PowerLOK Rack PDU
Comparative Reliability Analysis

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The purpose of this report is to present the simplified drawing of a representative configuration of the PowerLOK Rack PDU (Power Distribution Unit). Other configurations are possible and can be presented in a similar fashion. The report includes preliminary results.

The simplifications in this drawing bundle multiple components into assemblies that can then be treated as basic events for purposes of calculating reliability.

Viewing the simplified drawings (PowerLOK, page 5; Competitor, page 6) from left to right:

a) The plug is assumed to be a NEMA L21-20P (3 phases, 1 neutral, 1 ground). Other plugs could be used by modifying the graphic of the shape and the failure rate.
b) The entrance module (EM) is a screw-down terminal block. The PowerLOK EM uses 6 soldered connections instead of 6 crimped connections on the competitor EM.
c) Three connector groups are shown for each design. A PowerLOK connector group comprises 3x quad IEC 320 C13 receptacles plus 2x IEC 320 C19 receptacles. A competitor connector group comprises 2x hex IEC 320 C13 receptacles plus 2x IEC 320 C19 receptacles. Other groupings could be used with minor modifications.

The definition of failure for a PDU is the loss of electrical continuity to any receptacle connection. A fault tree describing this event, TOP-POWERLOK-PDU, appears on page 8. The shape at the top of the fault tree is an OR gate, which means that its output is TRUE (Failed) if ANY of its inputs is TRUE (Failed). The names that appear in the tables below the OR gate are basic events. These names match the callouts in the simplified drawing. Another fault tree, TOP-COMPETITOR-PDU, appears on page 9.

Each fault tree was solved to produce the cut set reports that appear on page 10. The PowerLOK probability of failure over a one-year (8760 hour) mission is $1.33 * 10^{-4}$. The cut sets are presented in the order of most likely to least likely. In this case, failures of the 4x C13 groups are responsible for ~58% of PDU failures, the plug/entrance module for ~20%, and the 2x C19 groups for ~22%.

A representative competitor PDU has been modeled using the same analysis technique. The simplified drawing is essentially the same; only the failure rates associated with the components are changed. Where the PowerLOK PDU uses PCBs with plated through holes (PTHs) and machine soldering, the competitor PDU uses crimped fastons, Insulation Displacement Connectors (IDCs), and riveted bus bars.

The competitor PDU probability of failure over a one-year (8760 hour) mission is $3.65 * 10^{-4}$. Approximately 70% us due to failure of hex C13 groups, ~20% is due to failure of dual C19 groups, and ~10% is due to failure of the plug and entrance module.

The competitor PDU has ~3 times higher probability of failure per year of operation than the PowerLOK PDU. The additional Faston connectors, insulation displacement connectors, and riveted bus bars in the competing product introduce opportunities for failure that are not present in the PowerLOK product.

The PowerLOK product has relatively equal distribution of failures among the component sub-assemblies. This is typical of products engineered for high reliability. The difference between the lowest and highest probability of failure is slightly over a factor of 2. The competitor product concentrates ~70% of all failures in three C13 groups.

Because there are no redundant power paths[1] in either PDU, the reliability is dependent on the failure rates of the basic events in the fault tree.

Page 11 contains information about the basic events in the fault trees.

Notes on component failure rates and modeling

Failure rates and sources

Component	Failure rate	Probability of failure in 1 year	Source
Crimp	2.60E-10	2.28E-6	MIL-HDBK-217F, 17.1, $\pi_Q = 1.0$, $\pi_E = 1.0$ (IDC connector failure rate is assumed to be the same as crimped connection)
Solder	6.90E-11	6.04E-7	MIL-HDBK-217F, 17.1, $\pi_Q = 1.0$, $\pi_E = 1.0$
Plated-through hole (pth)	4.10E-11	3.59E-7	MIL-HDBK-217F, 16.1, $\pi_C = 1.0$, $\pi_Q = 1.0$, $\pi_E = 1.0$
Rivet	8.00E-08	7.01E-4	NSWC-11, 23.12.2
Power pin	8.27E-10	7.24E-6	MIL-HDBK-217F, 15.1, T = 45 °, insert material B, $\pi_K = 1.0$, $\pi_P = 1.0$, $\pi_E = 1.0$
Faston	1.09E-9	9.52E-6	1x crimp + 1x power pin
IDC/faston	1.65E-9	1.45E-5	2x power pin
Quad C13	9.90E-10	8.67E-6	9x solder + 9x pth
PowerLOK EM	1.70E-9	1.49E-5	4x crimp + 6x solder + 6x pth
PowerLOK dual C19	1.10E-9	9.64E-6	10x solder + 10x pth
Plug	1.30E-9	1.14E-5	5x crimp
Hex C13, Type 1	4.45E-9	3.89E-5	2x IDC/faston + 1x faston + 2x dual rivet failure
Hex C13, Type 2	5.01E-9	4.39E-5	3x faston + 2x dual rivet failure
Competitor EM	2.60E-9	2.28E-5	10x crimp
Competitor dual C19	3.12E-9	2.73E-5	6x crimp

Table 1: Failure rates and sources

[1] The PowerLOK PDU has redundancy in each group's ground path. Ground continuity is lost if 2 of 6 ground wire connections fail OR if both crimped terminal lugs fail. The probability of this event is very small relative to failures in the power paths and can be ignored.

Failure rate of an assembly

> "A set of components is said to be *in series* from a reliability point of view if the success of the system depends on the success of all the system components. The components themselves need not be physically or topologically in series; what is relevant is only the fact that all of them must succeed for the system to succeed."[2]

The quotation above describes both the PowerLOK PDU and the competitor PDU analyzed in this report. It also provides the basis for modeling these systems as OR gates in their fault trees: if a system succeeds only if ALL of its components succeed, then that system will fail if ANY of its components fails.

A corollary of this statement is that the reliability of a series system of components is equal to the product of the component reliabilities:

$$R_{system} = R_{component1} {}^{*} R_{component2} * \ldots * \; R_{componentN}$$

The reliability of a component with a constant failure rate is:

$$R_{component} = e^{-\lambda * t}$$

where λ is the component failure rate and *t* is the mission time. (This report considers a mission of 1 year = 8760 hours.) The unreliability of a component is $Q = 1 - R$.

If all of the systems components have constant failure rates, then the system's failure rate is the sum of the component failure rates:

$$\lambda_{system} = \sum_{i=1}^{N} \lambda_i$$

The failure rates of the PDU components (receptacle groups, EMs, plug) have been calculated based on these assumptions.

[2] Engineering Reliability: Fundamentals and Applications, p 148, R. Ramakumar, Prentice Hall, Englewood Cliffs, NJ, 1993

Failure Rate Assumptions

1) Plugs and entrance modules have higher failure rates than IEC 320 modules because of hand assembly
 a) plug, 1.30 * 10^{-9} per hour
 b) EM, 1.70 * 10^{-9} per hour

2) IEC 320 groups failure rates from MIL-HDBK-217F, 16.1 (PCBs w/ PTHs, π_Q = 1, π_C = 1.0, π_E = 1.0) & 17.1 (Reflow soldered connections, π_Q = 1, π_E = 1.0)

 a) 3x quad C13: 2.97 * 10^{-9} per hour
 b) 2x C19: 1.10 * 10^{-9} per hour

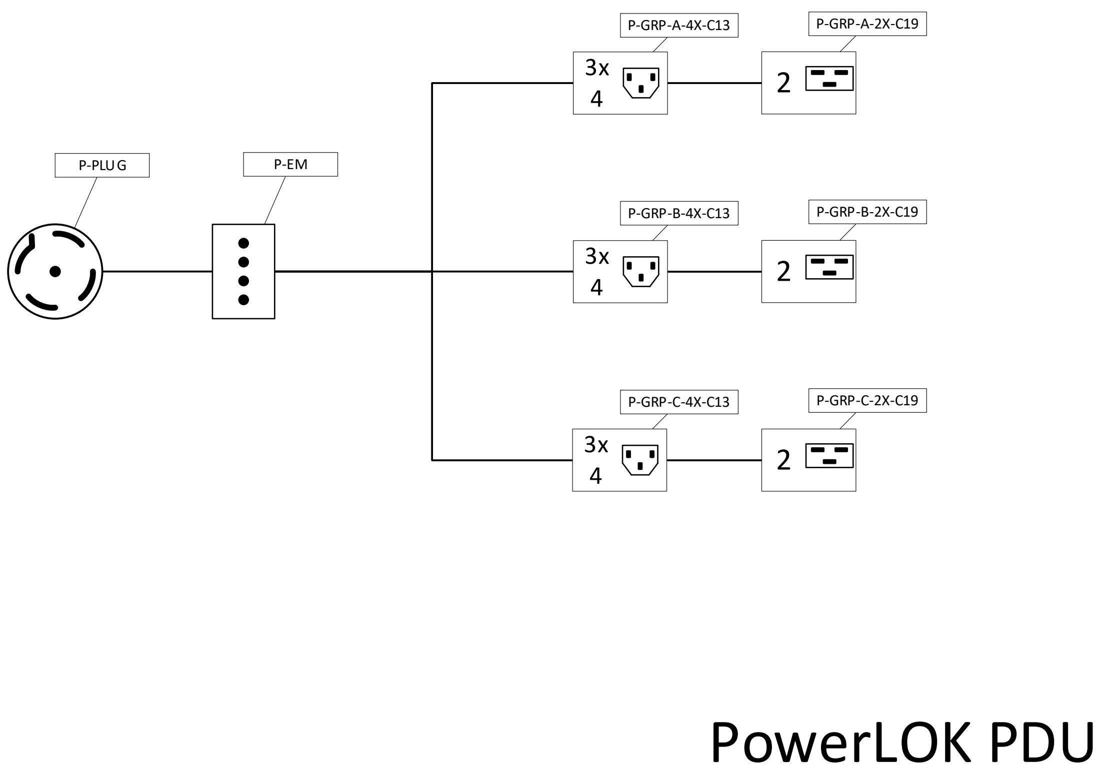
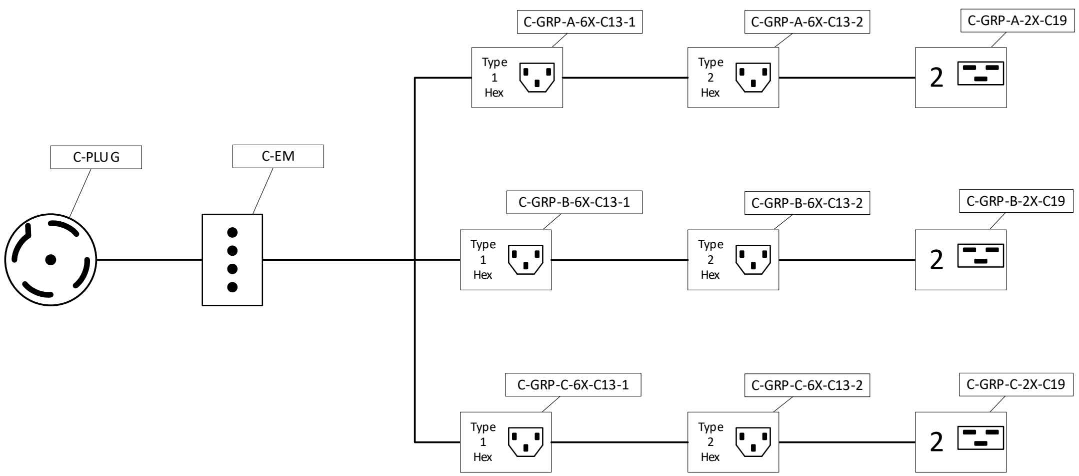


Figure 1: PowerLOK PDU



Failure Rate Assumptions

1) Plug's failure rate is the same as for PowerLOK PDU. MIL-HDBK-217F, 17.1 (π_Q = 1.0, π_E = 1.0) crimp failure rate (x5 = 1.3 * 10^{-9} per hour)

2) Competitor entrance module has 6 additional faston connections. Failure rate = 2.69 * 10^{-9} per hour

3) Insulation displacement connector failure rate is the same as 2x power pin. MIL-HDBK-217F, 15.1 (T = 45 °C, insert material B, π_K = 1.0, π_P = 1.0, π_E = 1.0), 8.27 * 10^{-10} per hour

4) IEC 320 groups failure rates from MIL-HDBK-217F, (Crimp connections, 17.1, π_Q = 1.0, π_E = 1.0; power pin, 15.1, T = 45 °C, insert material B, π_K = 1.0, π_P = 1.0, π_E = 1.0) & "Handbook of Reliability Prediction Procedures for Mechanical Equipment", Naval Surface Warfare Center (NWSC-11), 23.12.2, Rivet Failure Rate
 a) Hex C13, Type 1: 4.45 * 10^{-9} per hour
 b) Hex C13, Type 2: 5.01 * 10^{-9} per hour
 c)2x C19: 3.12 * 10^{-9} per hour

Competitor PDU

Figure 2: Competitor PDU

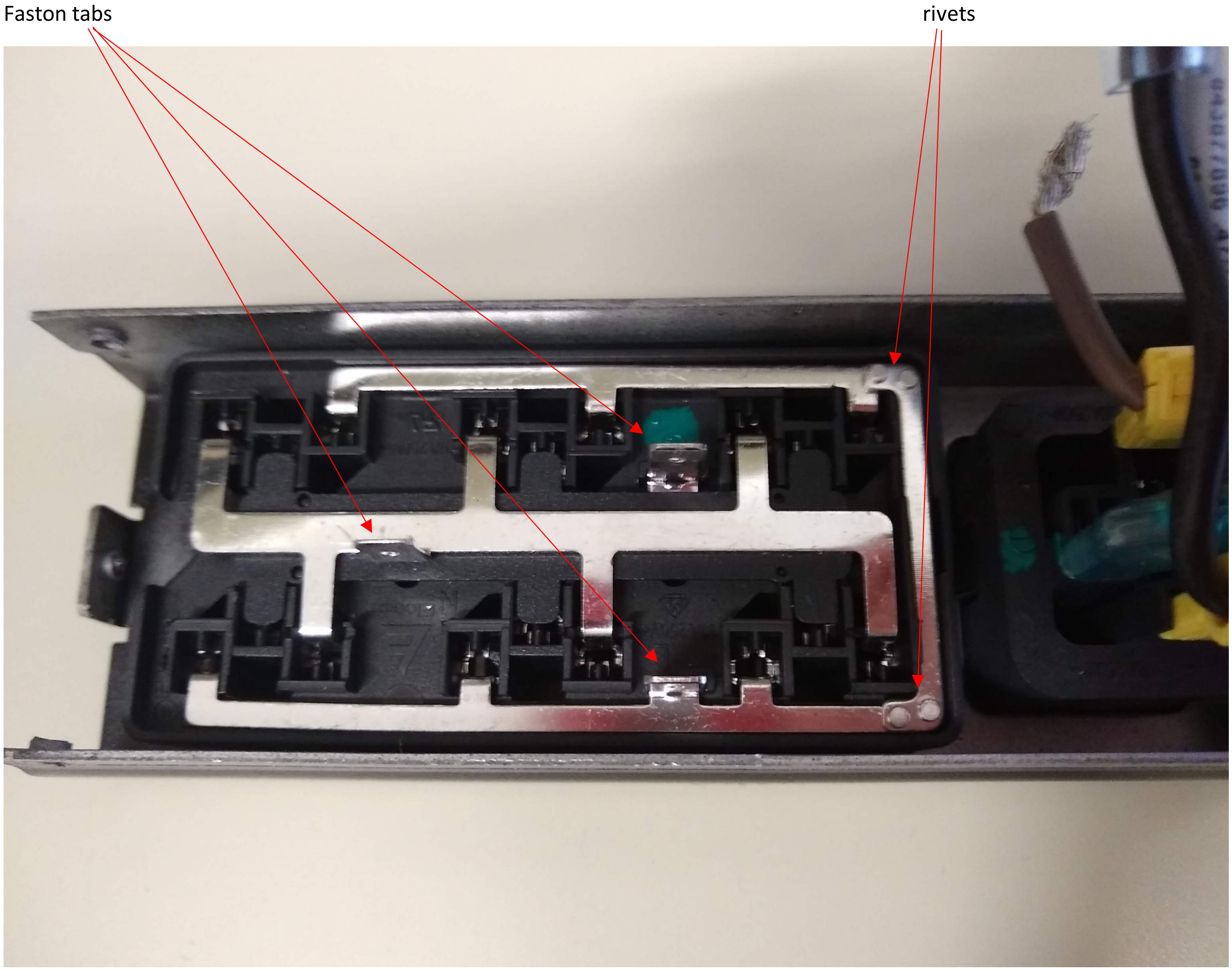


Figure 3: Additional Faston tabs and riveted bus joints in C13 connections of competitor's product

PowerLOK PDU fails

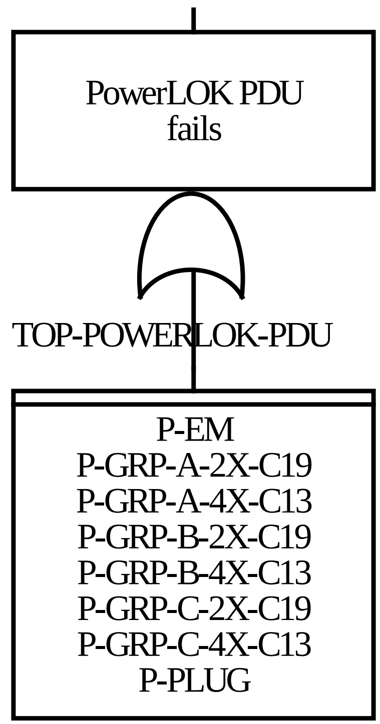


Figure 4: PowerLOK PDU Fault Tree

Competitor PDU fails

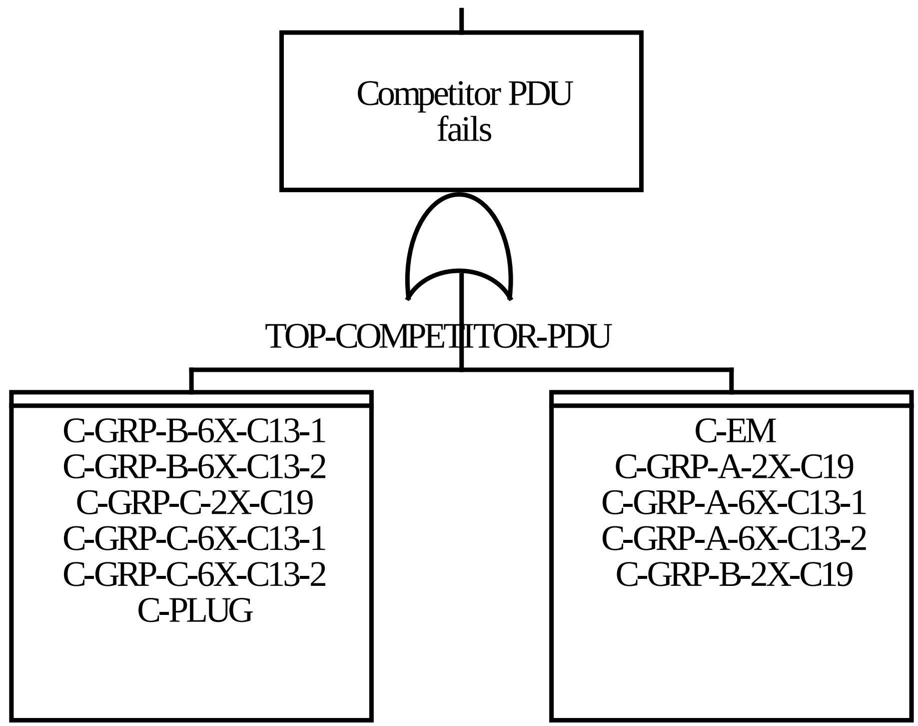


Figure 5: Competitor PDU Fault Tree

Cut set reports

PowerLOK PDU

FAULT TREE CUT SETS (DETAILED) REPORT					
Project:	GATEVIEW		Analysis:	RANDOM	
Fault Tree:	TOP-POWERLOK-PDU		Case:	CURRENT	
			Mincut Upper Bound:	1.33E-04	
Cut #	Cut Set %	Prob/Freq	Basic Event	Description	Prob
1	19.5	2.60E-05	P-GRP-A-4X-C13	3X QUAD C13 GROUP FAILS	2.60E-05
2	19.5	2.60E-05	P-GRP-B-4X-C13	3X QUAD C13 GROUP FAILS	2.60E-05
3	19.5	2.60E-05	P-GRP-C-4X-C13	3X QUAD C13 GROUP FAILS	2.60E-05
4	11.2	1.50E-05	P-EM	POWERLOK ENTRANCE MODULE FAILS	1.50E-05
5	8.6	1.10E-05	P-PLUG	PLUG FAILS	1.10E-05
6	7.2	9.60E-06	P-GRP-A-2X-C19	2X C19 GROUP FAILS	9.60E-06
7	7.2	9.60E-06	P-GRP-B-2X-C19	2X C19 GROUP FAILS	9.60E-06
8	7.2	9.60E-06	P-GRP-C-2X-C19	2X C19 GROUP FAILS	9.60E-06

Competitor PDU

FAULT TREE CUT SETS (DETAILED) REPORT					
Project:	GATEVIEW		Analysis:	RANDOM	
Fault Tree:	TOP-COMPETITOR-PDU		Case:	CURRENT	
			Mincut Upper Bound:	3.65E-04	
Cut #	Cut Set %	Prob/Freq	Basic Event	Description	Prob
1	12	4.40E-05	C-GRP-A-6X-C13-2	HEX C13 TYPE 1 GROUP FAILS	4.40E-05
2	12	4.40E-05	C-GRP-B-6X-C13-2	HEX C13 TYPE 1 GROUP FAILS	4.40E-05
3	12	4.40E-05	C-GRP-C-6X-C13-2	HEX C13 TYPE 1 GROUP FAILS	4.40E-05
4	10.7	3.90E-05	C-GRP-A-6X-C13-1	HEX C13 TYPE 1 GROUP FAILS	3.90E-05
5	10.7	3.90E-05	C-GRP-B-6X-C13-1	HEX C13 TYPE 1 GROUP FAILS	3.90E-05
6	10.7	3.90E-05	C-GRP-C-6X-C13-1	HEX C13 TYPE 1 GROUP FAILS	3.90E-05
7	7.5	2.70E-05	C-GRP-A-2X-C19	2X DUAL C19 GROUP FAILS	2.70E-05
8	7.5	2.70E-05	C-GRP-B-2X-C19	2X DUAL C19 GROUP FAILS	2.70E-05
9	7.5	2.70E-05	C-GRP-C-2X-C19	2X DUAL C19 GROUP FAILS	2.70E-05
10	6.3	2.30E-05	C-EM	COMPETITOR ENTRANCE MODULE FAILS	2.30E-05
11	3.1	1.10E-05	C-PLUG	PLUG FAILS	1.10E-05

Appendix A: Basic Events

PowerLOK PDU

basic event report		
event name	**failure rate**	**template**
P-EM	1.70E-09	P-EM-TEMPLATE
P-GRP-A-2X-C19	1.10E-09	RG2C19-TEMPLATE
P-GRP-A-4X-C13	2.97E-09	3XRG4C13-TEMPLATE
P-GRP-B-2X-C19	1.10E-09	RG2C19-TEMPLATE
P-GRP-B-4X-C13	2.97E-09	3XRG4C13-TEMPLATE
P-GRP-C-2X-C19	1.10E-09	RG2C19-TEMPLATE
P-GRP-C-4X-C13	2.97E-09	3XRG4C13-TEMPLATE
P-PLUG	1.30E-09	PLUG-TEMPLATE

Competitor PDU

basic event report		
event name	**failure rate**	**template**
C-EM	2.60E-09	C-EM-TEMPLATE
C-GRP-A-2X-C19	3.12E-09	2X2C19-TEMPLATE
C-GRP-A-6X-C13-1	4.45E-09	HEXC13-1-TEMPLATE
C-GRP-A-6X-C13-2	5.01E-09	HEXC13-2-TEMPLATE
C-GRP-B-2X-C19	3.12E-09	2X2C19-TEMPLATE
C-GRP-B-6X-C13-1	4.45E-09	HEXC13-1-TEMPLATE
C-GRP-B-6X-C13-2	5.01E-09	HEXC13-2-TEMPLATE
C-GRP-C-2X-C19	3.12E-09	2X2C19-TEMPLATE
C-GRP-C-6X-C13-1	4.45E-09	HEXC13-1-TEMPLATE
C-GRP-C-6X-C13-2	5.01E-09	HEXC13-2-TEMPLATE
C-PLUG	1.30E-09	PLUG-TEMPLATE

Appendix B: Template Events

template event report			
template	***failure rate***	***FR component***	***FR source***
2X2C19-TEMPLATE	3.12E-09	2x2C19	MIL-HDBK-217F, 17.1 (PiQ = 1.0, PiE =1.0), crimp * 12 (per group)
3XRG4C13-TEMPLATE	2.97E-09	RG4C13	MIL-HDBK-217F, 16.1 (PiQ = 1, PiE = 1.0, PiC = 1.0) & 17.1 (PiQ = 1.0. PiE = 1.0), PCB w/ PTHs * 27 + reflow soldered connection * 27 (per group)
C-EM-TEMPLATE	2.60E-09	Competitor entrance module	MIL-HDBK-217F, 17.1, 10x crimp
HEXC13-1-TEMPLATE	4.45E-09	HexC13, Type 1	2x IDC/faston +1x faston + 2x dual rivet (MIL-HDBK-217F,15.1, T=45 deg C, insert material B, PiK = 1.0, PiP = 1.0, PiE = 1.0; 17.1, PiQ = 1.0, PiE = 1.0, NSWC-11, 23.2.2)
HEXC13-2-TEMPLATE	5.01E-09	HexC13, Type 2	3x faston + 2x dual rivet (MIL-HDBK-217F,15.1, T=45 deg C, insert material B, PiK = 1.0, PiP = 1.0, PiE = 1.0; 17.1, PiQ = 1.0, PiE = 1.0, NSWC-11, 23.2.2)
P-EM-TEMPLATE	1.70E-09	PowerLOK entrance module	MIL-HDBK-217F, 17.1, 4x crimp + 6x solder
PLUG-TEMPLATE	1.30E-09	L21-20P	MIL-HDBK-217F, 17.1, 5x crimp
RG2C19-TEMPLATE	1.10E-09	RG2C19	MIL-HDBK-217F, 16.1 & 17.1, PCB w/ PTHs * 10 + reflow soldered connection * 10

Revision History

November 18, 2019	Initial commit
November 20, 2019	Added date & “draft” watermark
November 22, 2019	Removed circuit breakers; new date on first page
November 25, 2019	Added competitor PDU; new date on first page
November 26, 2019	Revised to reflect Lynn Schultz’s comments; new date on first page
December 3, 2019	Edited for clarity, added image of competitor PDU, noted different distribution of failure probabilities.
December 4, 2019	Revised to make uniform references to “PowerLOK”; new date on cover
December 5, 2019	Revised TOP event name, etc; new date on cover
December 16, 2019	Revised to reflect Lynn Schultz’s comments; new date on first page
January 17, 2020	Revised logos & date on cover page
January 20, 2020	Revised Table 1; new date on cover, removed “DRAFT” & watermark; revised text; updated competitor PDU drawing, fault tree, cut set report, basic & template event reports