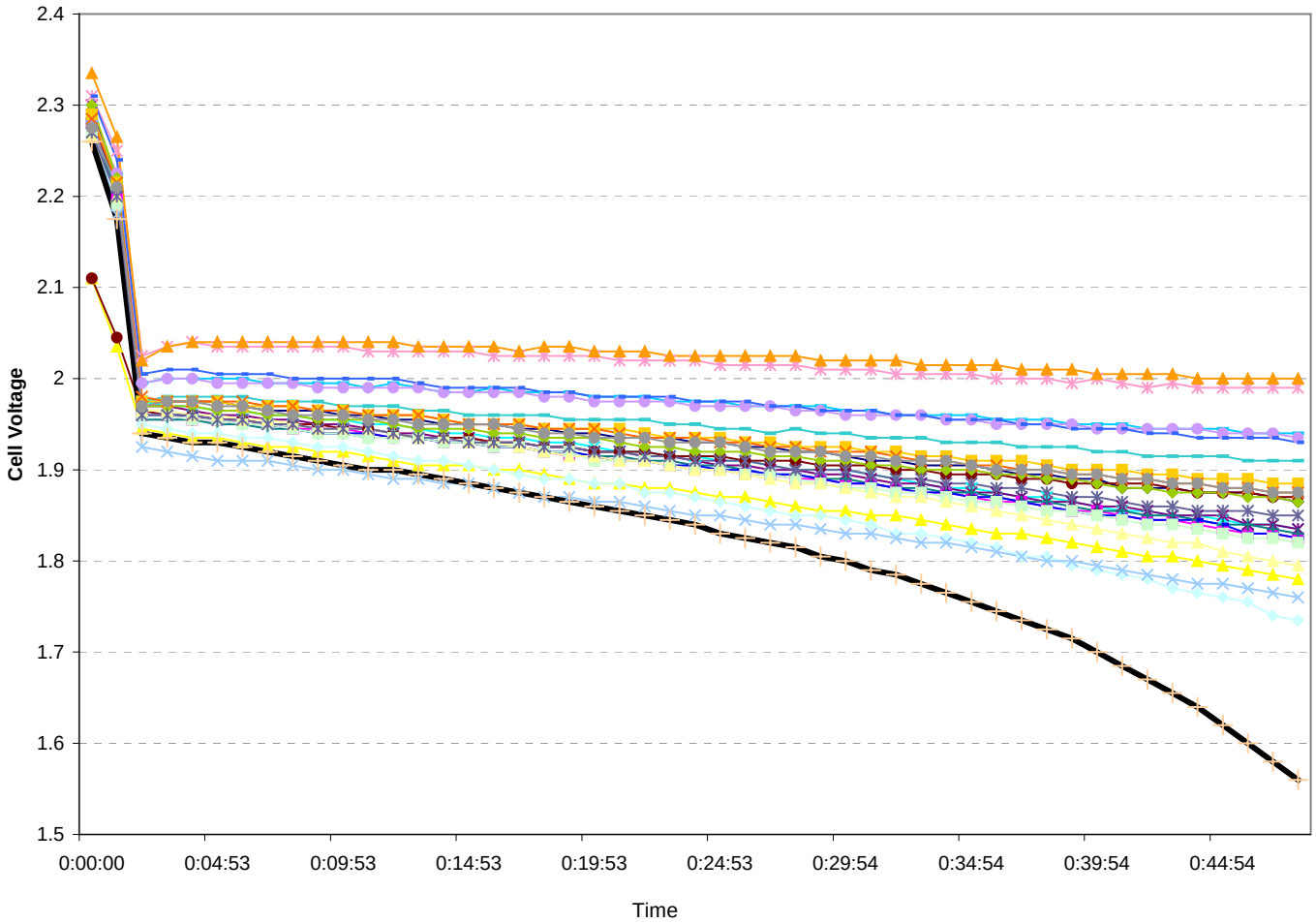
Technology	Procedure	Advantages	Disadvantages
Float Current	Float current is monitored	• Inexpensive, simple test • Continuous monitoring	• System level measurement • Ability to identify a bad cell decreases as cell count increases
Internal Ohmic	New cells are measured to establish a baseline, periodic readings are taken and compared to baselines	• Non-invasive • Simple, on-line test	• Infers individual cells' health • "Does not precisely predict overall battery capacity"[4]
Traditional Load Test	Battery string is removed and discharged using a load bank	• Provides accurate measurement of battery capacity	• Labor intensive and expensive • Battery is not available during test • Backup capacity temporarily diminished by test • Temporary battery needed

4. **Davis, E, Funk, D, and Johnson, W, "*Internal Ohmic Measurements and Their Relationship to Battery Capacity – EPRI's Ongoing Technology Evaluation*," pp 12-9, BATTCON 2002 Paper, 2002.**

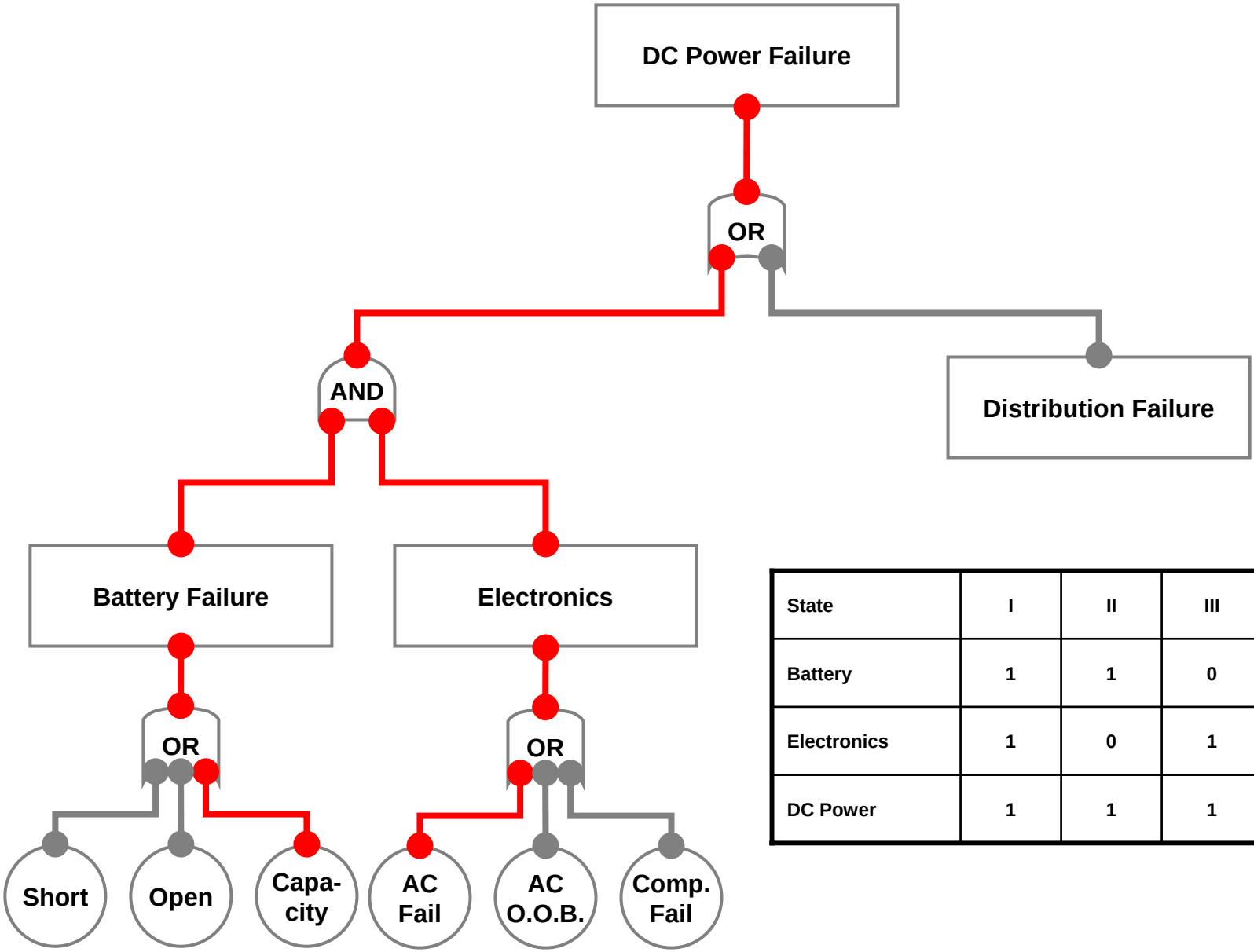
Typical Discharge Curve



Individual Cell Performance



Fault Tree Analysis – State IV

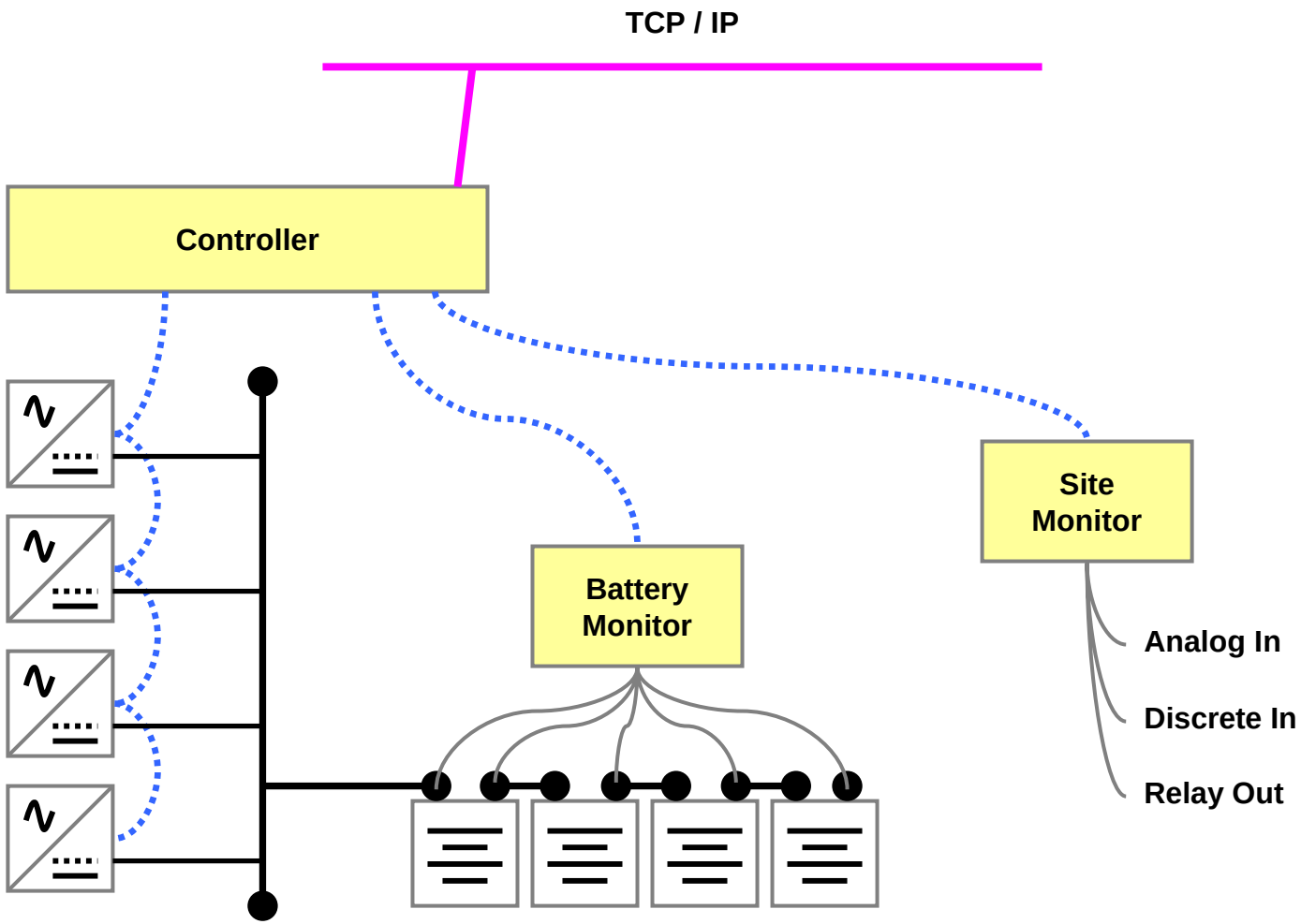


State	I	II	III	IV
Battery	1	1	0	0
Electronics	1	0	1	0
DC Power	1	1	1	0

System Level Approach to Availability

- **Improvements in component reliability**
  - **Input voltage**
  - **Temperature extremes**
- **Increased equipment monitoring**
- **Deterministic battery testing**
- **Avoidance of overcharge conditions**

DC System Architecture



Integrated Load Testing

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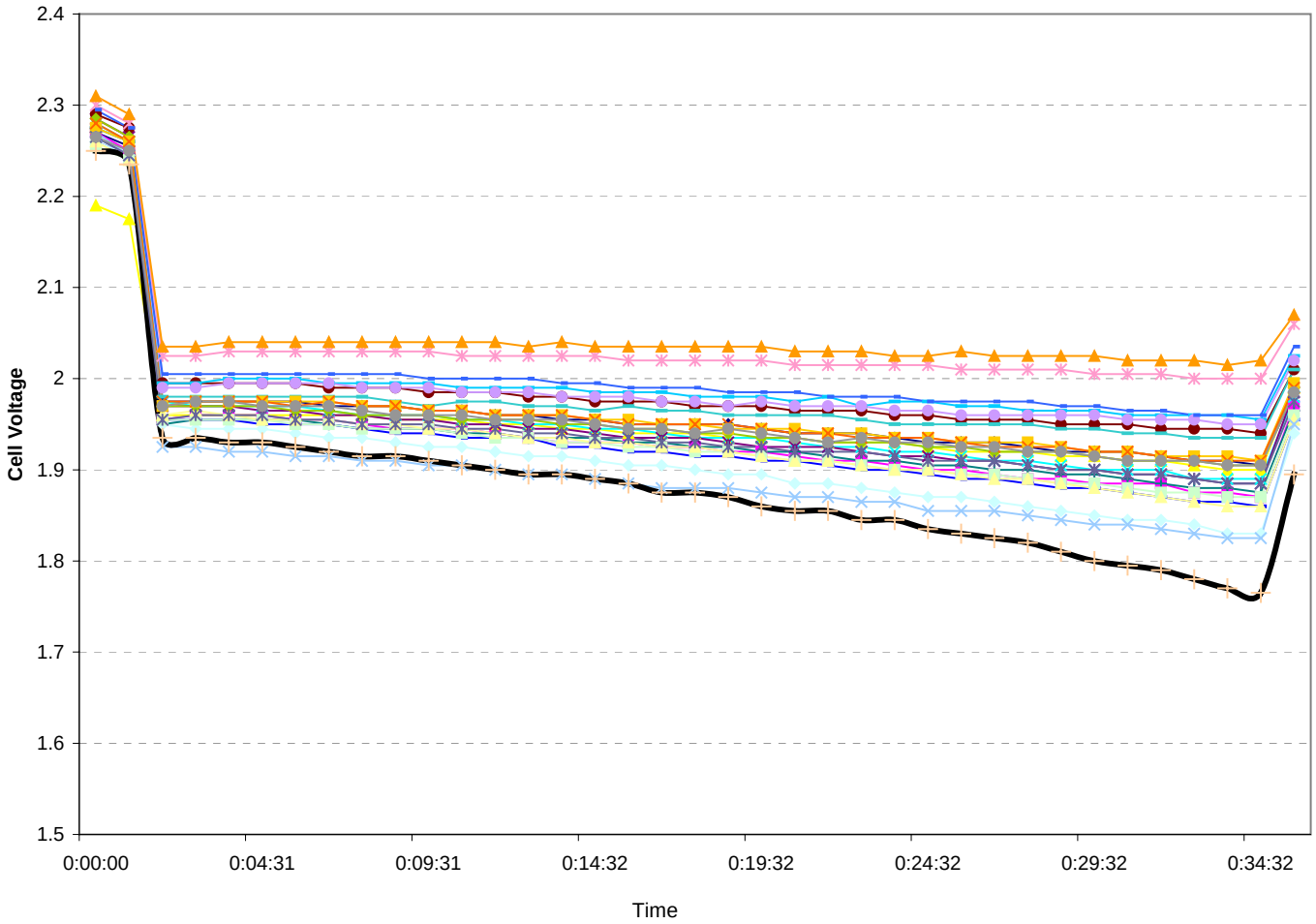
Traditional Load Test	Battery string is removed and discharged using a load bank	• Provides accurate measurement of battery capacity	• Labor intensive and expensive • Battery is not available during test • Backup capacity temporarily diminished by test • Temporary battery needed
Integrated Load Test	Battery string is discharged using the system load	• Inexpensive • On-demand testing • Provides accurate measurement of battery capacity	• Backup capacity temporarily diminished by test

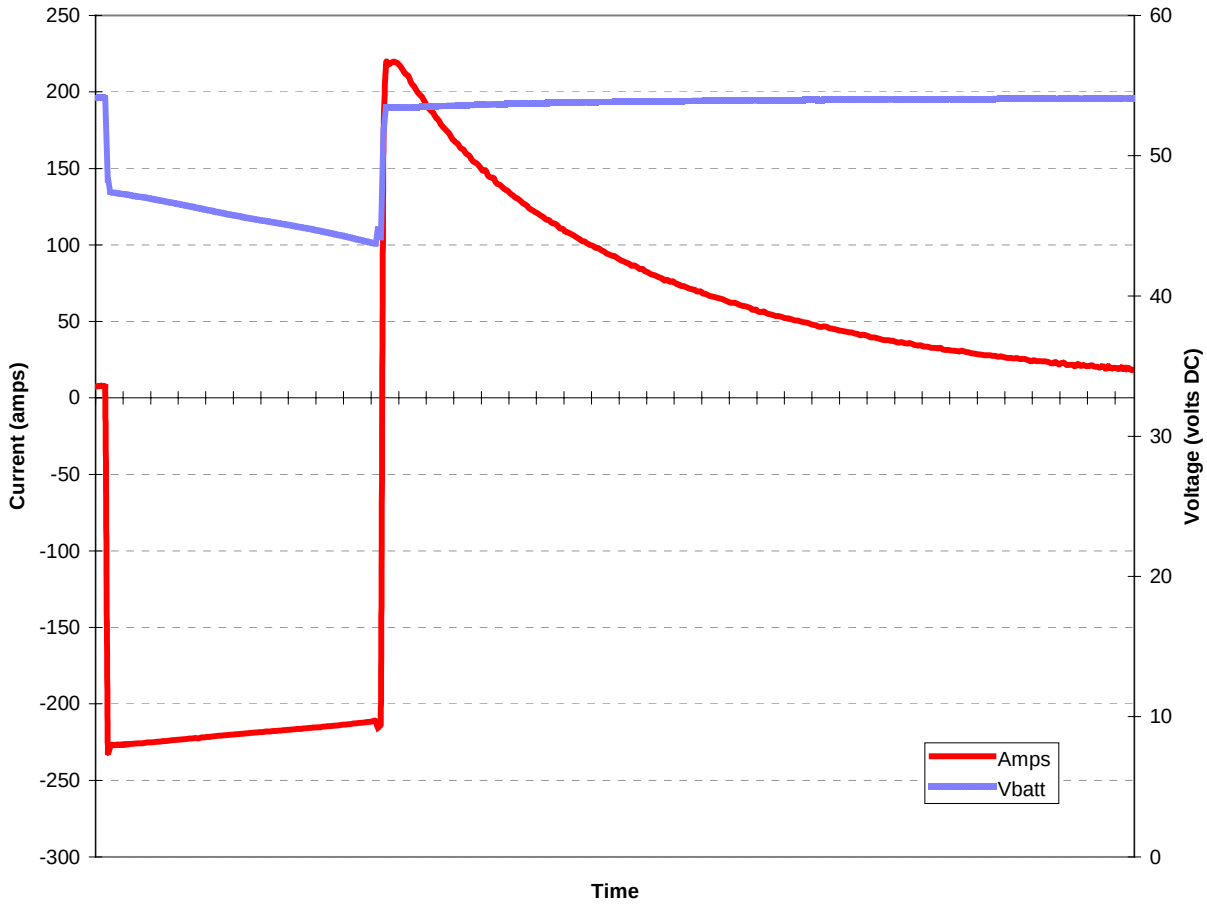
System Level Load Testing

- **Discharge test terminates automatically if:**
  - **Individual cell voltage below low configurable low limit**
  - **Individual cell voltage outside of configurable deviation limit**
  - **Bus voltage below configurable low limit**
  - **Any system alarm (i.e. loss of AC)**

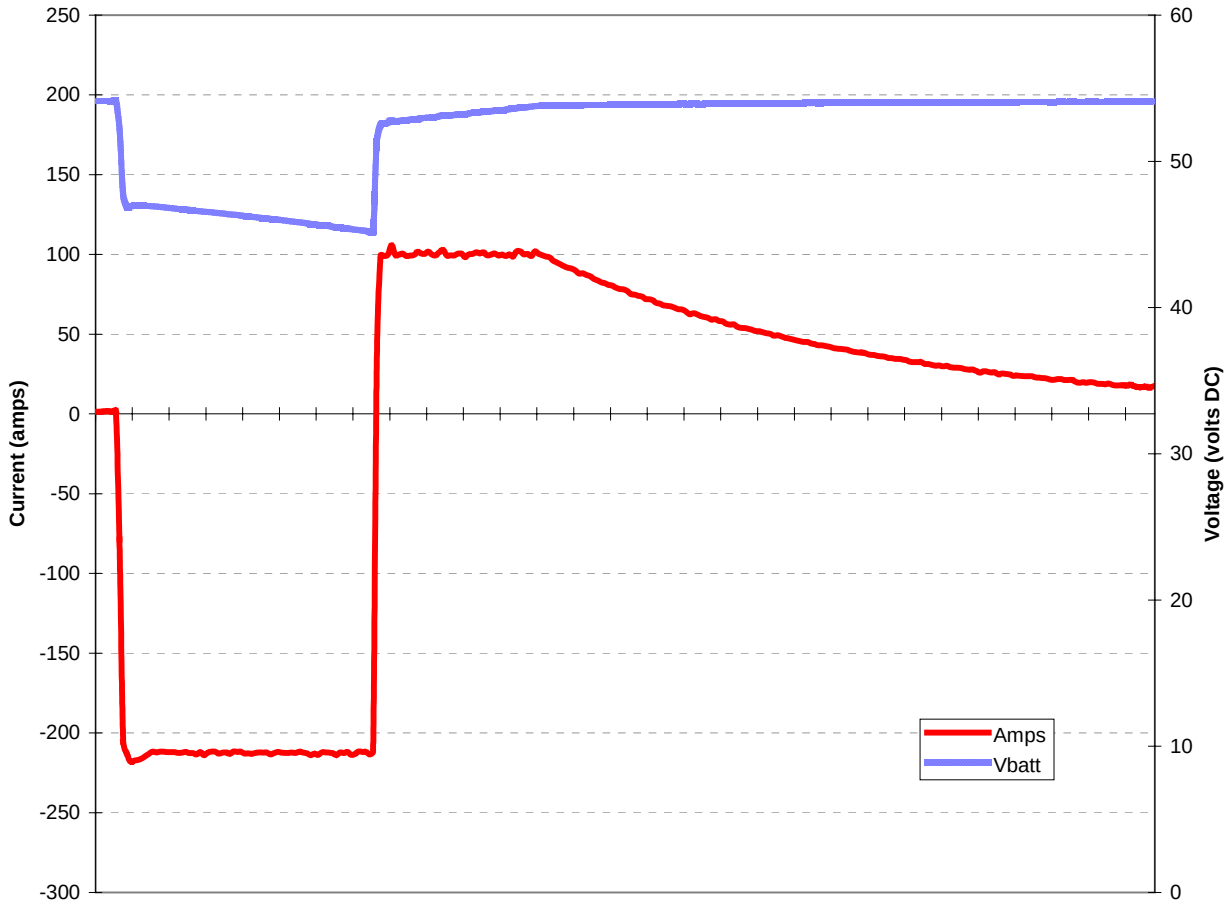
Integrated Discharge Test



Typical Recharge Current



Recharge Current Limit



Total Cost of Ownership

	7 Year Life No Testing	10 Year Life Traditional Testing[(b)]	10 Year Useful Life Integrated Testing[(c)]
Installation and Setup[(a)]	$2,080	$2,080	$2,080
Maintenance and Operations[(d)]	$455	$15,650	$1,950
Removal and Disposal	$1,300	$1,300	$1,300
Battery	$12,000	$12,000	$12,000
Power Plant	$12,600	$12,600	$12,600
Total Cost	**$28,435**	**$43,630**	**$29,930**
Useful Life	7 years	10 years	10 years
Annual Cost	**$4,062**	**$4,363**	**$2,993**

(a) All labor cost calculated at $65 per hour

(b) 10 year life based on 10 load tests at $1500 per test, typical market rate

(c) 10 year life based on 10 load tests at $130 per test, 2 hours per test at $65 per hour

(d) Cost based on 1 hour per normal maintenance plus the cost of load testing

Failure Modes and System Reponses

	Prevention	System Response
State II		
AC Fail	AC subsystem design and maintenance	AC input and generator monitoring
AC Out-of Bounds	Design and maintenance	Increase operating range
Component Failure		
• Component Quality	Product design and manufacturing	Internal diagnostics
• Environmental	Facility design and maintenance	Adaptive power output
State III		
Short	Product quality and maintenance	Voltage monitoring
Open	Product quality and maintenance	Integrated load testing
Capacity		
• Age	None	Integrated load testing
• Usage	Increased availability of electronics	Integrated load testing
• Recharge Current	DC Plant design	Recharge current limit

Key Points

- **Systematic analysis of the DC Power System can help reveal less obvious failure modes.**

- **Advances in electronics now provide increased capabilities that improve the availability of the DC Power Plant.**

- **Integrated battery testing is now available. This capability dramatically lowers the cost of determining the state of any battery deployed in the network.**

Thank You!