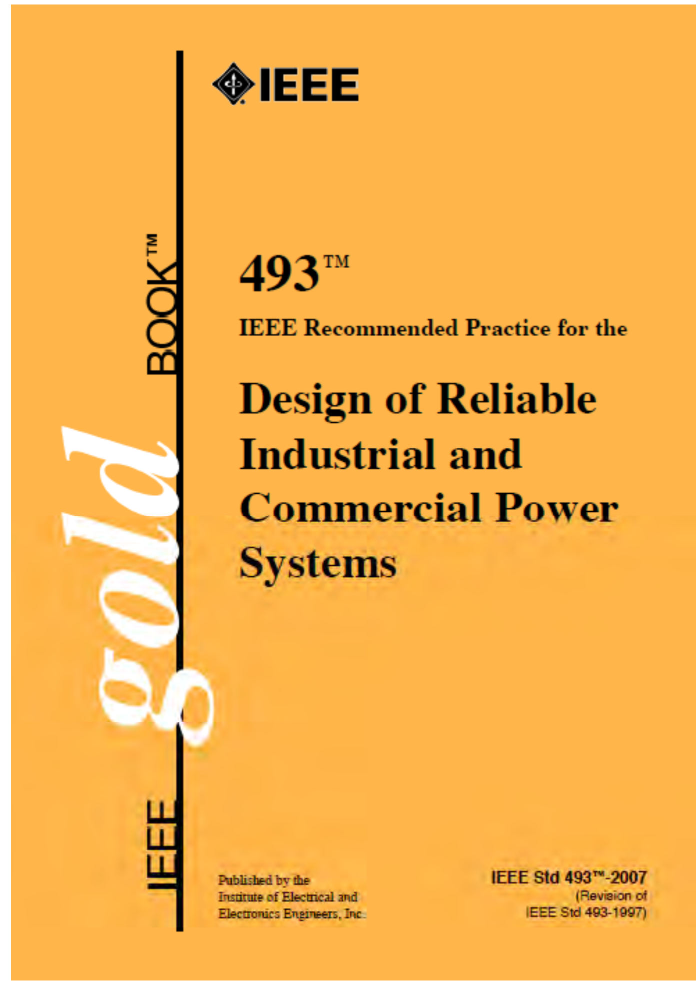
Overview of IEEE Std 3006.7 – 2013 Recommended Practice for Determining the Reliability of "7 x 24" Continuous Power Systems in Industrial and Commercial Facilities

Presented By
Robert Schuerger, P.E.

HP Critical Facility Services delivered by EYP MCF

Origins of Std 3006.7-2013

- All of the IEEE Color Books are being revised and repackaged as "3000 Series" Standards
- IEEE Gold Book, Std. 493-2007 has Chapter 8 "7 x 24" Continuous Power Facilities
- Chapter 8 has become Std 3006.7
- Std 3006.7 includes both electrical distribution and mechanical cooling systems used in critical facilities



Std 3006.7 – 2013 Developed by:

Power System Reliability Working Group:

Chair: Robert Arno

Members:

- William Braun
- Timothy J. Coyle
- Neal Dowling
- Peyton Hale
- Masoud Pourali
- Robert Schuerger
- Michael Simon
- Christopher C Thompson, Jr
- Joseph Weber

3006.7 Working Group

Chair: Robert Schuerger

Members:

- Robert Arno
- Jose Cay II
- Raymond Chiu
- Edwin Cothran
- Ann'claude Coutu
- Neal Dowling
- Addam Friedl
- Joaquin Fuster
- Gardson Githu
- Peter Gross
- Ian Levine
- Michael Simon
- Sonny K. Siu

Reliability

- Today the term "reliability" is used as an umbrella definition covering a variety of subjects including availability, durability, quality and sometimes the function of the product
- Currently for critical facilities, when the subject is reliability, it is very common to see statements about "five 9's"

Five 9's refers to Availability

$$\textbf{Availability} = \left(\frac{\textbf{Total Time - Downtime}}{\textbf{Total Time}} \right)$$

- *Availability* (A): Availability is the long-term average fraction of time that a component or system is in service and satisfactorily performing its intended function
- Five 9's means an availability of 99.999%.

Availability

$$\textbf{Availability} = \left(\frac{\text{Total Time - Downtime}}{\text{Total Time}} \right)$$

In terms used for statistics, for a constant failure rate:

- Downtime = Time it takes to repair the failure
- Average downtime = Mean time to Repair (MTTR)
- Average uptime = Mean Time Between Failures (MTBF)
- Total time = (MTBF) + (MTTR)

$$\textbf{Availability} = \left(\frac{\text{MTBF}}{(\text{MTBF + MTTR})} \right)$$

Availability of 99.999%

This could be:

- 5.3 minutes of downtime each year *or*
- 1.75 hours of downtime every 20 years

Availability does not specify how often an outage occurs

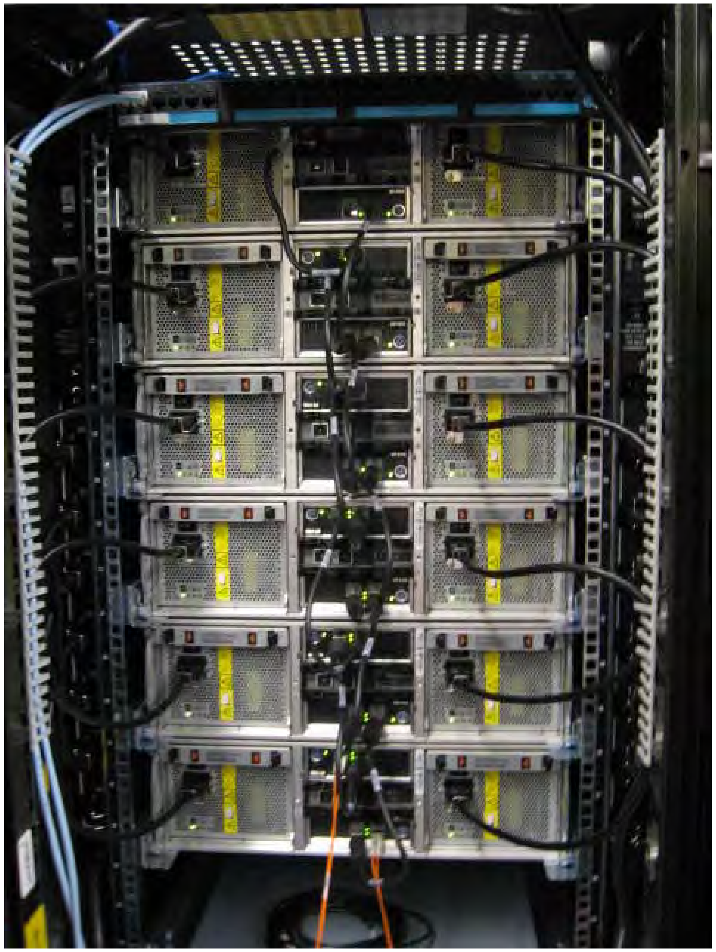
Availability	Number of outages per year	Length of outage	Failure rate (failure/hour)	MTBF (hours)	MTBF (years)
0.99999	315	1 second	3.60E-02	27.81	0.0032
0.99999	1	5.3 minutes	6.05E-04	1,652.80	0.189
0.99999	0.05	1.75 hours	5.71E-06	175,200	20

Reliability has a specific definition

- Reliability (R) is the probability that a product or service will operate properly for a specified period of time under design operating conditions without failure.
- Reliability = Probability of Successful Operation

  (for a specific time period)
- Probability of Failure =

  (1 – Reliability)



Reliability and Availability – both important metrics

- Availability gives the average percentage of "uptime"
- Reliability gives an indication of long it will operate before it fails

Availability	Number of outages per year	Failure rate - failure/hour	MTBF (hours)	MTBF (years)	Reliability (1 year)
0.99999	315	3.60E-02	27.81	0.0032	0%
0.99999	5.3	6.05E-04	1,652.8	0.189	0%
0.99999	0.05	5.71E-06	175,200	20	95.12%

MTBF – Mean Time Between Failures

Performing Reliability Analysis

- There are several ways to perform calculate reliability and availability
- P3006.7 presents several methods
  - Reliability Block Diagrams (RBD)
  - Fault Tree Analysis (FTA)
  - Failure Mode Effects and Criticality Analysis (FMECA)
- Each method has a different approach to the analysis
  - RBD is a model of the system flow; the one-line diagram or piping diagram
  - FTA starts at the top with the failure to be analyzed and works down the "tree" with all of the potential causes of the top event
  - FMECA is a deep dive into how all of the components or systems can fail (failure modes), what the effect of that failure would be and how critical it would be to the overall mission

Performing Reliability Analysis – RBD

- Many of the comparisons between electrical and mechanical systems in P3006.7 have been done using Reliability Block Diagrams
- The individual components are represented by blocks.

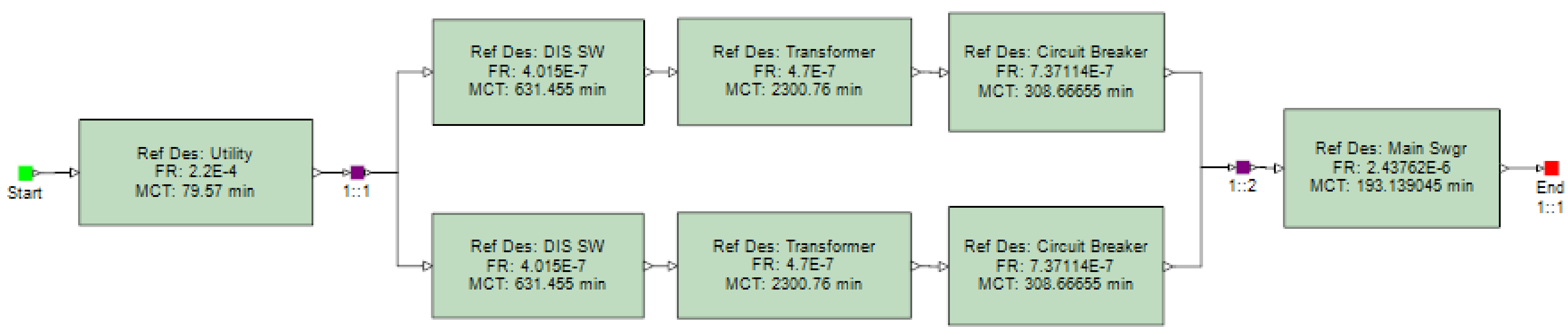


Figure 8 — RBD of Utility power to two fused disconnects, two transformers, and two circuit breakers, either one of which can power the Main Switchgear

Performing Reliability Analysis – FTA

- Some of the comparisons in P3006.7 have been done using Fault Tree Analysis
- Boolean Algebra with "OR," "AND," etc. are used to analyze the fault tree

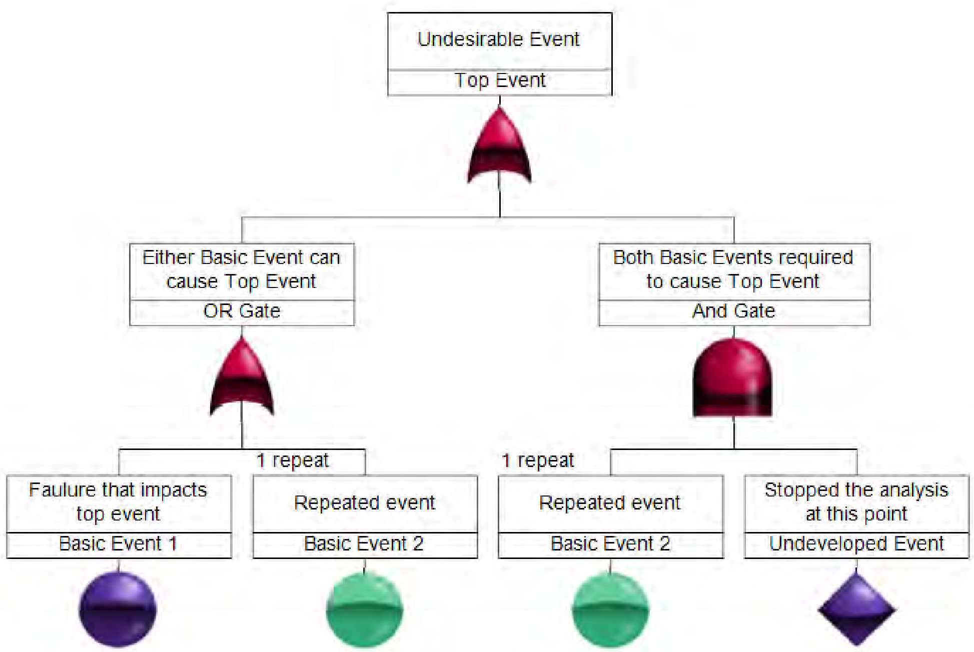
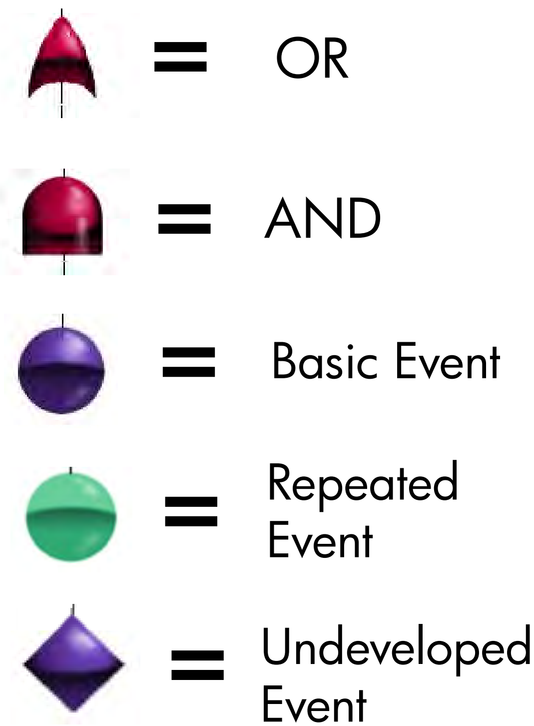


Figure 10 – Example Fault Tree



Performing Reliability Analysis – FTA

- Fault Tree for a top event of “loss of power to the Main Switchgear” fed by Utility power from two fused disconnects, two transformers, and two circuit breakers

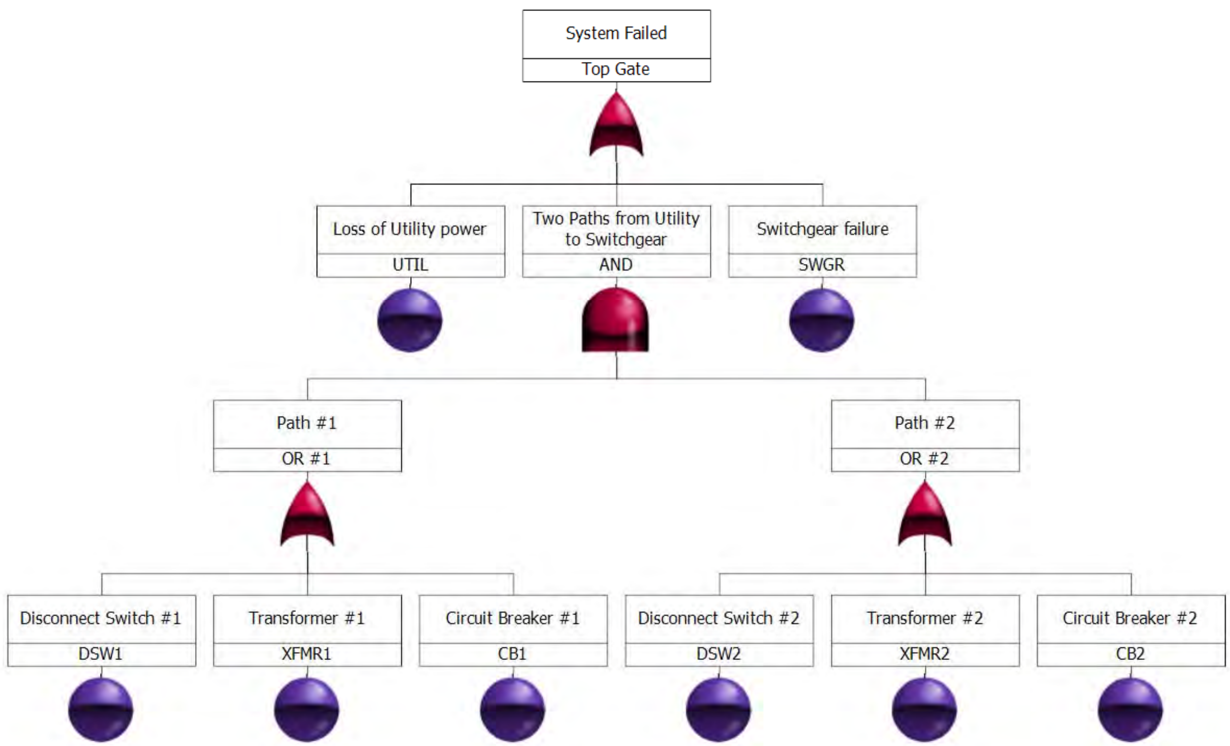
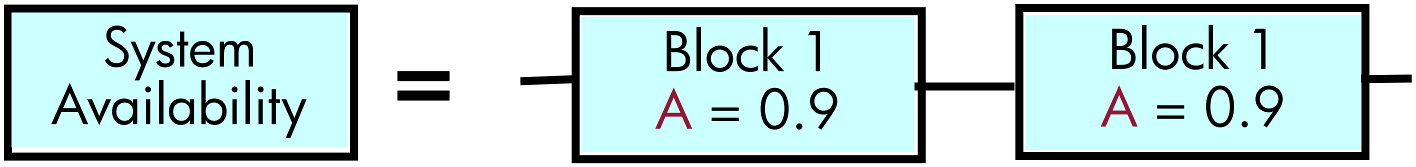


Figure 11 – FTA for power to Main Switchgear

Availability for multiple components

Series System – Each block is a Single Point of Failure (SPOF)

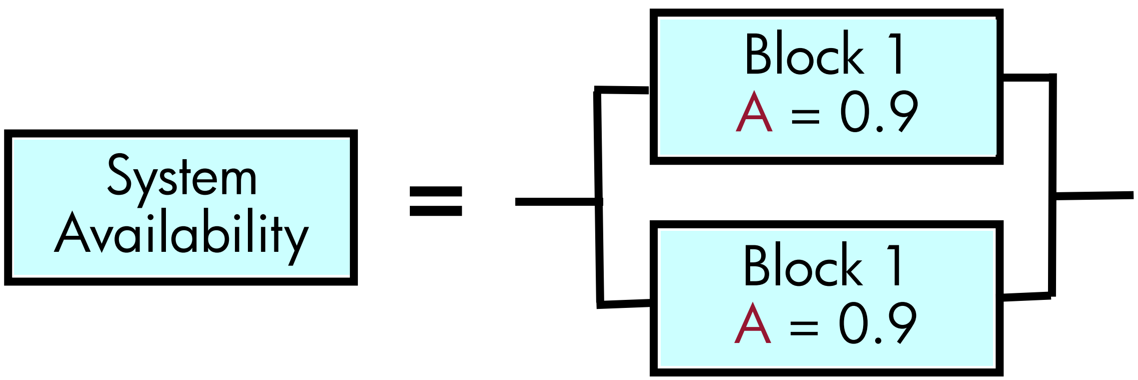


This is also "AND" for **FTA**

Each **component** has availability of 90% or 0.9 (one "9")

0.81 = 0.9 x 0.9

Parallel System (having redundancy)



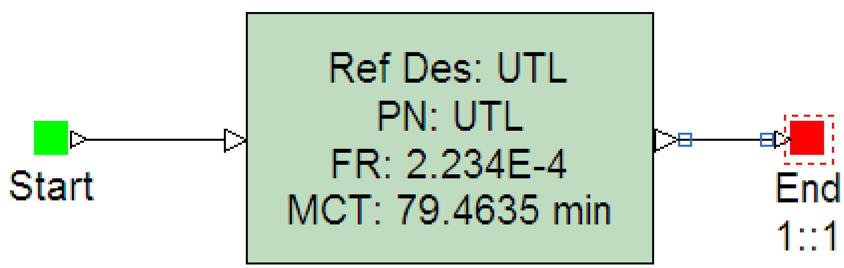
This is also "OR" for **FTA**

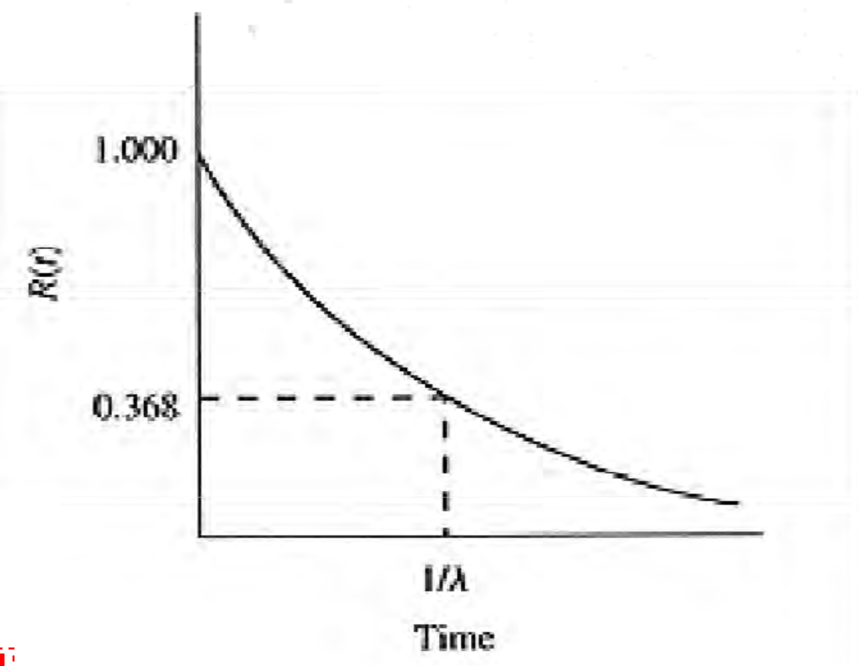
0.99 = 1 – [(1- 0.9) x (1- 0.9)]

Reliability vs. time

- For a single block that has a constant failure rate λ, reliability as a function of time is:

$$R(t) = e^{-\lambda t}$$

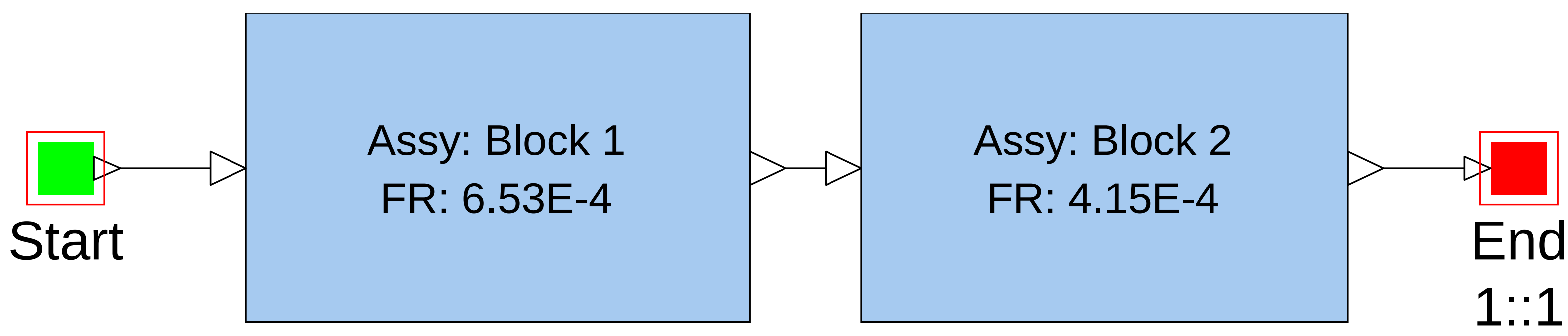




Reliability for multiple components

- For two blocks in *series* with failure rates of $\lambda 1$ and $\lambda 2$, the reliability as a function of time R(t) is:

$R(t) = R(1) \times R(2) = e^{-(\lambda 1 + \lambda 2) t}$ This is also "AND" for FTA



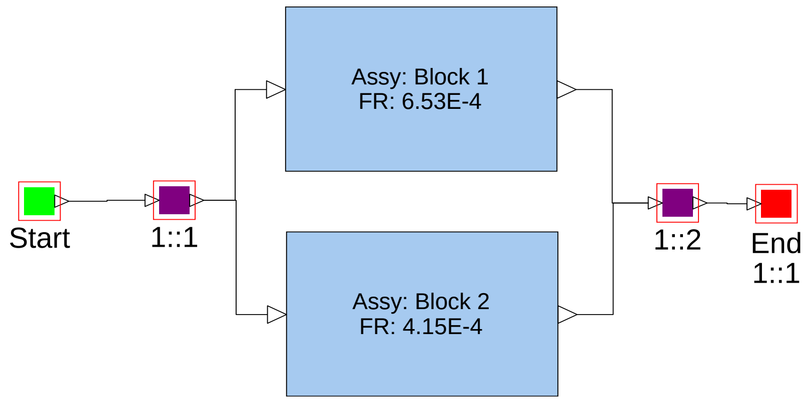
Reliability for multiple components

- For two parts in *parallel* with redundancy, where 1 out of 2 is necessary for successful operation, the reliability as a function of time R(t) is:

$$R(t) = R(1) + R(2) - [R(1) \times R(2)]$$

$$R(t) = e^{-\lambda 1 t} + e^{-\lambda 2 t} - [e^{-(\lambda 1 + \lambda 2) t}]$$

This is also "OR" for FTA

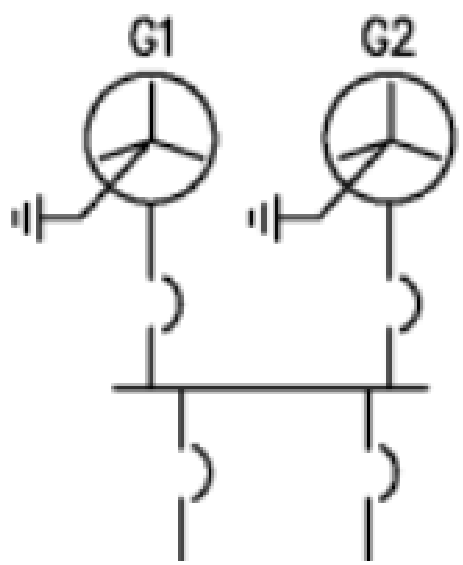


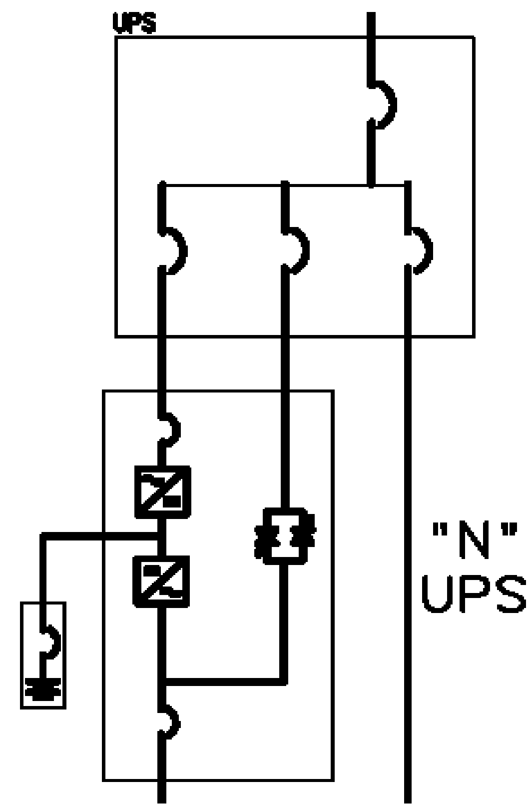
Component failure data is required to perform Reliability analysis

- The primary source of failure and repair rates used for the modeling of critical electrical (and mechanical) distribution systems is IEEE Gold Book, Standard 493-2007 Recommended Practice of the Design of Reliable Industrial and Commercial Power Systems
- A large part of the of the data in the IEEE Gold Book was provided by the Army Corp of Engineers which was collected as part of the Power Reliability Enhancement Program (PREP)
- Another source is the Reliability Analysis Center (RAC) Non-electronic Parts Reliability Data

Data center nomenclature – N

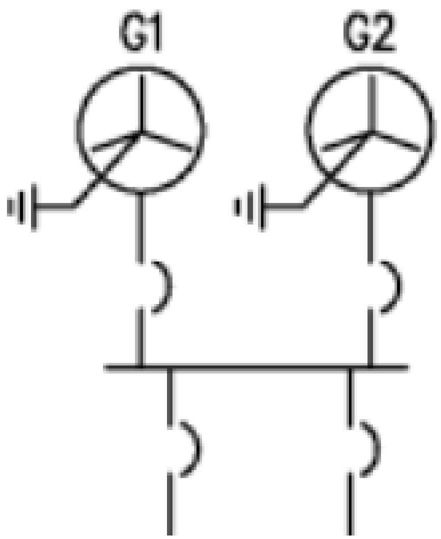
- A single piece of equipment by itself is "N"
- If there are two, but both are needed to carry the load, that is still "N"
- "N" means the "number needed"

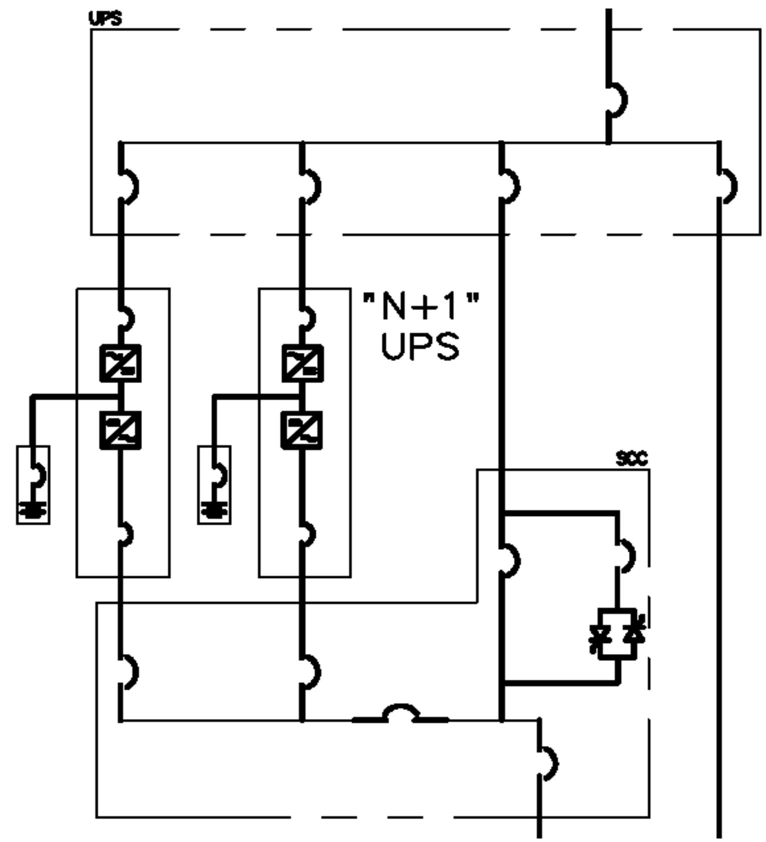




Data center nomenclature – N+1

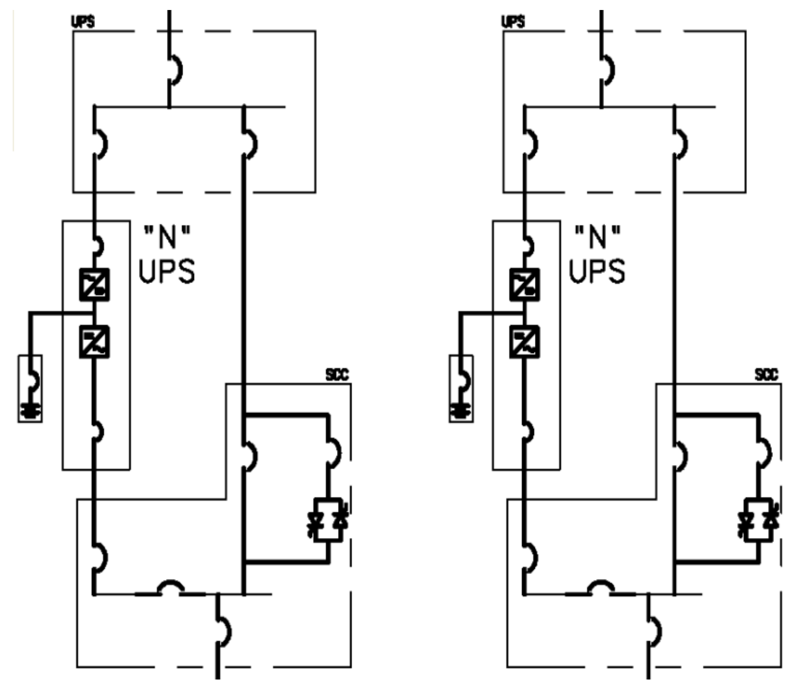
- "N + 1" means that there is a spare unit; one is needed to carry the load and the second one is redundant
- This is "component redundancy," since only the UPS (or generator) is redundant

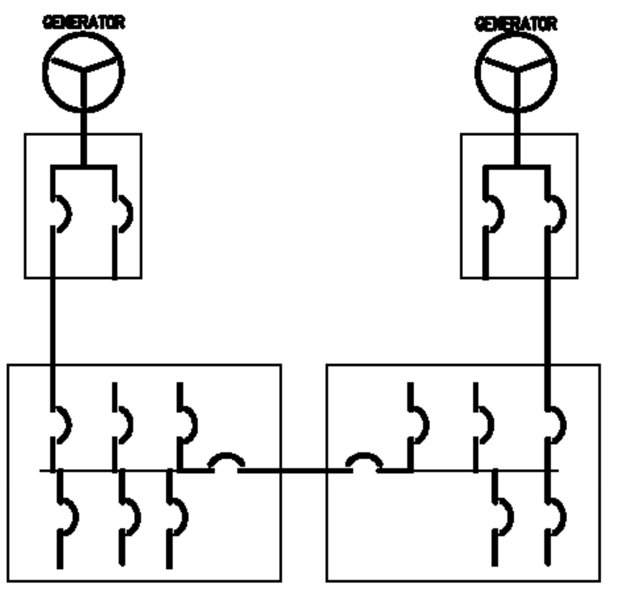




Data center nomenclature – 2N

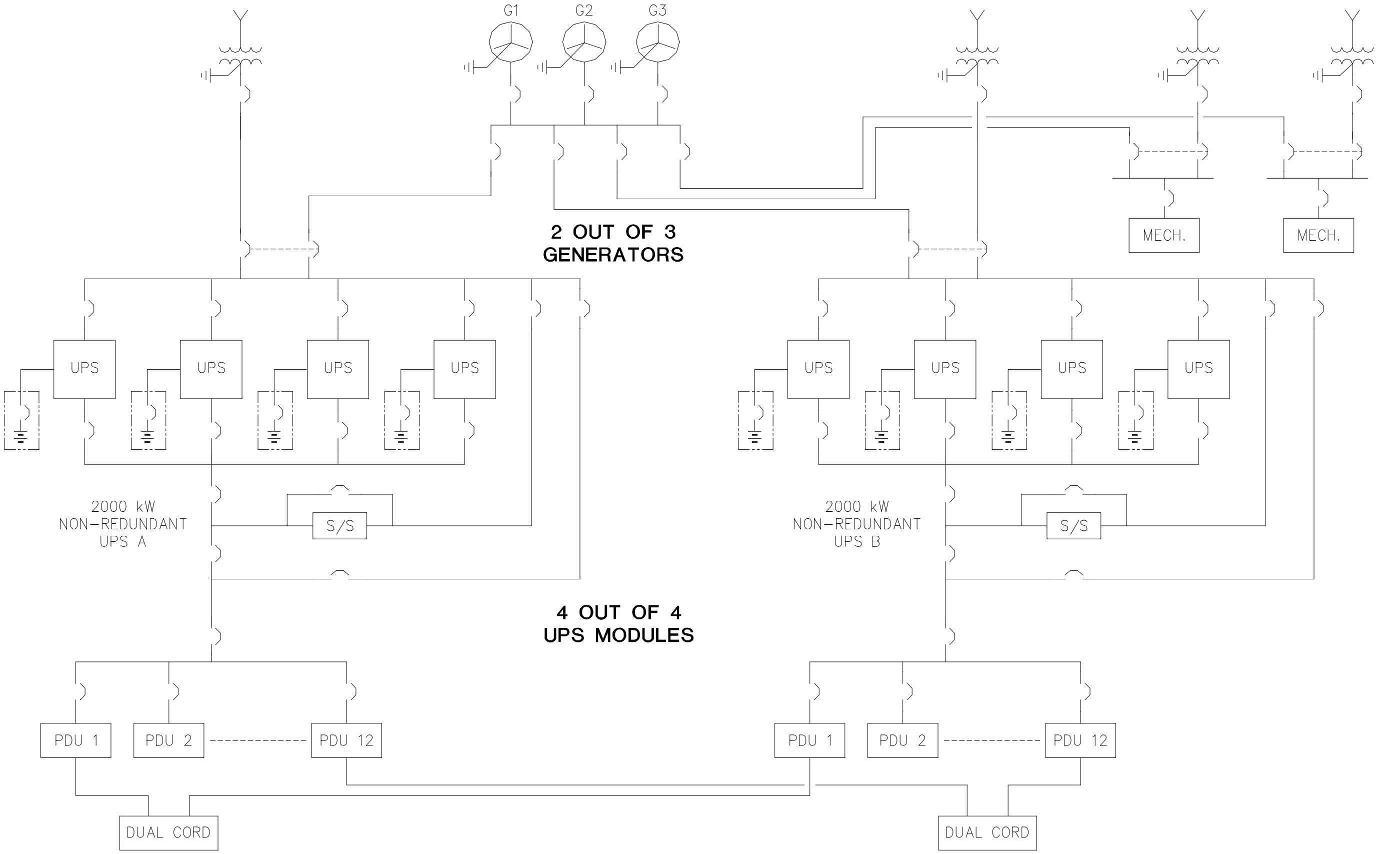
- “2N” means that there are two systems; one system is needed to carry the load and the second one is redundant
- This is “system redundancy,” since there two separate systems





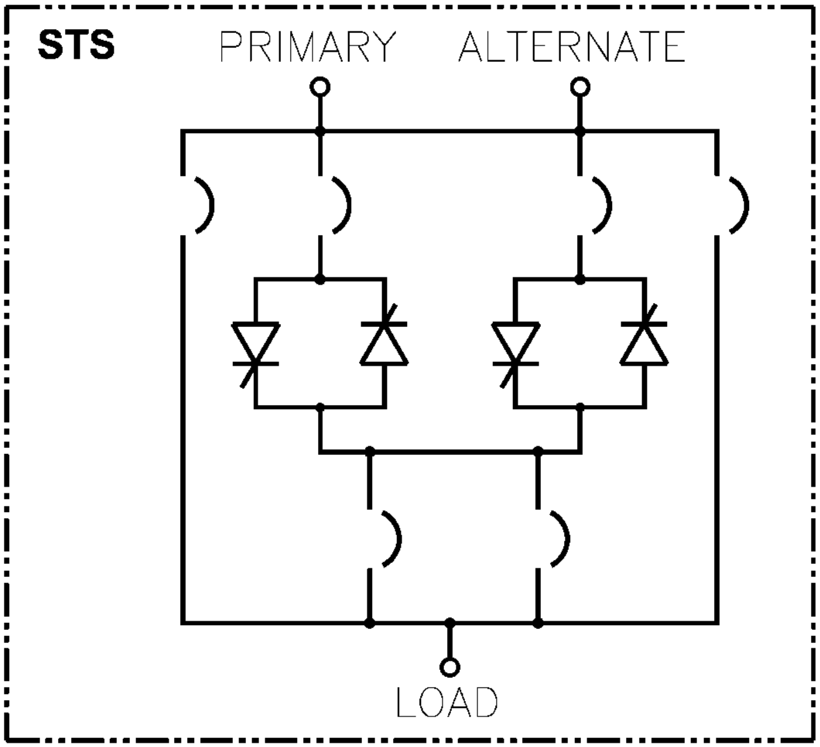
When in doubt – be specific

The design below is "2N" for the UPS system, but "N+1" for the standby generators



Special equipment - STS

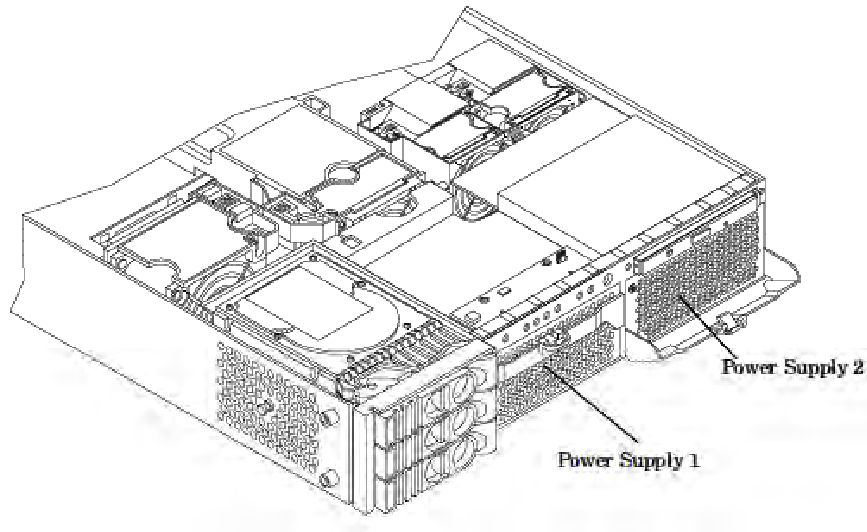
- Static Transfer Switches (STS) were developed to improve the reliability of power to the IT equipment
- STS is designed to transfer between sources in ¼ of a cycle and therefore the IT equipment is unaffected

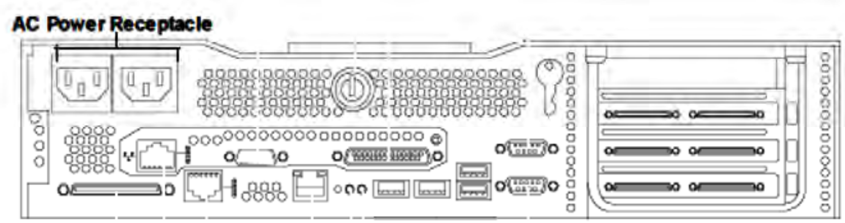


Single and Dual cord IT equipment

Another very important consideration is the configuration of the power supplies in the IT equipment itself

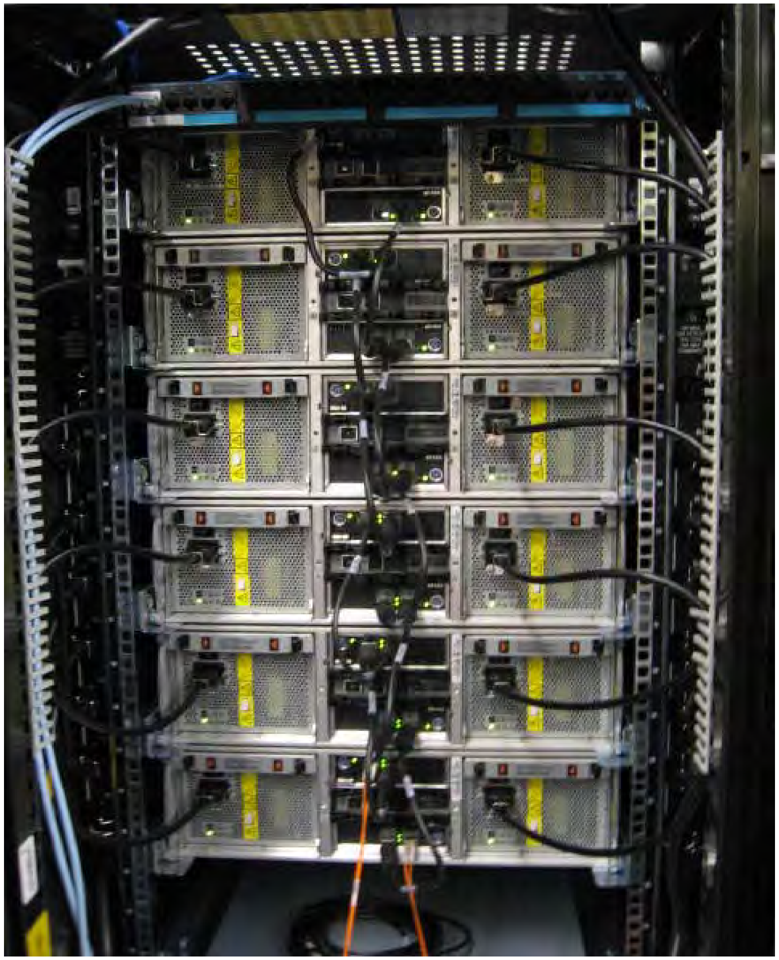
- "Single cord" IT equipment means there is only one power cord supplying it
- "Dual cord" IT equipment has two power cords, each one individually capable of carrying the load





Dual cord IT equipment

- We will see later in this presentation that it is very important to properly connect the Dual cord IT equipment so each cord is powered by a different source



Special Mechanical equipment - CRAC

- Computer Room Air Conditioning (CRAC) units have been used to provide cooling since the early main frame computers were developed

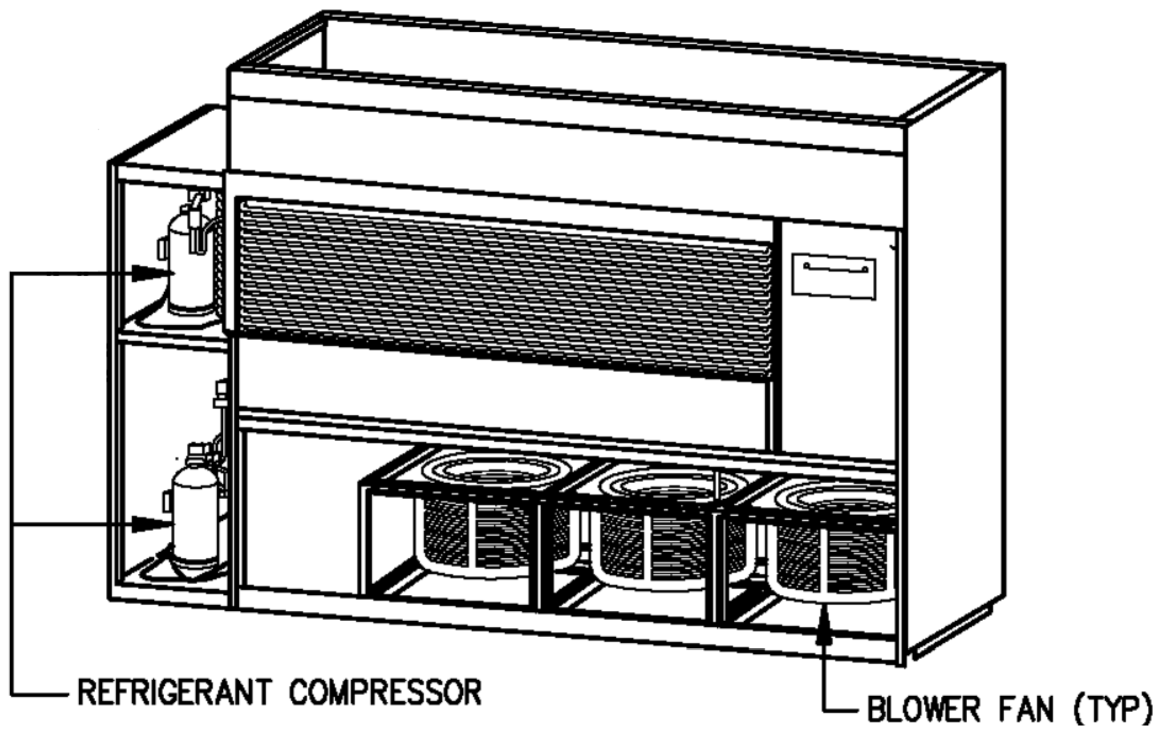


Figure 15 – N + 1 generators and UPS

The design below is "N+1" for the standby generators and UPS system to single cord loads

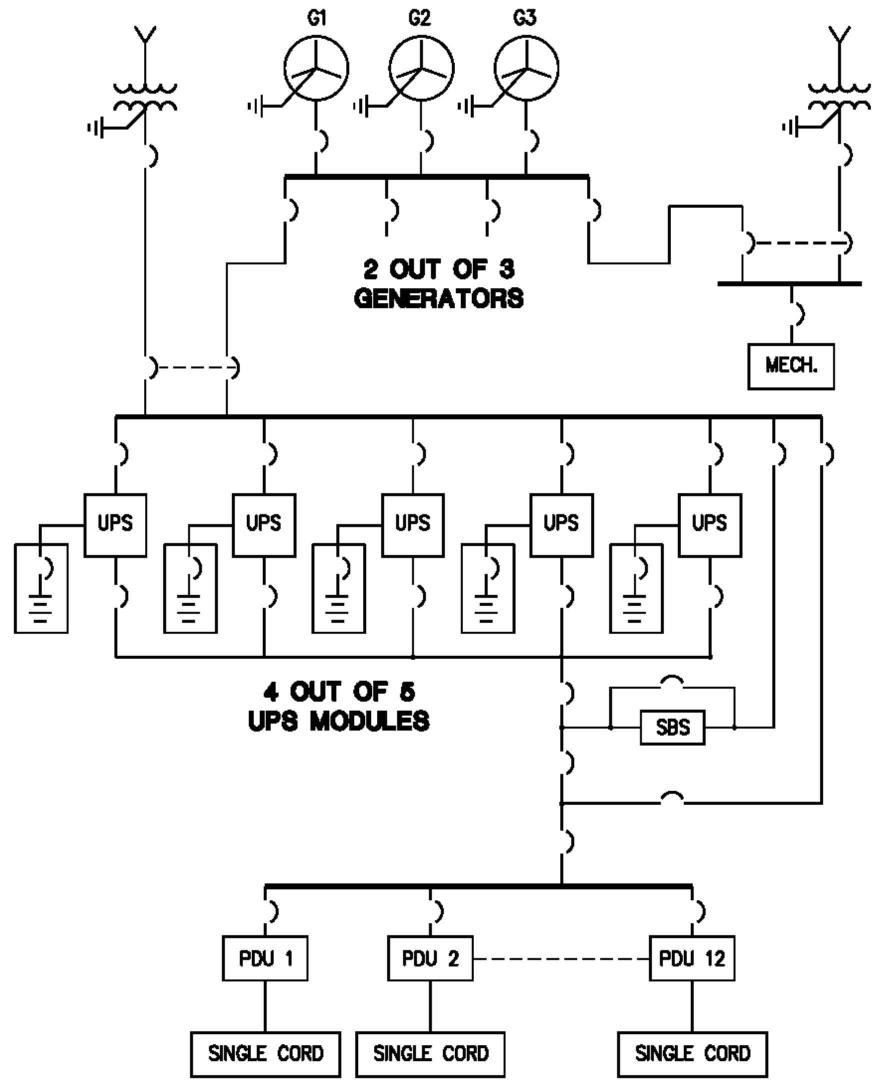


Figure 16 – 2N electrical distribution

The design below is "2N" for the UPS system and standby generators

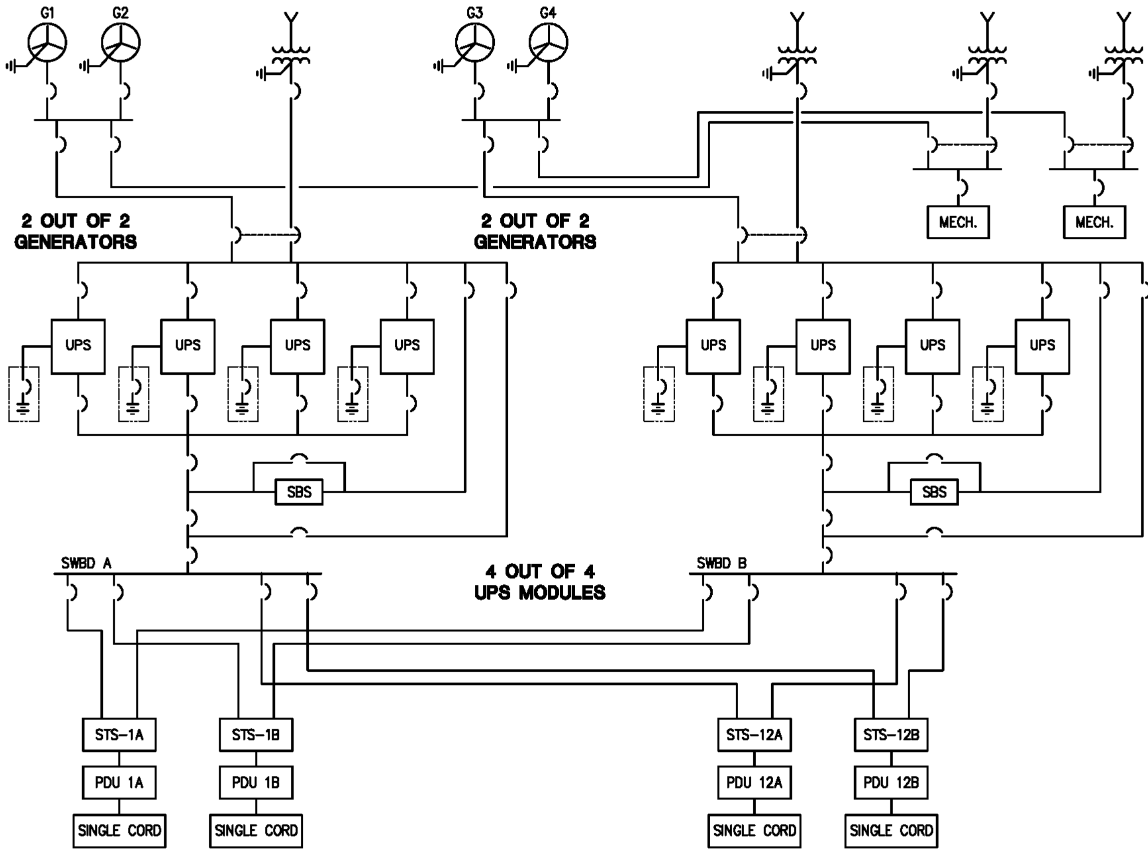


Figure 17 – N+1 gens, 2(N+1) UPS system

The design below is N+1 standby generators and 2(N+1) UPS system

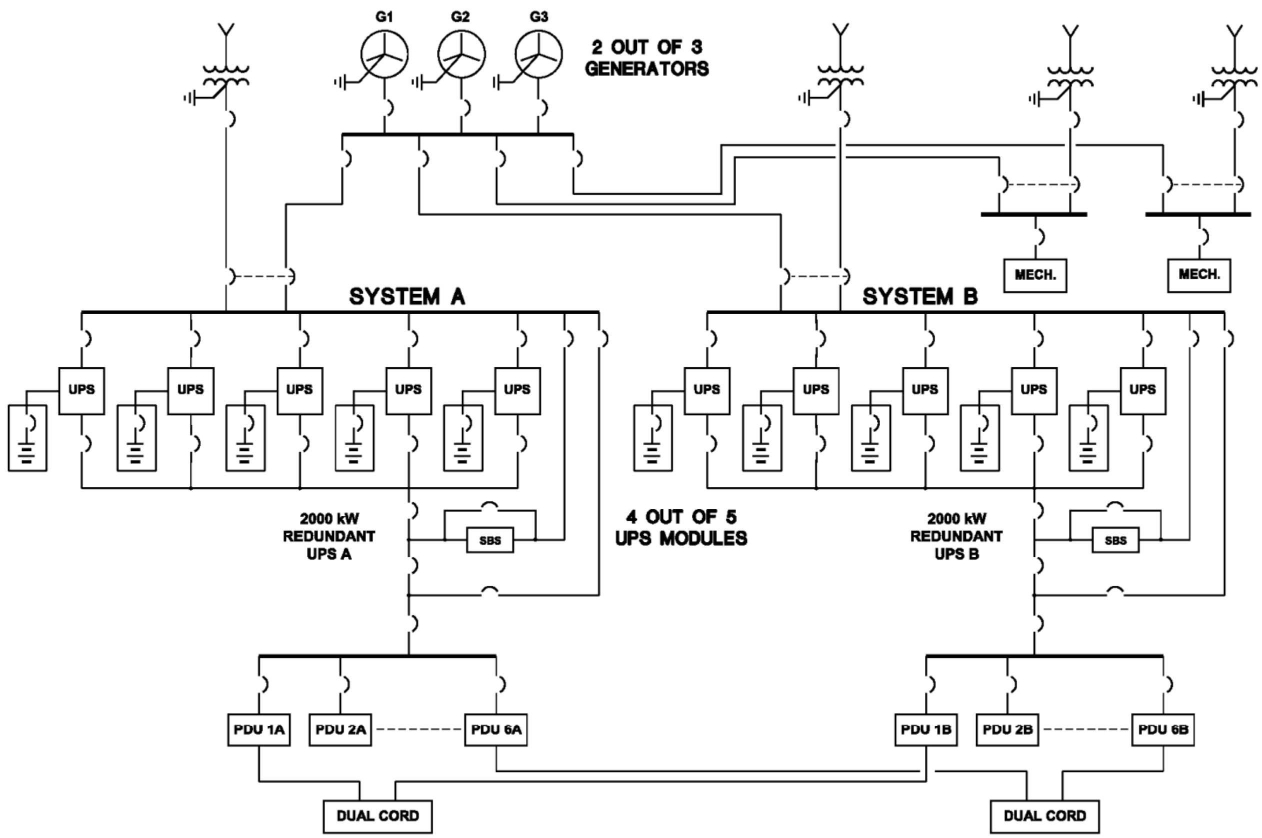
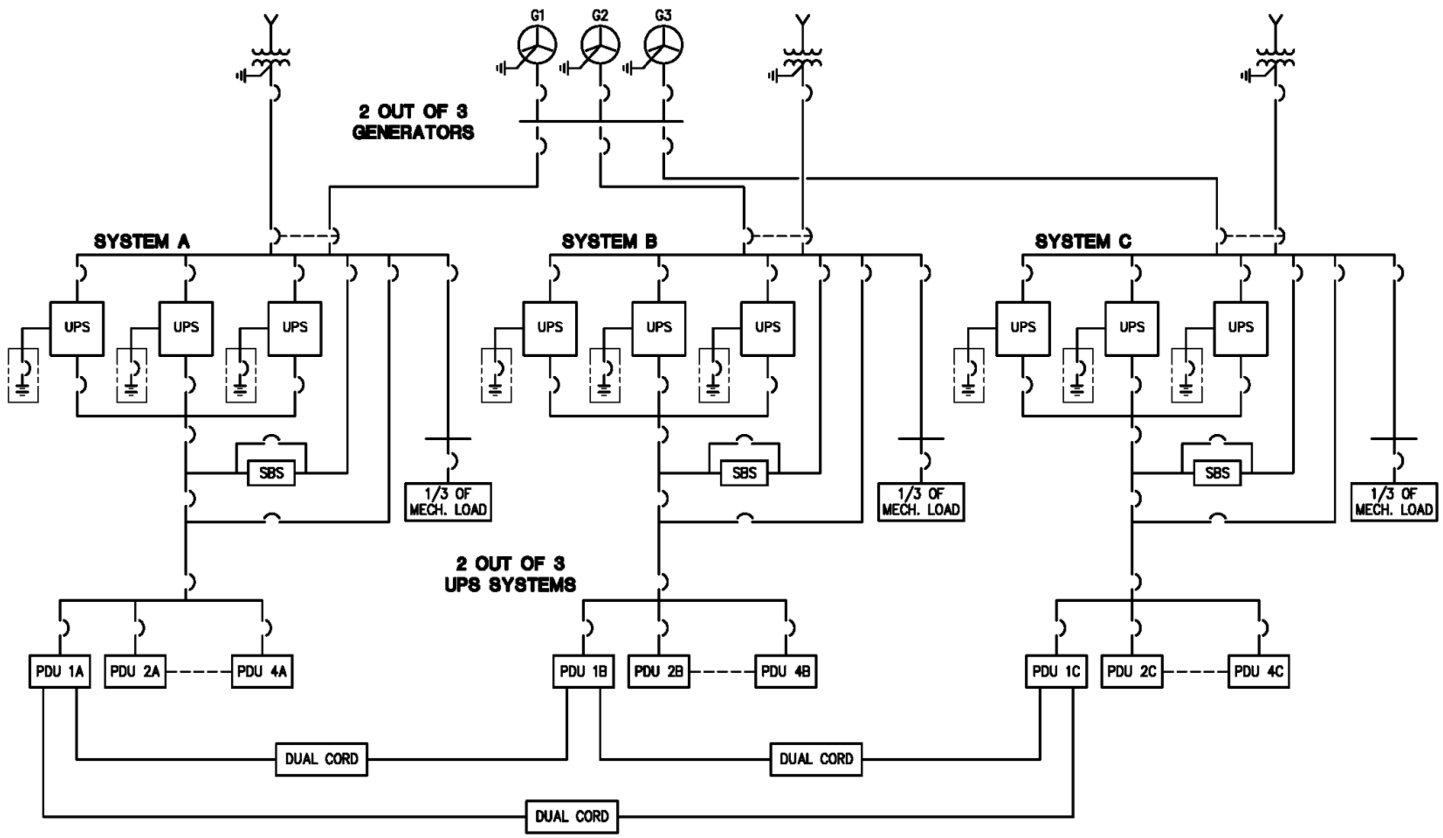


Figure 18 – Distributed Redundant UPS

The design below is N+1 standby generators and Distributed Redundant 2 of 3 UPS system



Reliability and availability – single cord

Name	Description of Critical Distribution System	MTBF (years)	MTTR (Hours)	Inherent Availability	Probability of Failure
Figure 15: N + 1 (GEN + UPS)	Gen (2-3), UPS (4-5) 12 single cord loads	7.4	11.29	0.9998253	49.11%
Figure 16: 2N (GEN + UPS)	2X [Gen (2-2), UPS (4-4)] 12 STS/PDU single cord loads	8.9	10.96	0.9998592	39.82%
N+1 GEN 2(N + 1) UPS	Gen (2-3), 2X [UPS (4-5)] 12 STS/PDU single cord loads	8.9	11.06	0.9998576	39.47%
N+1 Gen: DR (2-3) UPS	Gen (2-3), DR (2-3) X [UPS (2-3)], 12 STS/PDU single cord loads	8.7	11.08	0.9998549	40.71%

MTBF – Mean Time Between Failures

Reliability and availability – dual cord

Name	Description of Critical Distribution System	MTBF (years)	MTTR (Hours)	Inherent Availability	Probability of Failure
2N Gen 2N UPS	2X [Gen (2-2), UPS (4-4)] 12 dual cord loads	68.9	2.57	0.9999958	6.96%
N+1 Gen 2N UPS	N + 1 Gen (2-3), 2N UPS(4-4) 12 dual cord loads	66.6	2.50	0.9999957	7.57%
Figure 17: N+1 Gen 2(N + 1) UPS	Gen (2-3), 2X [UPS (4-5)] 12 dual cord loads	67.5	2.50	0.9999958	7.18%
Figure 18: N+1 Gen DR (2-3) UPS	Gen (2-3), DR (2-3) X [UPS 2-3], 12 dual cord loads	65.9	2.52	0.9999956	7.69%

MTBF – Mean Time Between Failures

Figure 27 – Chilled Water Central Plant

The design below is N+1for the cooling towers, chillers and pumps and N+4 for the CRAH units

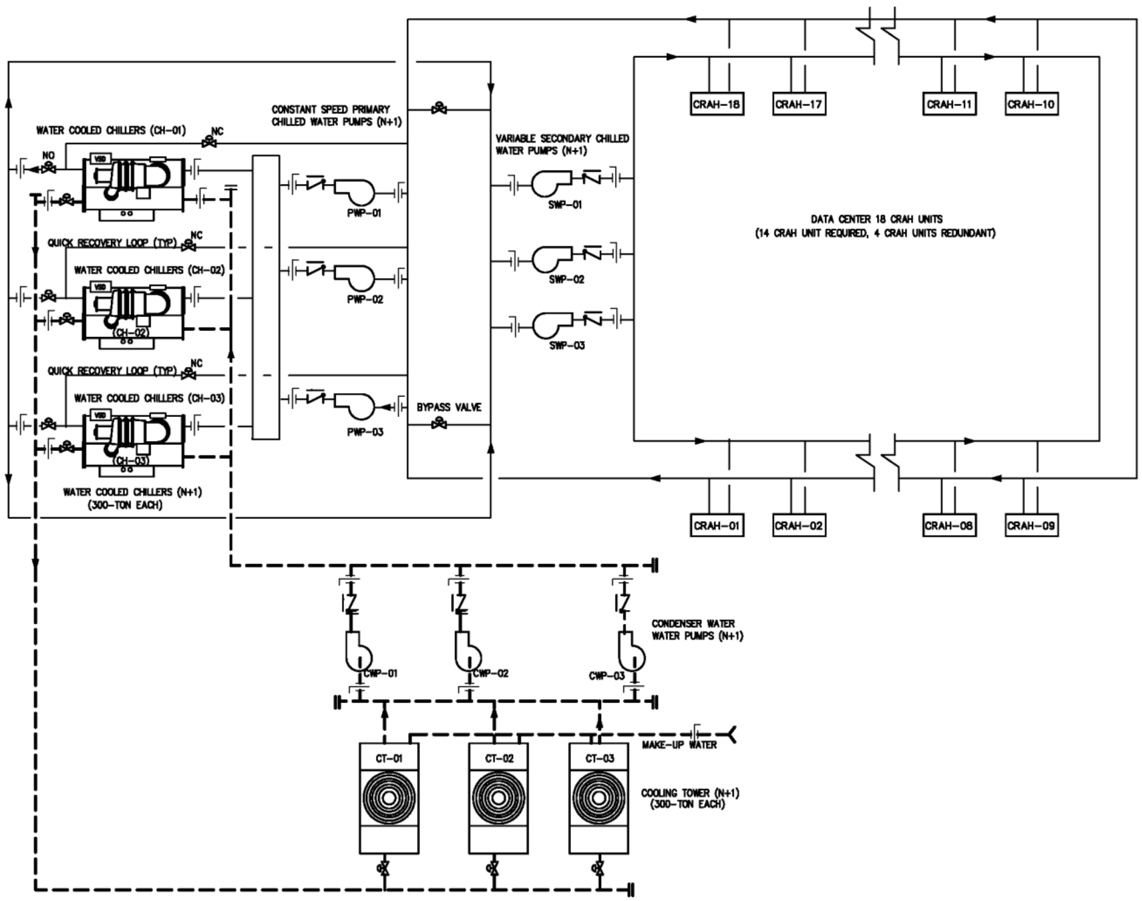


Figure 29 – Air Cooled Chilled Water Plant

The design below is N+1for the chillers and pumps and N+4 for the CRAH units

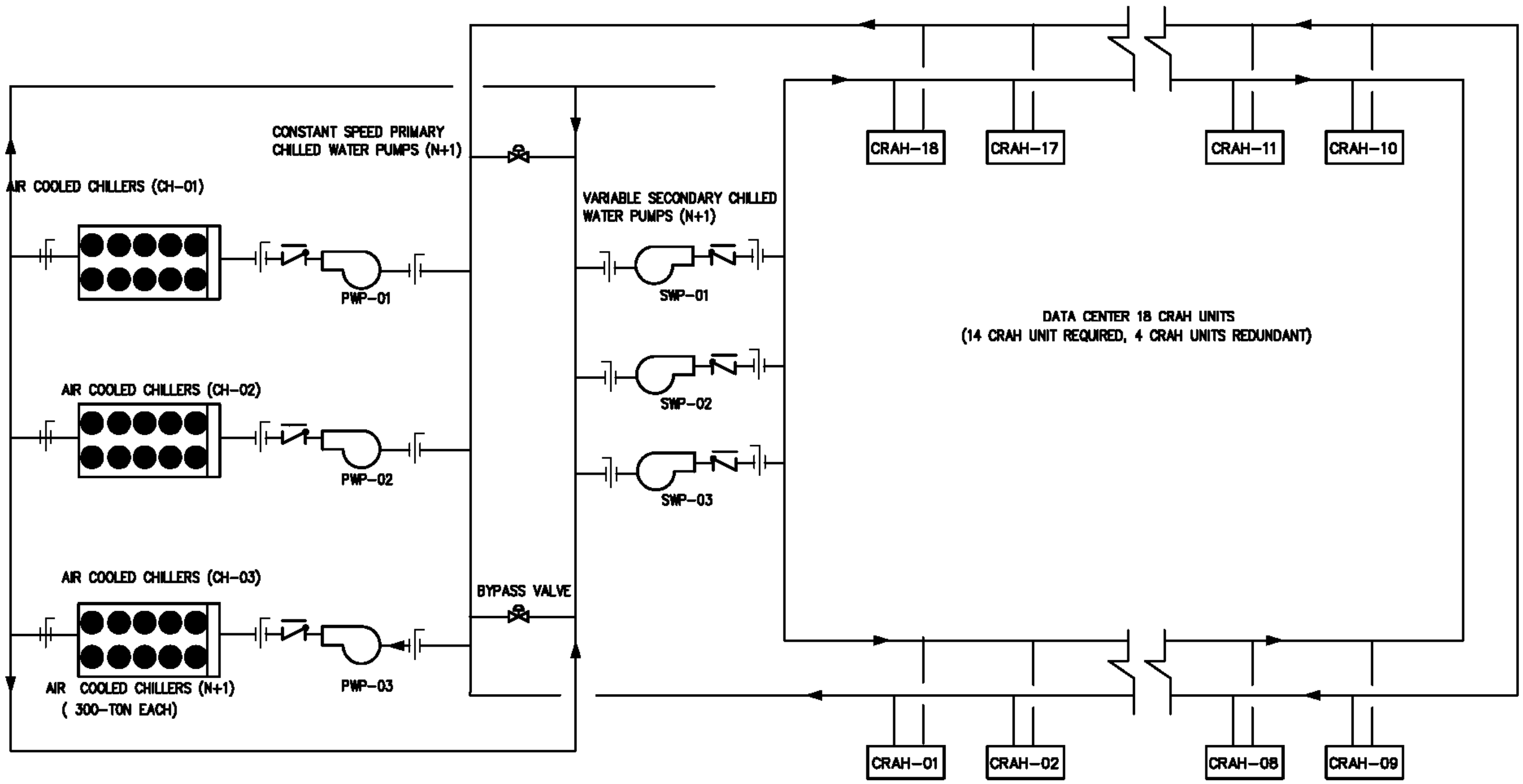
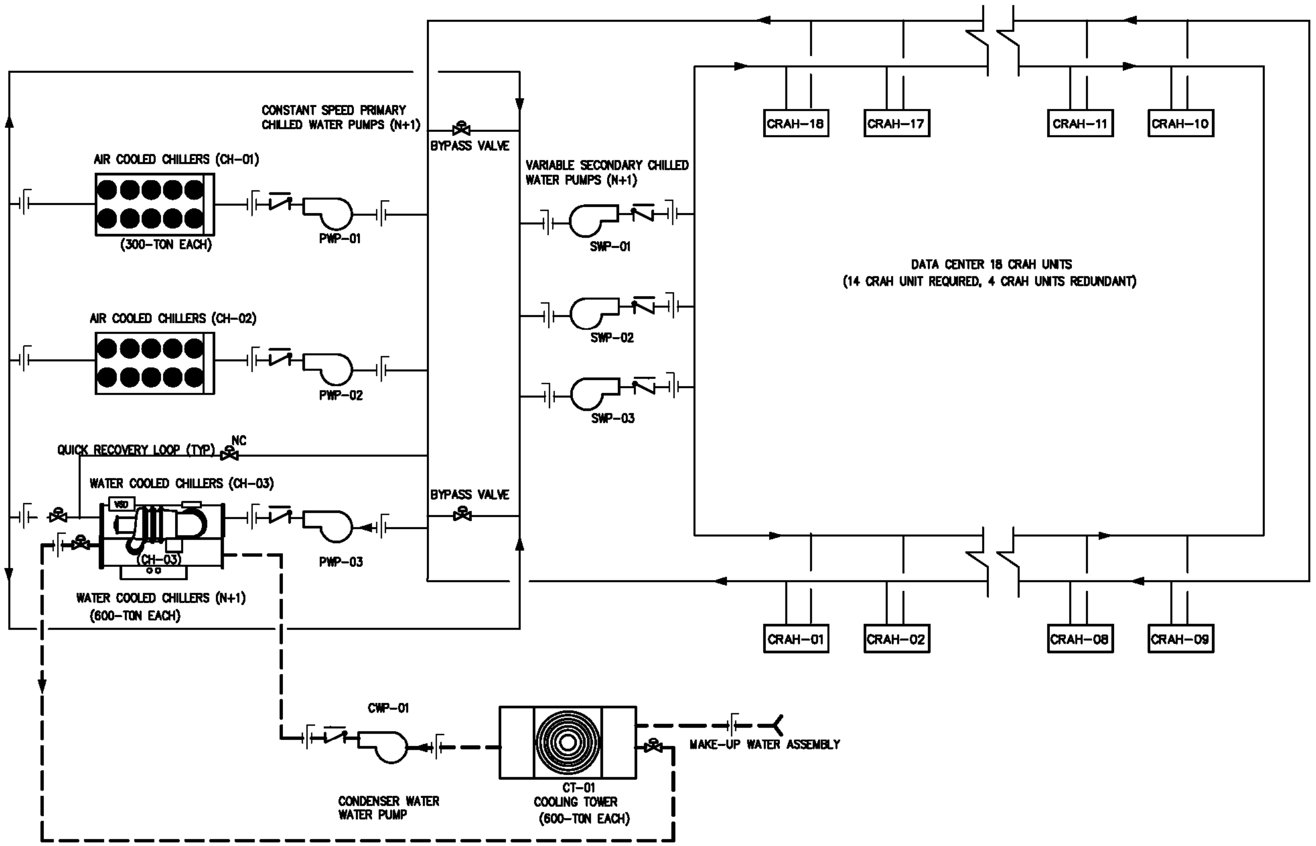


Figure 30 – Air & Water Cooled CWP

The design below is N+N for the air cooled and water cooled chillers, pumps, etc. and N+4 for the CRAH units



Reliability and availability – Mechanical

Name	Description of Critical Distribution System	MTBF (years)	MTTR (Hours)	Inherent Availability	Probability of Failure
Figure 27	2 of 3 [CT, Dedicated (CWP, WC CH, PWP), SWP] + (14 of 18) CRAH units	77.9	6.65	0.9999903	1.72%
Figure 28	2 of 3 [CT, CWP, WC CH, PWP, SWP] + (14 of 18) CRAH units	78.1	6.60	0.9999904	1.62%
Figure 29	2 of 3 [AC CH, PWP, SWP] + (14 of 18) CRAH units	495	13.46	0.9999969	0.95%
Figure 30	1 [CT, CWP, WC CH, PWP] + 2 [AC CH, 2 PWP] + (2 of 3 SWP) + (14 of 18) CRAH units	226	8.96	0.9999955	2.17%

MTBF – Mean Time Between Failures

Figure 32 – 2N Electrical System feeding N+1 Water Cooled CWP

The design below powers the 2 out of 3 water cooled chillers, pumps, etc. from a 2N electrical system

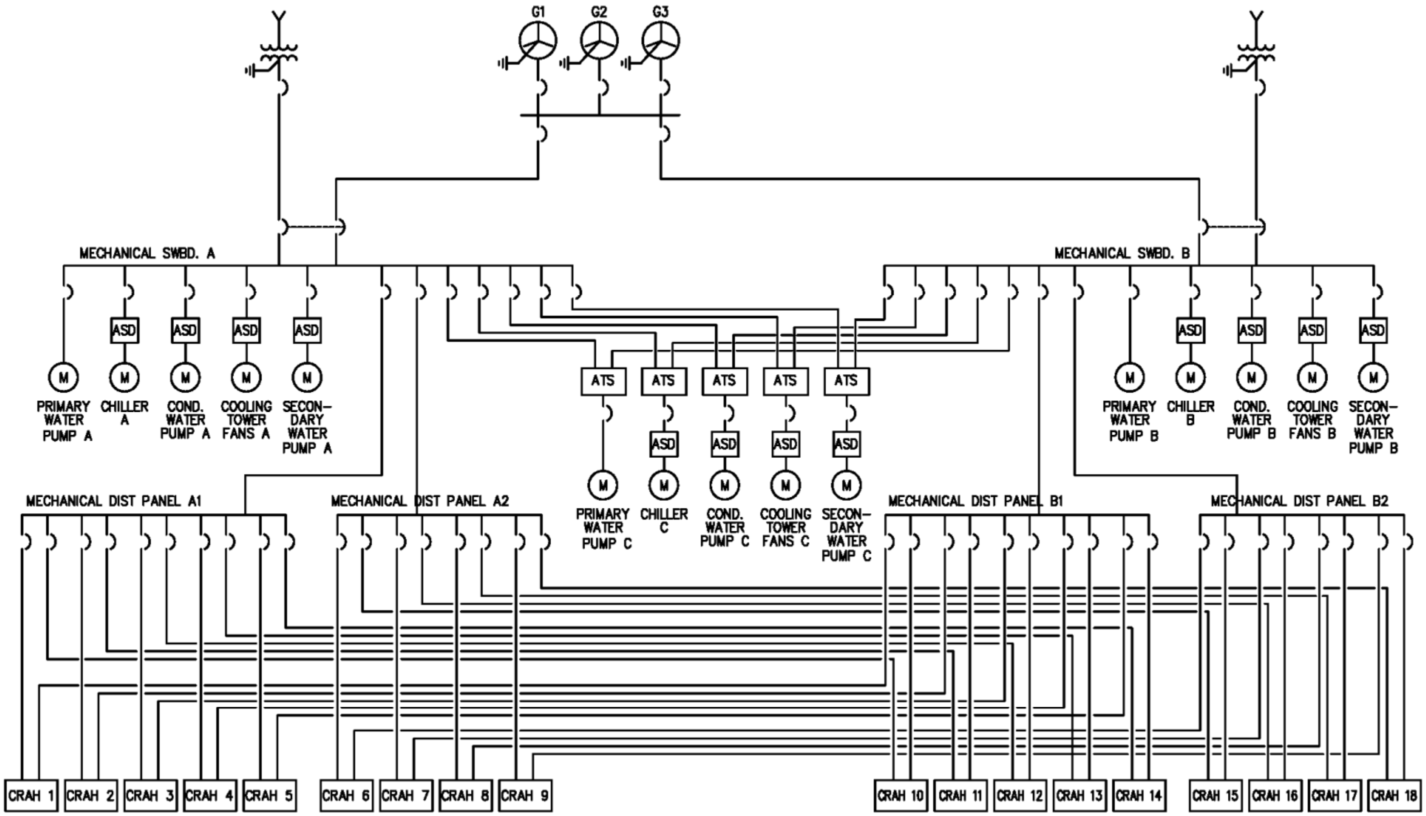


Figure 33 – 2N Electrical System feeding N+1 Water Cooled CWP

The design below uses 3 switchboards with circuit breaker transfer pairs from a 2N electrical system

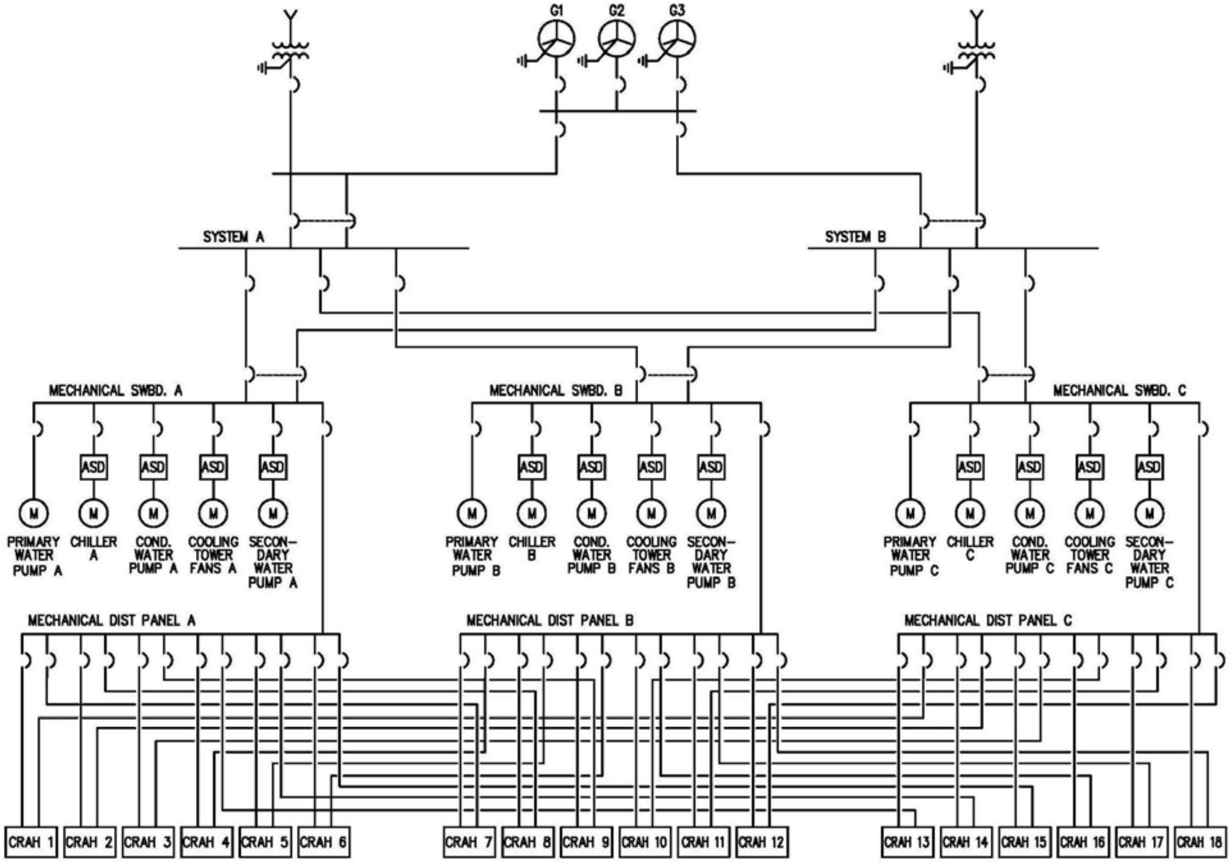
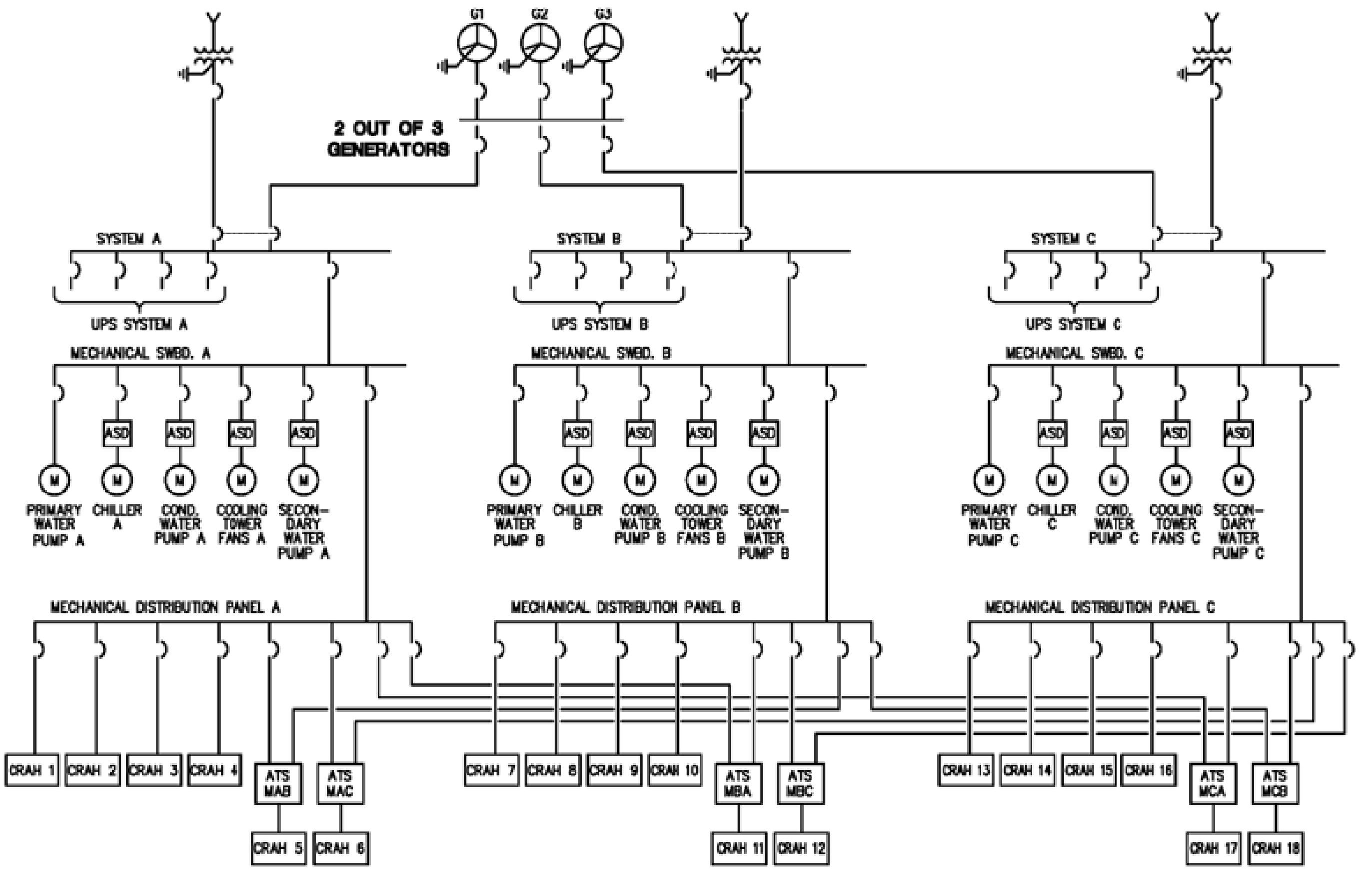


Figure 34 – 2 of 3 Electrical & Mechanical Systems

The 2 of 3 Distributed Redundant electrical system with a 2 of 3 Water Cooled Chiller plant and N+4 CRAH units

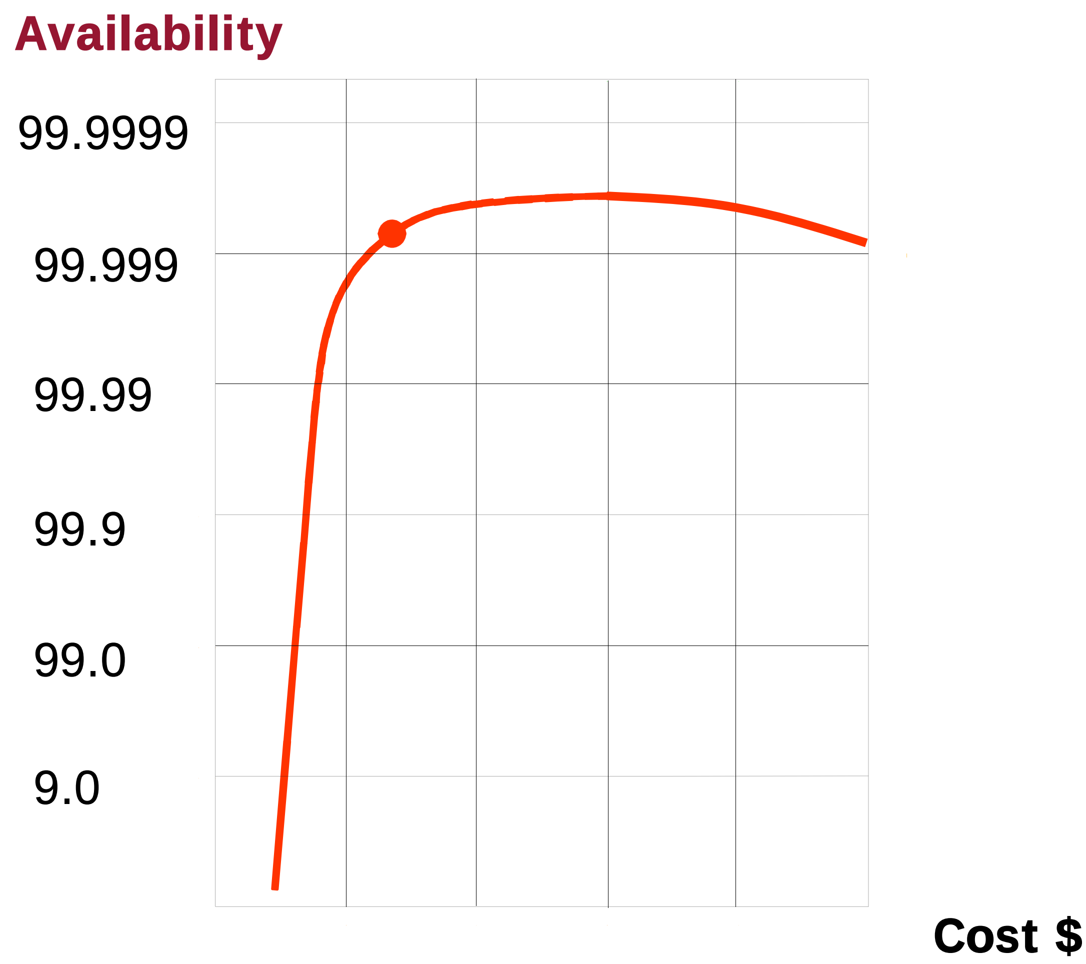


Reliability and availability – Mechanical

Name	Description of Critical Distribution System	MTBF (years)	MTTR (Hours)	Inherent Availability	Probability of Failure
Figure 34 without ATSs	2 of 3 Mech Swbds feeding (14 of 18) CRAH	5.2	2.78	0.9999389	61.62%
Figure 34	2 of 3 Mech Swbds feeding (14 of 18) CRAH with 6 ATS for 6 CRAH	70.2	2.00	0.9999968	6.86%
Figure 34 with contactors	2 of 3 Mech Swbds feeding (14 of 18) CRAH with two contactors in each	147.4	1.20	0.9999991	3.52%
Figure 32	2N feeding 2 Mech Swbds with ATS feeding one set of chillers, etc. + (14 of 18) CRAH with two contactors in each	90.7	1.61	0.9999980	5.69%
Figure 33	2N feeding 2 of 3 Mech Swbds with breaker transfer pairs + (14 of 18) CRAH with two contactors in each	192.3	1.15	0.9999993	2.79%

MTBF – Mean Time Between Failures

Cost Optimization is greatly assisted with Reliability and Availability analysis



Questions?

Robert Schuerger, PE
Principal Reliability Analysis
bschuerger@hp.com

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