Datacenter Load Modeling

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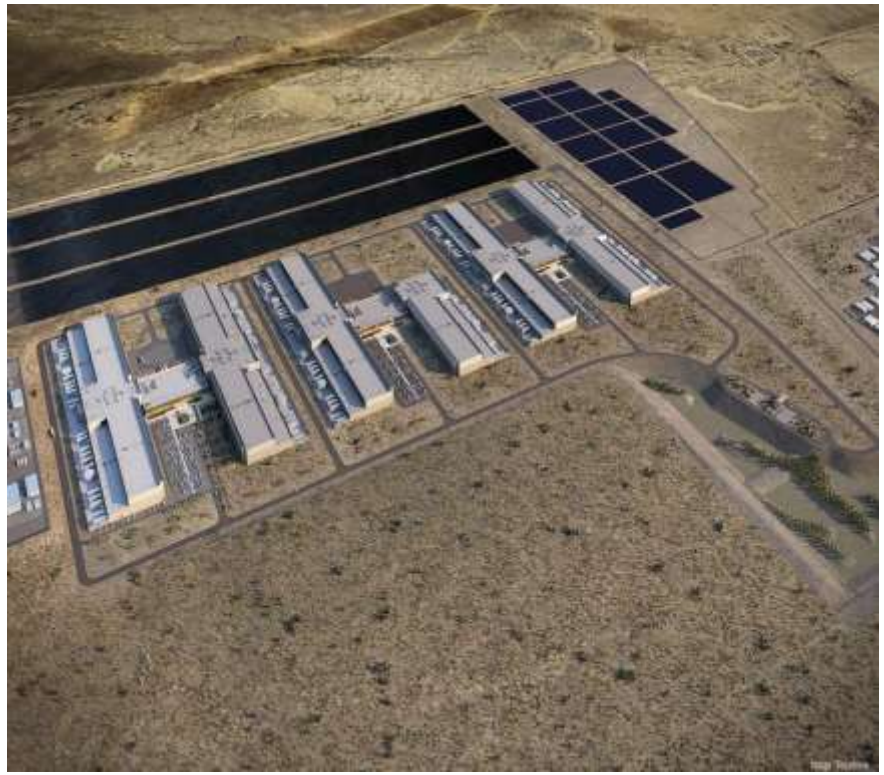
Introduction

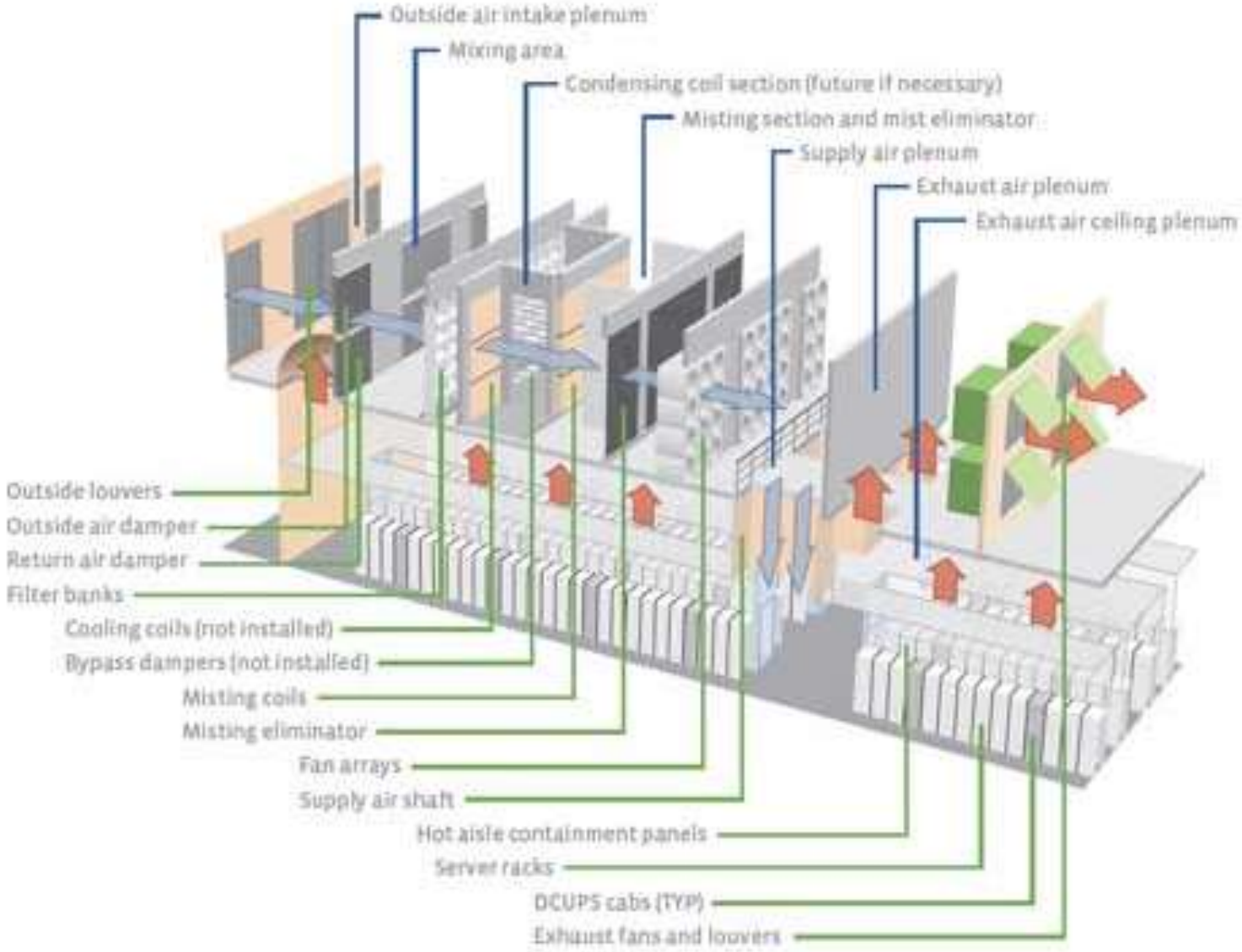
- Datacenter industry has created Open Compute project standard datacenter design.
- Used by 100s of companies including Apple, Amazon, Microsoft, Meta
- Free design and specifications.
- Higher efficiency than traditional designs.
- Scalable design built-up in data hall building blocks. Built-up in ~10 MW increments.
- Reliability with proven components and system design.
- The site pictured here has 22 data halls (~200 MW) and is located in the PNM service territory.



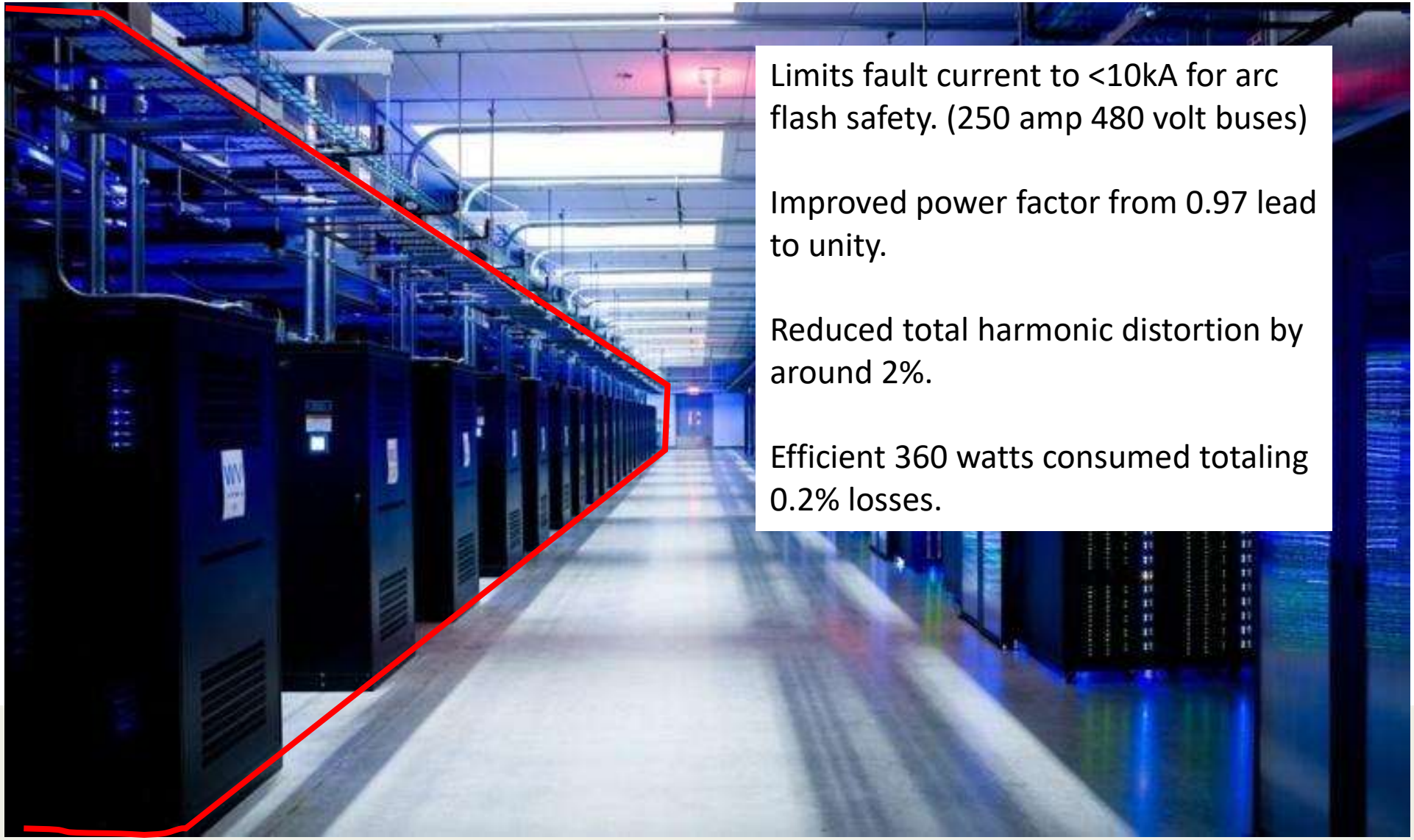
Datacenter Design

- 2N+1 redundancy: gear is loaded <50% normally
- The “+1” refers to backup generation. “Reduced gen” design has none.
  - For loss of utility (UVLS relay set for 80% at 0.5s) but not set to trigger for “brown-out” scenarios.
- Cooling load makes up around 5% of total and is 100% VFD driven pumps and fans.
- Server and network load are backed up by UPS and BBU respectively. Network load has much longer run time (hours), server load is only for switching purposes (Open transition) with 2 minute runtime.
- Utility outage is detected by drop in DC bus voltage below 48.5V for 2ms. This may not happen in a “brown-out” as the active rectifier will simply increase duty cycle, draw more current to regulate the DC voltage.

Data Hall Cross Section



Series Reactors (Reactor Power Panel RPPs)



Limits fault current to <10kA for arc flash safety. (250 amp 480 volt buses)

Improved power factor from 0.97 lead to unity.

Reduced total harmonic distortion by around 2%.

Efficient 360 watts consumed totaling 0.2% losses.

Network UPS

- Powers network equipment
- Typically loaded under 20%.
- Commercial Schneider Galaxy or Eaton PowerExpert UPS units rated at 1 MW.
- These units did switch to battery and back during the event discussed later.
- This load makes up <5% of the server load.

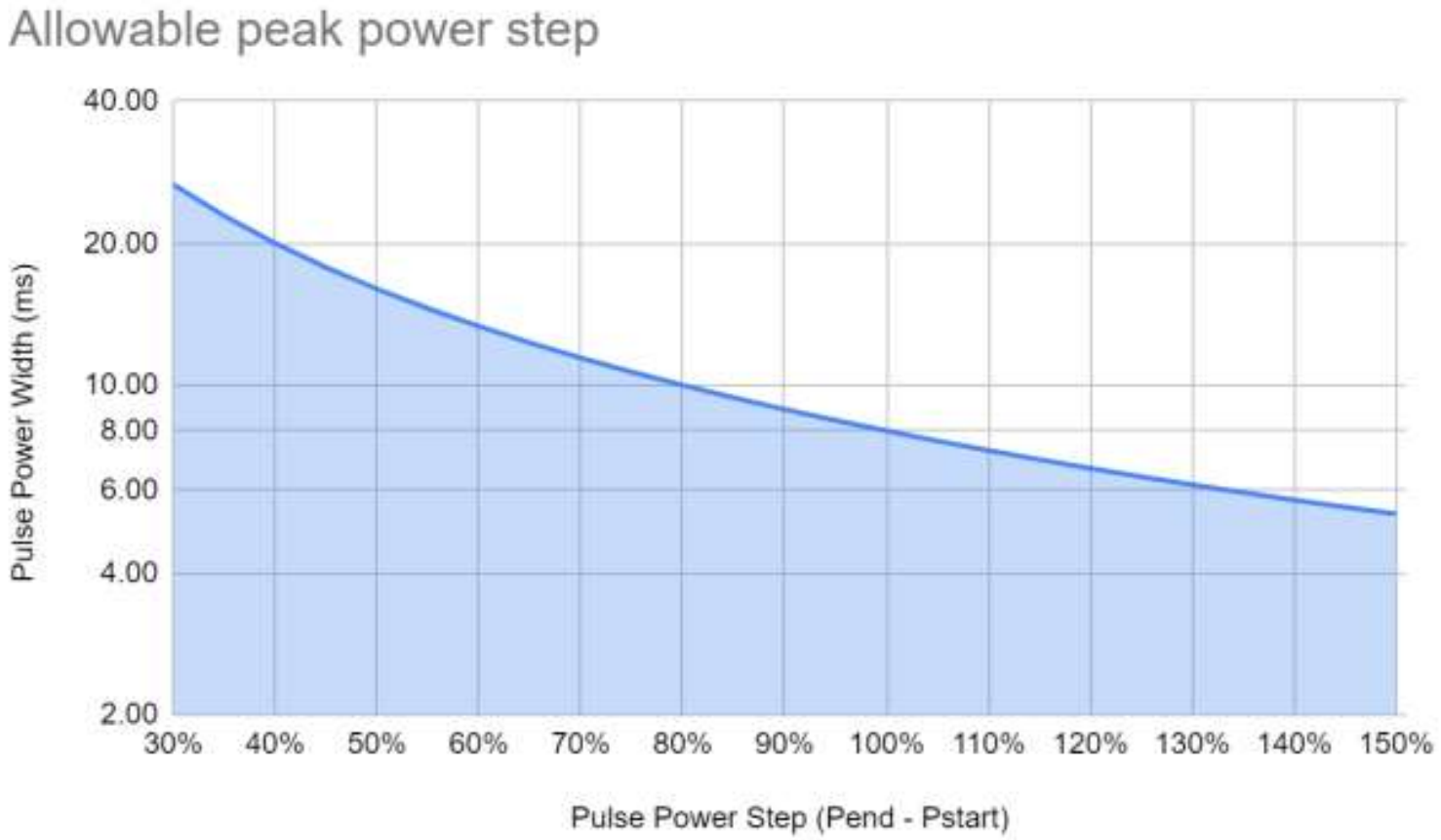
BBUs

- Rated for 2 minutes runtime to allow for open transitions.
- Lead acid chemistry - though lithium ion is under development.
- Typically built out with 2 power shelves and 2 battery shelves.
- 4kW output per BBU.
- Can only charge at 0.8 kW.
- Rack rated for either 56 or 75 kW.

https://www.murata.com/en-us/products/power/open-compute/overview/lineup/bbu

Murata Power Solutions

BBU (UPS) Can be 150% loaded



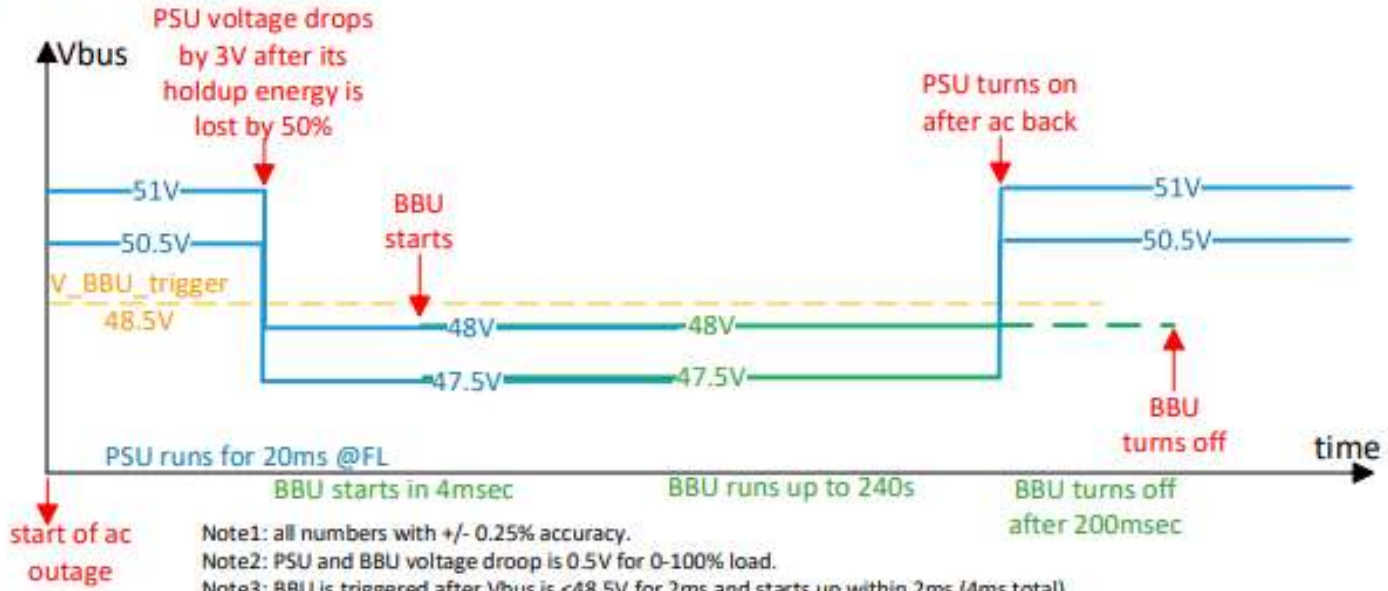
Note:
1. Absolute maximum magnitude is 150% of BBU maximum output power.
2. Average output power of BBU including peak load shall not exceed 100%.
3. Peak load frequency is TBD.
4. Minimum load before peak load step is 20%(TBD). Slew rate 1A/us.

BBU After Loss of AC

4.5. Transition between Power Shelf and BBU Shelf

BBU shall constantly monitor busbar voltage. When the busbar voltage declines to the BBU activation level 48.5V for 2ms+/-0.1ms (TBD), the BBU shelf output voltage shall ramp up to provide full power to the busbar within <2ms. During the transition, the busbar voltage shall never drop below 46V.
When the BBU shelf detects that the busbar voltage is above 48.5V for >200ms (TBD), the BBU shelf exits discharge mode.

PSU/BBU Power Transition Diagram
Figure 2



Note1: all numbers with +/- 0.25% accuracy.
Note2: PSU and BBU voltage droop is 0.5V for 0-100% load.
Note3: BBU is triggered after Vbus is <48.5V for 2ms and starts up within 2ms (4ms total).
Note4: if BBU current <0.1A and Vbus >48.5V for 200ms, BBU goes to the stand by mode.
Note5: PSU hold-up energy is 60J for loads up to 150%.
Note6: PSU 3V drop should occur after its hold-up energy is lost by 50%. This can be done by setting a proper trigger value on the PSU PFC bulk voltage.
Note7: PSU 3V drop fall time is 1ms (3V/ms.)

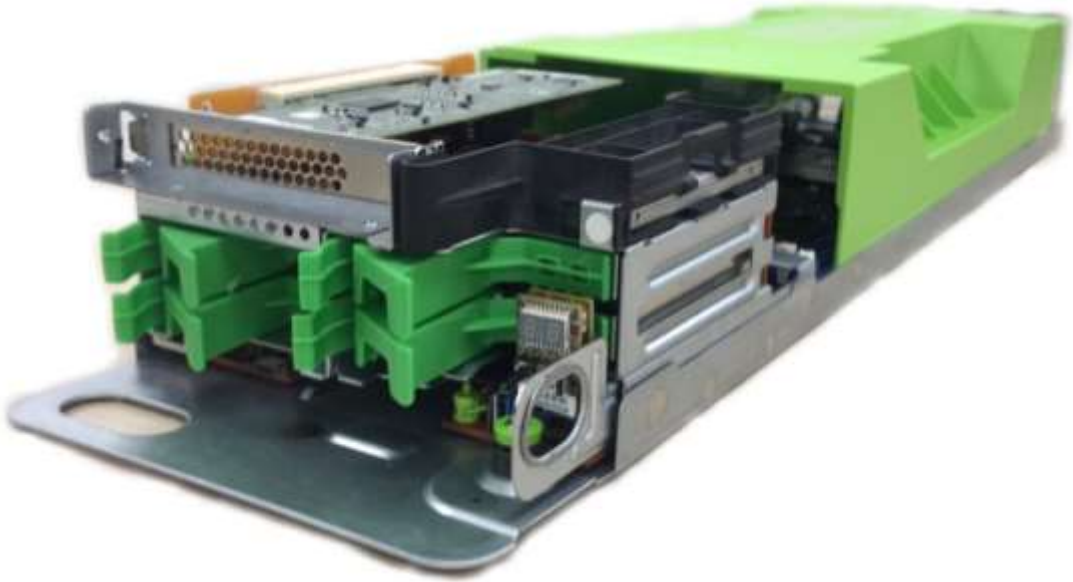
Power/Battery Shelf

- Converts 277 V line-neutral voltage from a single phase into 48 V DC for BBUs and servers.
- Dual AC input comes from separate circuits on the panel.
- Hot swappable power converters for maximum uptime.
- Battery shelf is similar in appearance but is designed to house BBUs.

Unit mounted

Servers

- 3 servers across a standard 21 inch rack. (Fit 3 servers in 2 U with this method.)
- Runs on 48V bus power from BCU
- Can buy various configurations of memory and CPU.
- Storage is done with dedicated storage servers connected over 100 gbps single mode fiber in a “Storage Area Network” SAN



Storage Servers

- 4U rack mounted and holds 72 mechanical hard drives.
- This disk shelf is a “dumb” unit that connects into a root storage node using fiber optics.
- Weighs around 100 kg thus sturdy handles on either side for 2 person lift.
- Stores 1.5 petabytes per shelf.

https://www.opencompute.org/products/337/wiwynn-high-density-storage-system-sv7000g4-l

Tape Storage

- Sensitive to humidity so is cooled with chilled water CRAH
- Stores 1 exabyte per cabinet.
- Sequential access only, has limited number of read heads.
- Robot librarian (center) physically picks up and moves tapes into read head.
- Used for backup/old data.
- Amazon calls this “glacier” storage

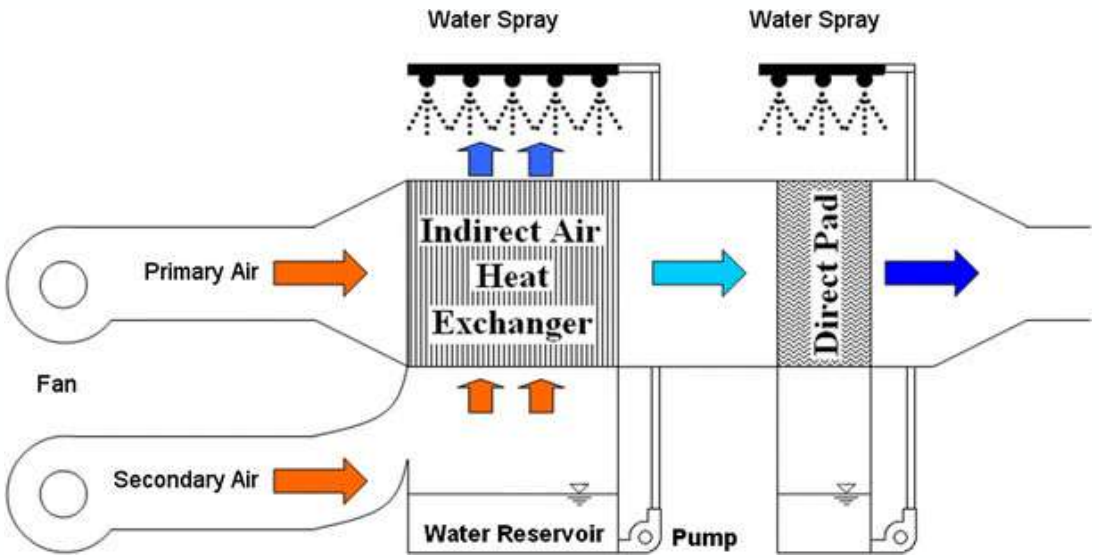
https://www.ibm.com/products/ts4500

Server Power Requirements

- Bulk of server load is made-up of high-density compute running on regulated 48V bus. May or may not come with high power GPU load.
- Storage servers also run with BCU regulated 48V bus. The majority of the load on the DC bus is stepper motor based mechanical hard drives.
- Both of the above are air cooled used split plenum hot/cold aisle.
- Least common server type is tape. Electromechanical librarian robot and read heads. Requires low-humidity air cooling w/ chilled water.

Cooling Methods

- Evaporative cooling (aka direct adiabatic cooling) is most economical and common to use.
- Indirect adiabatic cooling is next most common, combines 2 evaporative stages to cool/dehumidify the intake air.
- Air conditioning is most inefficient but is used where humidity is a concern.
- Building heating is done by the servers, no need for anything.



Indirect adiabatic cooling used in more humid climates.

Cooling Components

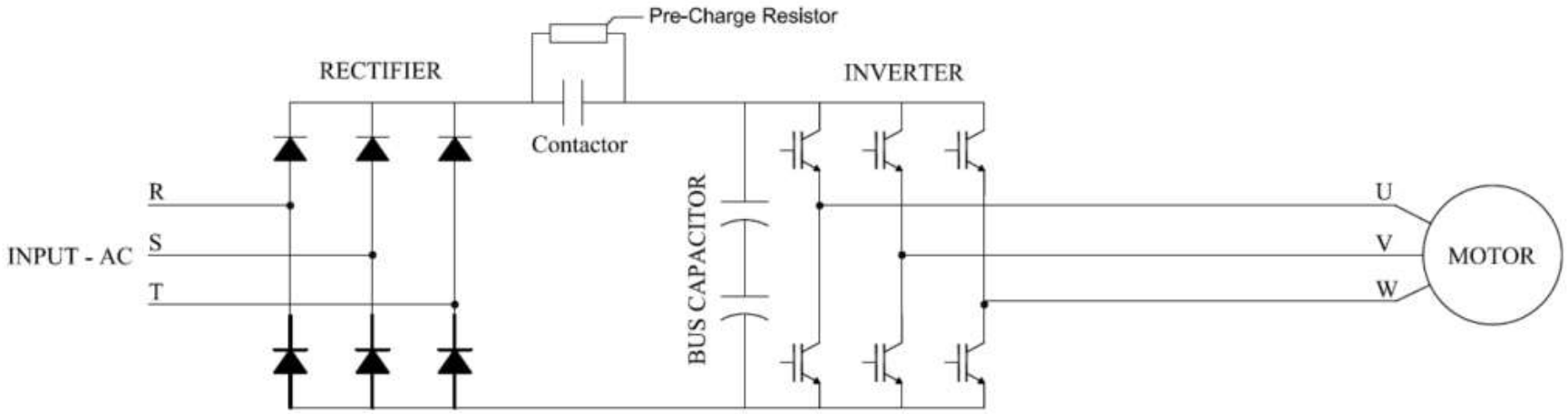
- To move millions of CFM of air, industrial impeller fan walls used from manufacturers such as Huntair with their branded VFDs.
- Exhaust fans driven by off-the-shelf VFDs from manufacturers like Eaton or ABB – though going out of style as loud and cheap exhaust fans annoy NIMBYs.

Pumping Loads

- Minimal VFD driven pumping load but pumps exist to keep the utility water tank buffer at a reasonable level, circulate water onto the evaporative pads, move chilled water, and to drain and flush the system with fresh water once the alkalinity and dissolved minerals make the water too hard to continue using.

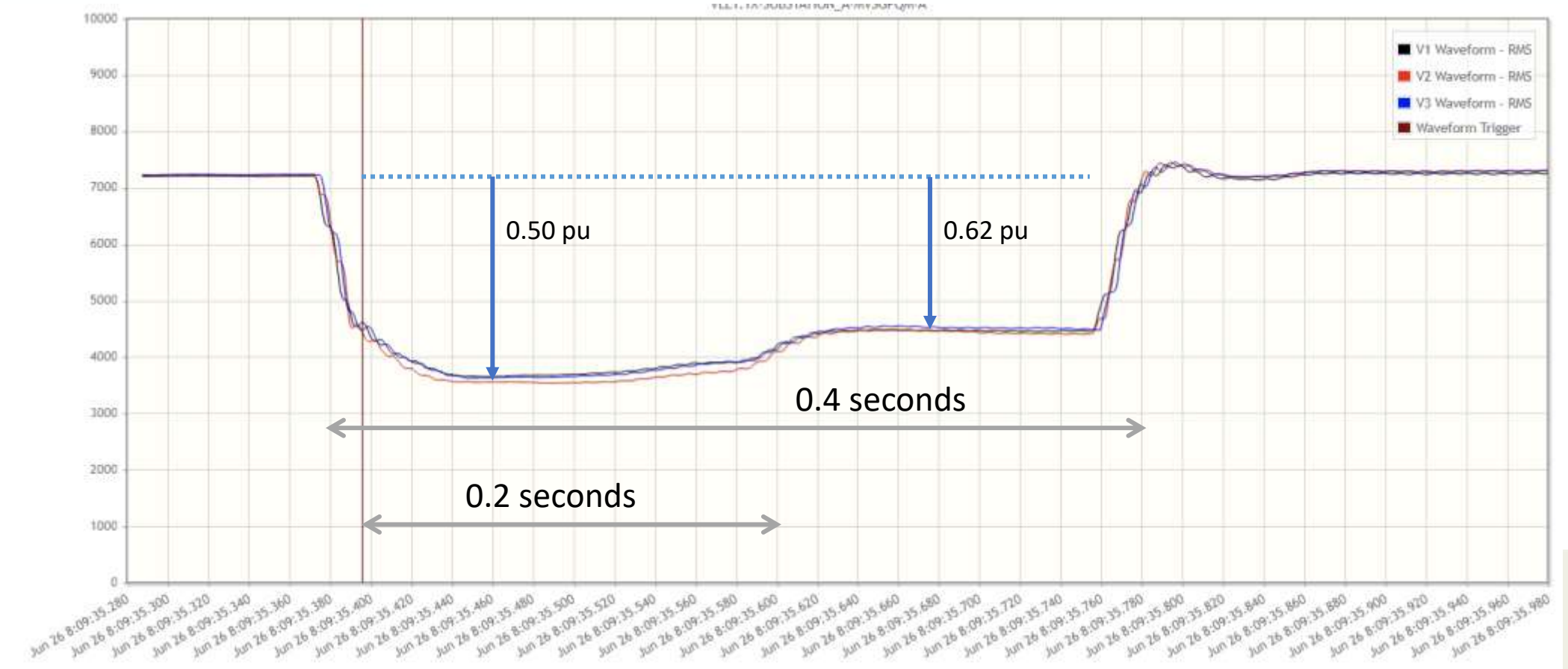
VFDs

- VFDs detect undervoltage off the DC bus just as the BBUs do. Because these are designed with redundancy, they're oversized. The bus capacitor holds the DC voltage up during the fault and they remain in service throughout the sag, just drawing more current through the active rectifier.



Utility Voltage Sag

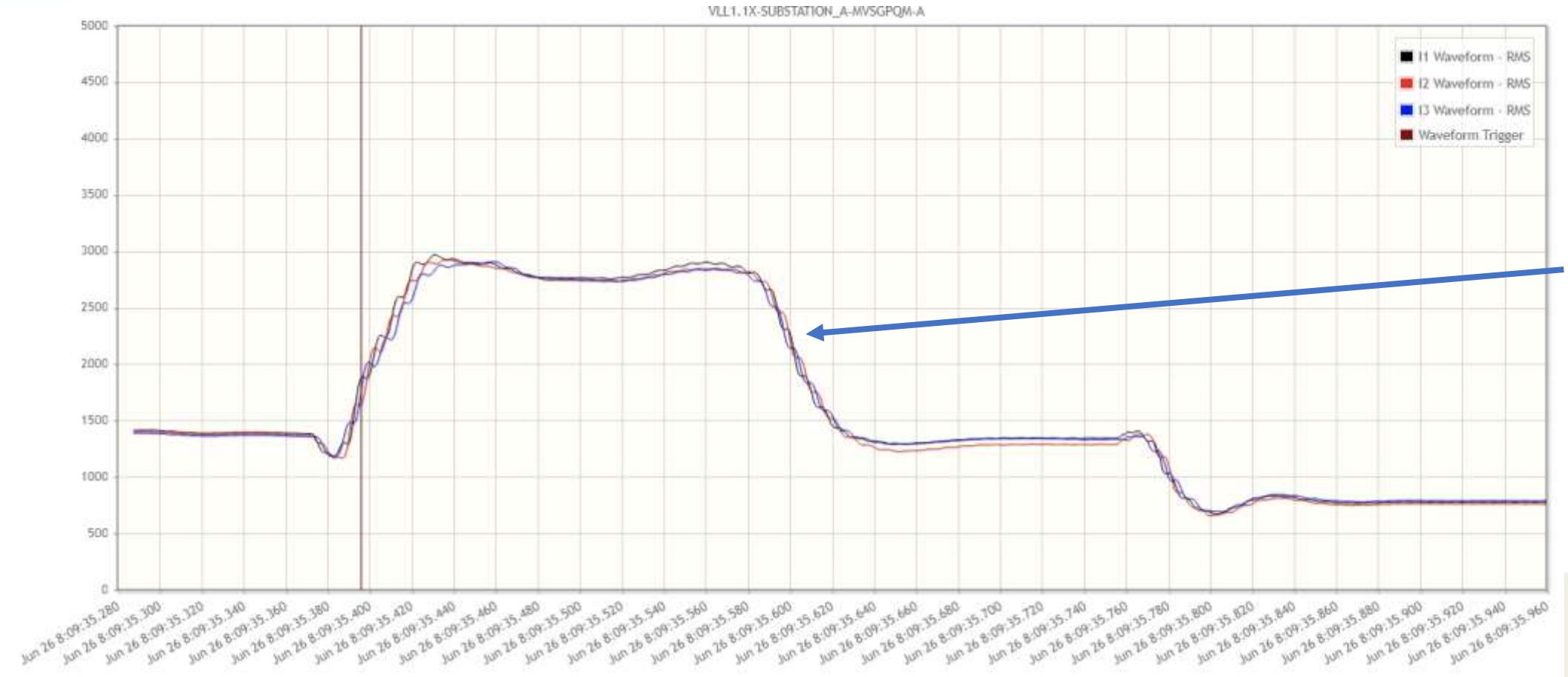
- The second voltage sag event occurred 85 seconds later result of manual reclose attempt.



MSG-A Voltage:
-7200V RMS is normal
-Voltage fell to 50% of nominal levels.
-Rise to 62% occurred 0.2s after initial dip
-Total event 0.4 seconds long for utility to clear

Utility Voltage Sag

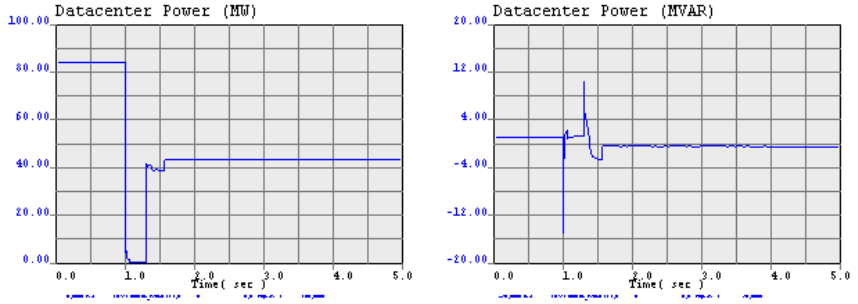
- These are MSG-A currents during the second dip.

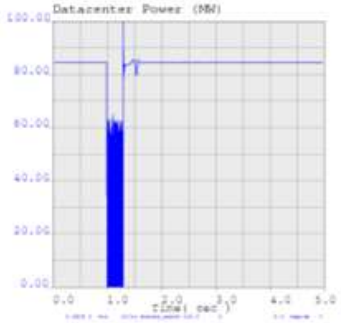


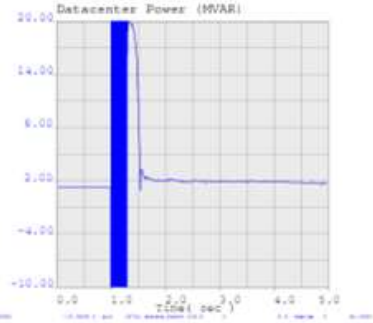
MSG-A Currents:
-1400A before voltage dip
-Jumps to 2800A after reclose (200%)
-Currents drop off at 0.2s after rise, corresponding to short time delay at SB CB1 breakers

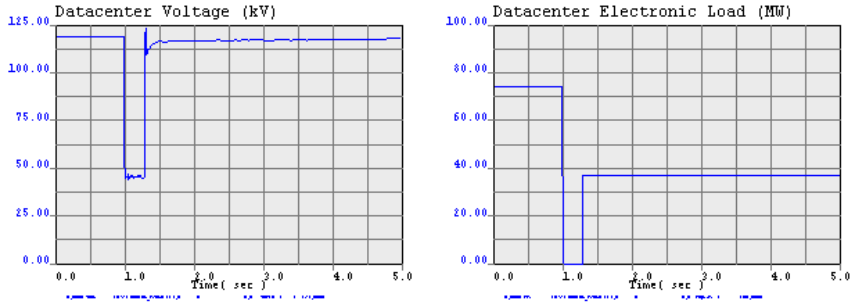
PSLF Dynamics Study

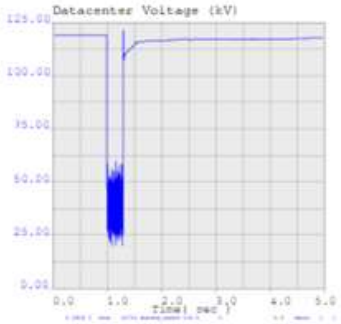
- Using the typical PSLF datacenter composite load model for a datacenter, the predicted response does not match the observed behavior of the real datacenter. Making constant P oscillates.

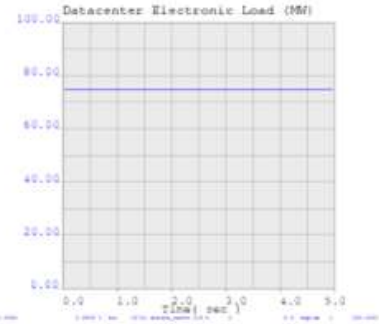












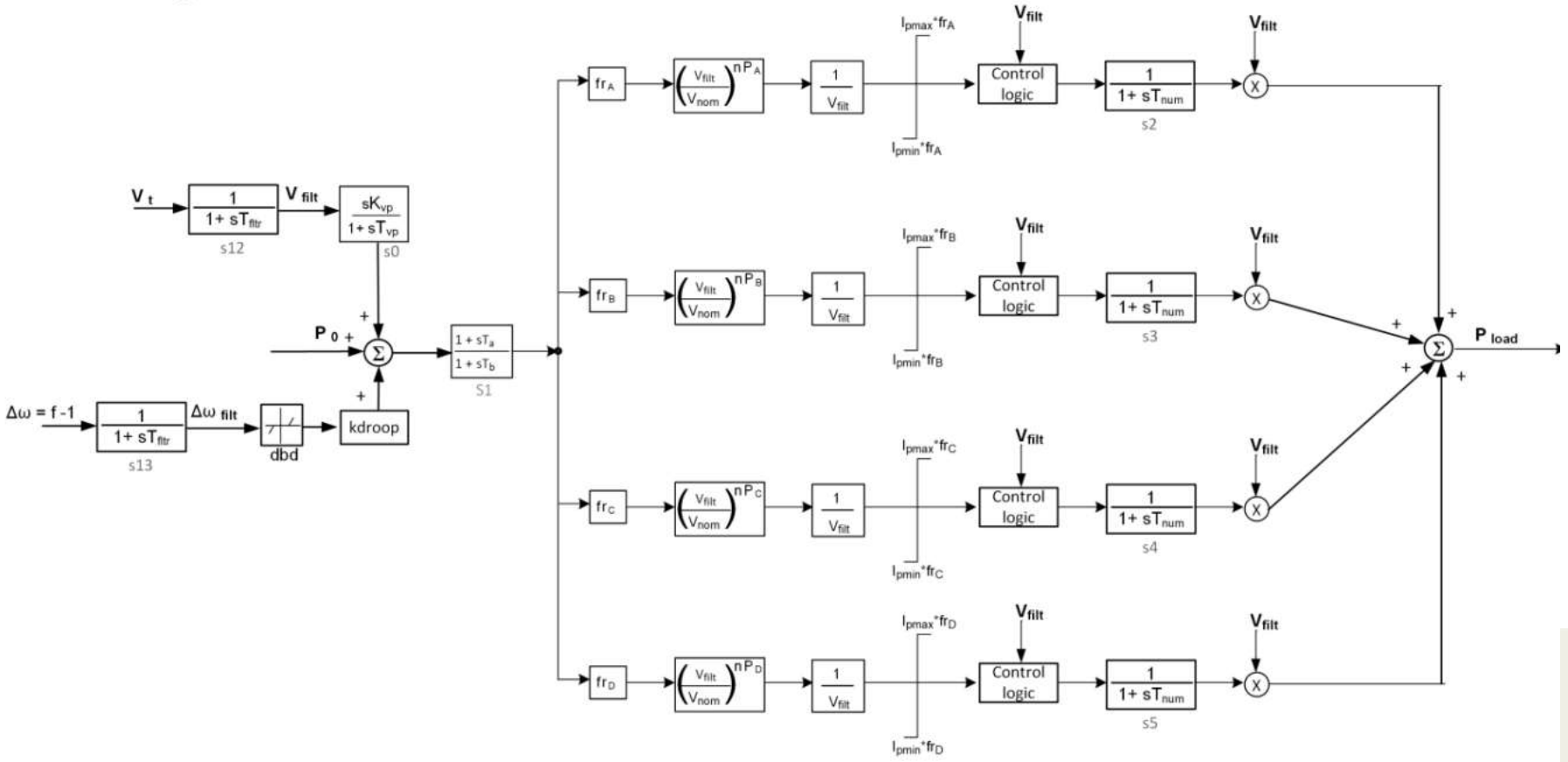
Composite Load Model Comparison

```
_cmpldw -114 "IND_SRF" 0 : #1.0  mva=-1.0 /
    "Pmin"  5.0  "PQmin"  1.4327  "Vmin"  0.93  "kVtresh"  40.0  /
    "Bss"     0.0  "Rfdr"    0.02   "Xfdr"  0.02  "Fb"  1.0  /
    "Xxf" 0.08  "TfixHS" 1.0  "TfixLS" 1.0  "LTC" 1.0  "Tmin" 0.9  "Tmax" 1.1  "step" 0.00625  /
    "Vmin" 1.0  "Vmax" 1.02  "Tdel" 999.0  "Ttap" 5.0  "Rcomp" 0.0  "Xcomp" 0.0   /
    "Fmc"  0.1  "Fma"  0.0  "Fmb"  0.0  "Fmd"  0.0  "Fel"  0.9  /
    "PFel"  1.0   "Vd1"  0.72   "Vd2"  0.52   "Frcel"  0.5  /
    "pfs"  1.0   "P1e"  2   "P1c"  1   "P2e"  1   "P2c"  0   "Pfreq"  0.0  /
                 "Q1e"  2   "Q1c"  1.0   "Q2e"  1   "Q2c"  0.0   "Qfreq"  -1.0  /
    "MtpA"  3   "MtpB"  0    "MtpC"  0   "MtpD"  0  /
    "Lfm"  0.8   "Rs"  0.01   "Ls"  3.1   "Lp"  0.1954   "LppA"  0.1557  /
    "Tpo"  0.4759   "Tppo"  0.0036   "H"  0.2   "etrq"  2.0  /
    "Vtr1"  0.7   "Ttr1"  0.05   "Ftr1"  0.3   "Vrc1"  1.0   "Trc1"  9999.0  /
    "Vtr2"  0.6   "Ttr2"  0.02   "Ftr2"  0.5   "Vrc2"  0.75   "Trc2"  0.25  /
    "DGtype"  2  "dgdatno"  -110.0  "dgmbase"  -0.9
```

```
_cmpldw -121 "DATACENTER" 0 : #1.0  mva=-1.0 /
    "Pmin"  5.0  "PQmin"  1.4327  "Vmin"  0.93  "kVtresh"  40.0  /
    "Bss"     0.0  "Rfdr"    0.02   "Xfdr"  0.02  "Fb"  1.0  /
    "Xxf" 0.08  "TfixHS" 1.0  "TfixLS" 1.0  "LTC" 1.0  "Tmin" 0.9  "Tmax" 1.1  "step" 0.00625  /
    "Vmin" 1.0  "Vmax" 1.02  "Tdel" 999.0  "Ttap" 5.0  "Rcomp" 0.0  "Xcomp" 0.0   /
    "Fmc"  0.1  "Fma"  0.0  "Fmb"  0.0  "Fmd"  0.0  "Fel"  0.95  /
    "PFel"  1.0   "Vd1"  0.8   "Vd2"  0.5   "Frcel"  1.0  /
    "pfs"  1.0   "P1e"  2   "P1c"  1   "P2e"  1   "P2c"  0   "Pfreq"  0.0  /
    "Q1e"  2   "Q1c"  1.0   "Q2e"  1   "Q2c"  0.0   "Qfreq"  -1.0  /
    "MtpA"  3   "MtpB"  0    "MtpC"  0   "MtpD"  0  /
    "Lfm"  0.8   "Rs"  0.01   "Ls"  3.1   "Lp"  0.1954   "LppA"  0.1557  /
    "Tpo"  0.4759   "Tppo"  0.0036   "H"  0.2   "etrq"  2.0  /
    "Vtr1"  0.7   "Ttr1"  0.05   "Ftr1"  0.3   "Vrc1"  1.0   "Trc1"  9999.0  /
    "Vtr2"  0.6   "Ttr2"  0.02   "Ftr2"  0.5   "Vrc2"  0.75   "Trc2"  0.25  /
    "DGtype"  2  "dgdatno"  -110.0  "dgmbase"  -0.9
```

Repurposing the new EV Model?

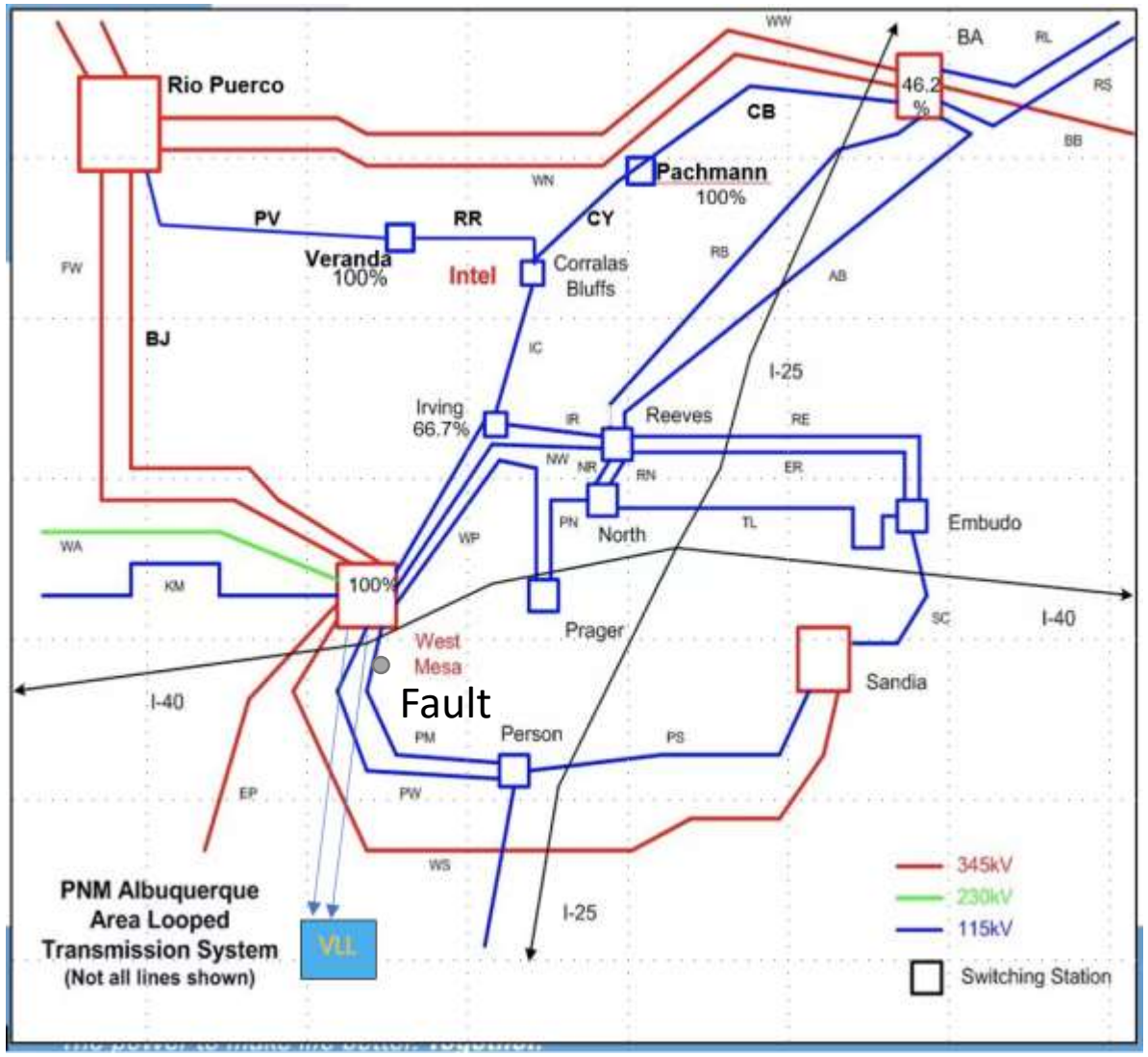
- Looking into repurposing the new _cmp_ev1 model in coordination with cmpldw2 model to provide inputs for constant current/constant power loads.



Discussion Points

Utility expectations?

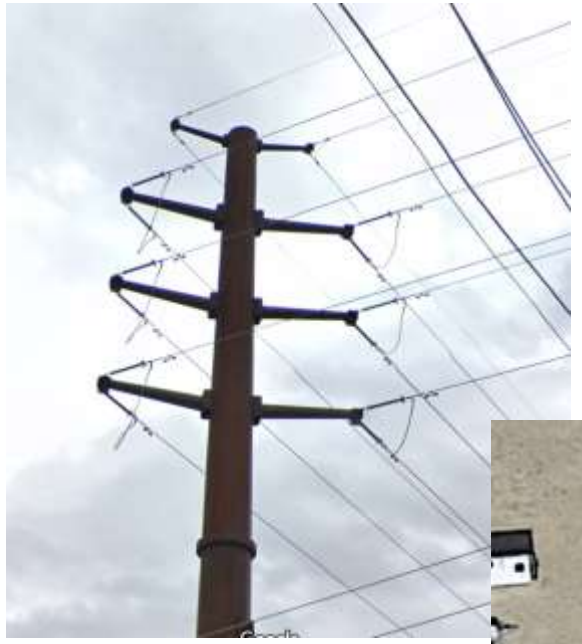
- The utility cleared in 0.4 seconds or 24 cycles.
  - Is this a zone 2 distance delay of 20 cycles and 4 cycle breaker operation?
  - The incident occurred on a double circuited leg of a tap point on the transmission system (no breakers)

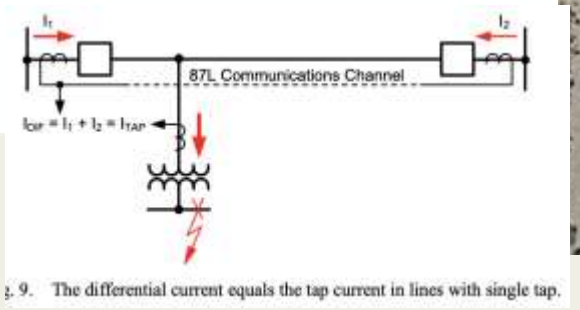


Discussion Points

Utility expectations?

- Tap point with parallel transformers and the balloon contacted ~0.1 mile from tap station (outside of high-speed zone 1)
- 13k people without power on this line. Standard procedure to attempt manual reclose.
- Additional information about [line protection of a tapped line]





. 9. The differential current equals the tap current in lines with single tap.

Discussion Points

Voltage Sag Ride Through SBs to STPU=5000A, STD = 0.5sec

Voltage Dip			SB Currents in Amps during Voltage Sag at Varied Power Levels (kW)													
Percent	Line-Line	Line-Ground	1612	1550	1500	1450	1400	1350	1300	1250	1200	1150	1100	1050	1000	950	900
100%	480	277	1939	1864	1804	1744	1684	1624	1564	1504	1443	1383	1323	1263	1203	1143	1083
95%	456	263	2041	1963	1899	1836	1773	1709	1646	1583	1519	1456	1393	1329	1266	1203	1140
90%	432	249	2154	2072	2005	1938	1871	1804	1737	1671	1604	1537	1470	1403	1336	1270	1203
85%	408	235	2281	2193	2123	2052	1981	1910	1840	1769	1698	1627	1557	1486	1415	1344	1274
80%	384	222	2424	2331	2255	2180	2105	2030	1955	1879	1804	1729	1654	1579	1504	1428	1353
75%	360	208	2585	2486	2406	2326	2245	2165	2085	2005	1925	1844	1764	1684	1604	1524	1443
70%	336	194	2770	2663	2578	2492	2406	2320	2234	2148	2062	1976	1890	1804	1718	1632	1547
65%	312	180	2983	2868	2776	2683	2591	2498	2406	2313	2221	2128	2036	1943	1851	1758	1665
60%	288	166	3232	3107	3007	2907	2807	2706	2606	2506	2406	2305	2205	2105	2005	1905	1804
55%	264	152	3525	3390	3280	3171	3062	2952	2843	2734	2624	2515	2406	2296	2187	2078	1968
50%	240	139	3878	3729	3609	3488	3368	3248	3127	3007	2887	2767	2646	2526	2406	2285	2165
45%	216	125	4309	4143	4009	3876	3742	3609	3475	3341	3208	3074	2940	2807	2673	2539	2406
40%	192	111	4847	4661	4511	4360	4210	4060	3909	3759	3609	3458	3308	3157	3007	2857	2706
35%	168	97	5540	5327	5155	4983	4811	4640	4468	4296	4124	3952	3780	3609	3437	3265	3093
30%	144	83	6463	6215	6014	5814	5613	5413	5212	5012	4811	4611	4410	4210	4009	3809	3609

- 1612kW is 97% of the rated 2000A SB bus.
- Red is above 3000A (short time pickup), orange is above 5000A DCIS suggestion
- 35MW of production IT load across 24 SBs (A/C pairs balance) is 1460kW

Purpose

- The questionnaire was distributed by NATF back in November 2023 to gather data on the load response of a data center.
- Motivated by several major disturbances near datacenters that have not followed existing model responses.
- Send responses to Olushola at NERC Olushola.Lutalo@nerc.net

Responding

- Will require collaboration with the datacenter owners.
- Contact through a business account representative.

What’s On the Questionnaire

Ratings

- How much load is at the datacenter and what fraction is:
  - IT/computer load
  - Cooling load
  - Lighting load
  - Distribution losses
- What is the overall power factor of the site?

Cooling Method

- What type of cooling method is used?
  - Air conditioning with refrigerant CRACs
  - Chilled water system CRAHs
  - Evaporative cooling AHUs
  - Other such as indirect adiabatic heat exchangers

Motor Drivers

- For motorized systems, what type of driver is used
  - Across the line/single speed
  - Variable frequency drive or otherwise electronically commutated
  - Other

Voltage/Frequency Performance

- What voltage/frequency levels sag/swell would trigger UPS or emergency generator? How is voltage measured

Restoration of Load

- How does load restoration work? Manual/automatic? What levels are programmed into any automation?

Backup Power Capability

- Can the datacenter stay self sufficient? Can this be offered as a service to the utility?


PNM