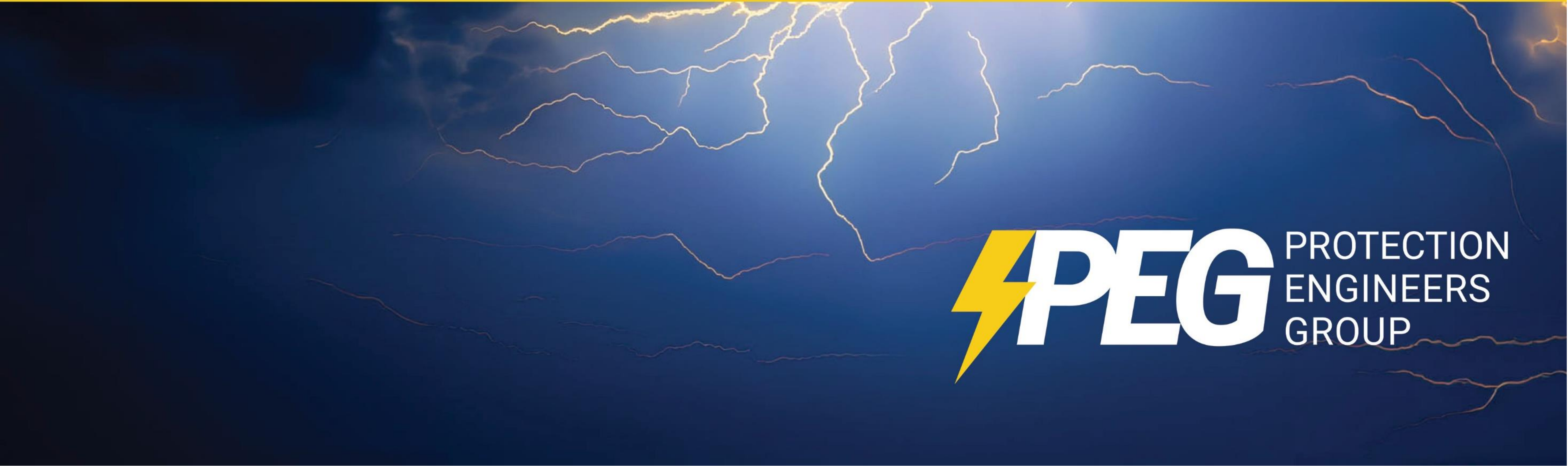
AT&T

Power Supply (PSU) Instability



PSU Instability | Agenda

- History
- Theory
- Examples
- Solutions
- Possible ATIS Action Items

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History | AT&T Events

2017

- An audible noise ‘like a washing machine” with physical vibration of 750MCM power cables was observed. Voltage oscillation at low frequency at the -48Vdc power plant with ~3V of ac ripple at float voltage was measured.

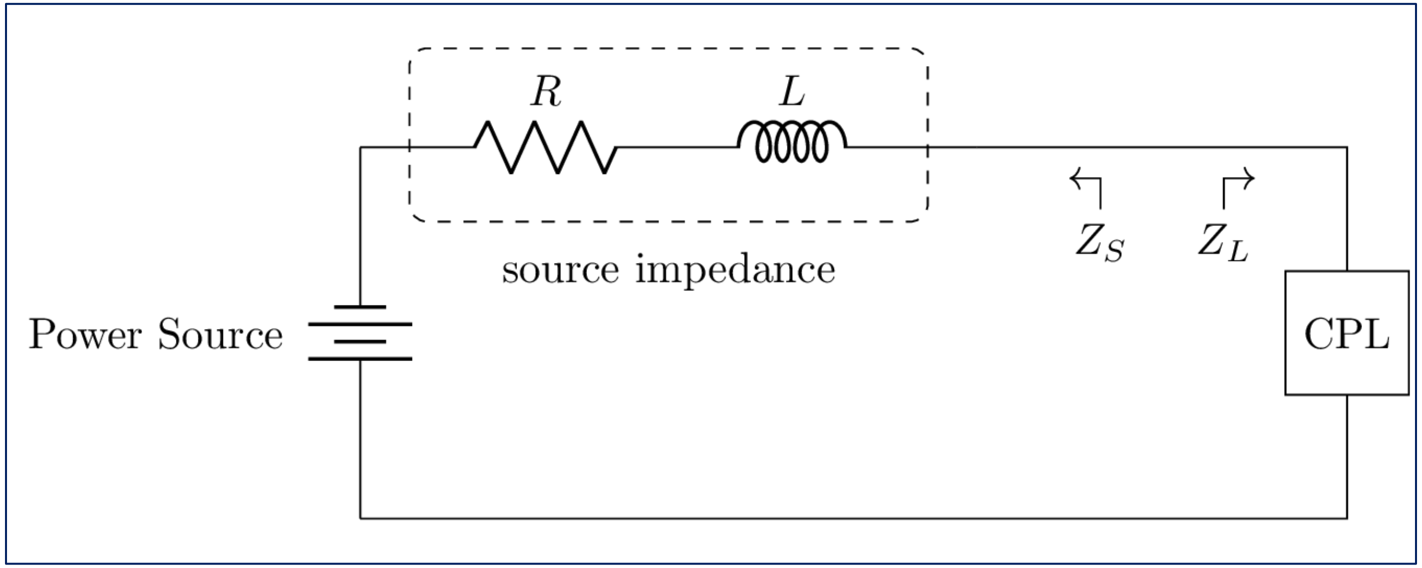
2020

- >800 amps of ac current measured on the dc power plant at float voltage.

2025

- Approximately 1 hr into a BoD with loss of HVAC, a low frequency oscillation event occurred that resulted in multiple PSU shutdowns, with physical vibration of the dc power plant busbar described as an audible “chatter”.

Theory | Source Impedance – Simplified Model



- Source: TPI Engineering

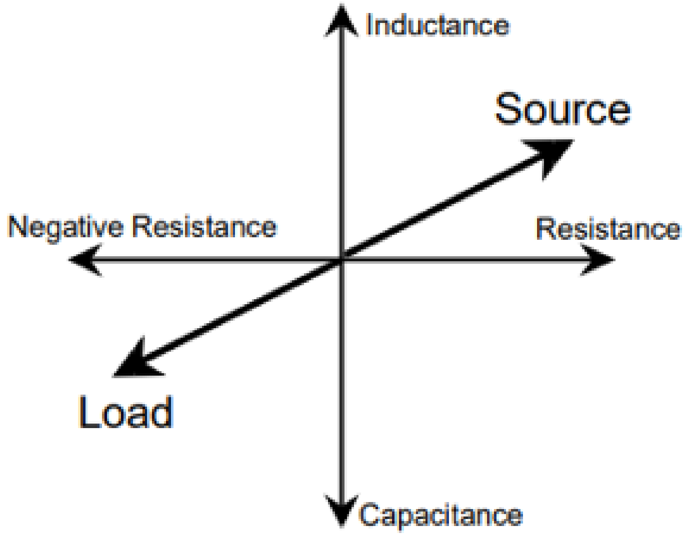
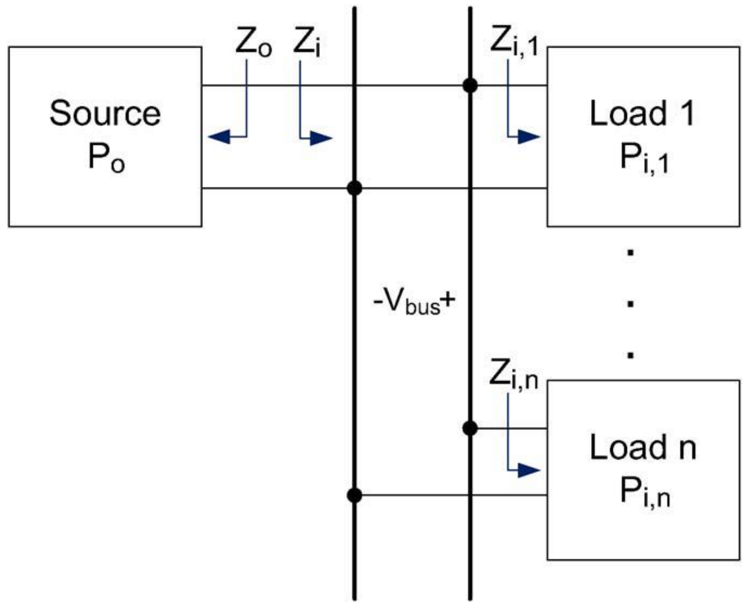
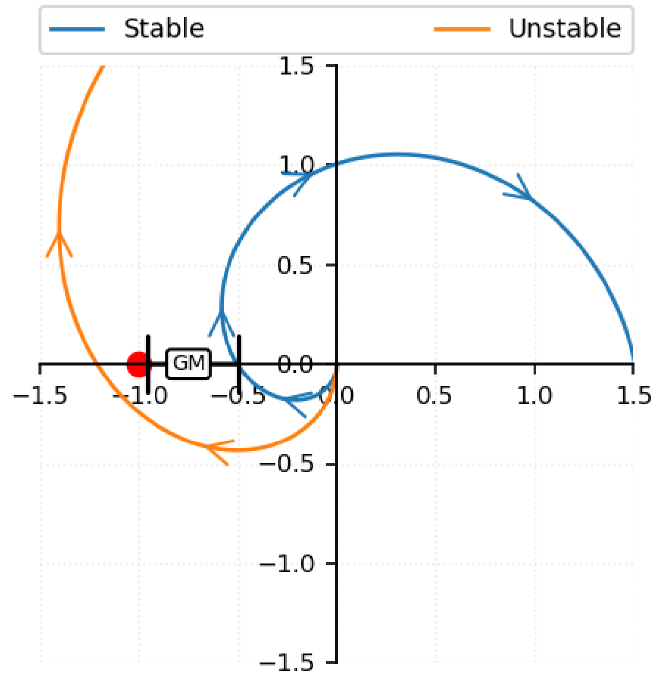


Figure 9. Polar plot of oscillation criteria

Source: *Distributed Power, What Causes These Systems to Oscillate*, Venable Instruments, 2017

Theory | Source Impedance << Load Impedance = Stability





$$\|Z_o\| \ll \|Z_i\| \text{ or equivalently } \|T_{MLG}\| = \left\|\frac{Z_o}{Z_i}\right\| \ll 1$$

- Source: *Comprehensive Review of Stability Criteria for DC Distribution Systems,* E Santi, A Riccobono, 2012 IEEE Explore

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Theory | PSU Load Impedance – Bode Plot dc-dc converter

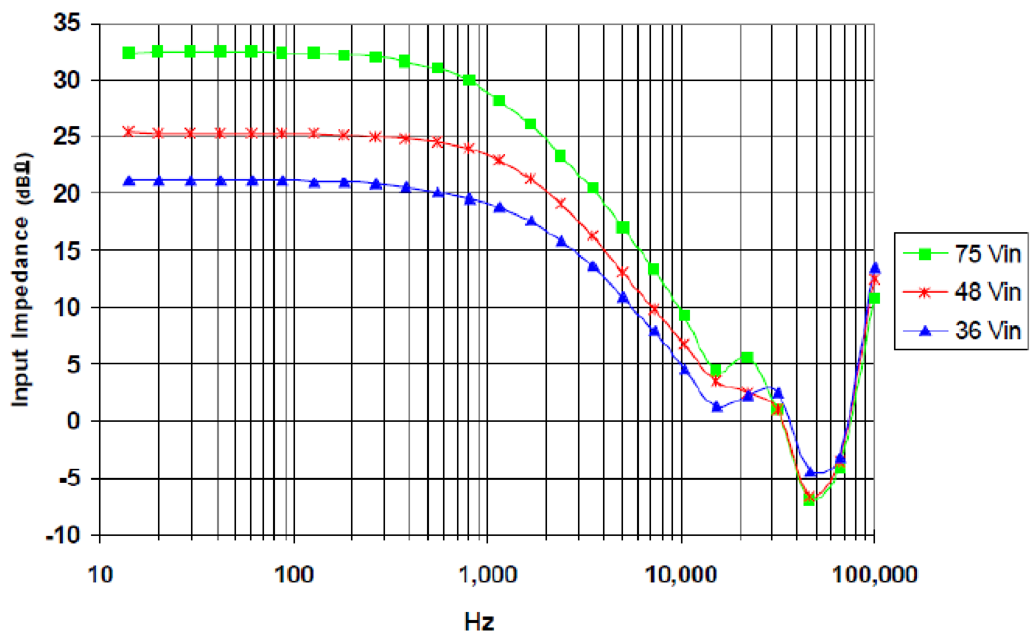

Figure 2: Input impedance ($Z_I = V_{IN}/I_{IN}$) for minimum, nominal, and maximum input voltage at full rate power for 3.3V_{OUT}, 30A half-brick dc/dc converter.

Z_L varies with frequency, input voltage, and output power.

Stability design is focused at the dc-dc converter switching frequency.

PSU resonance is occurring at very low frequency (typically 30-200 Hz).

If load impedance is high at low frequencies, why are we seeing instability / resonance at low frequency?

- ***PSU manufacturers are focused on the wrong Bode Plot***

- Source: SynQor -48Vin, 3.3Vout 30A dc-dc converter

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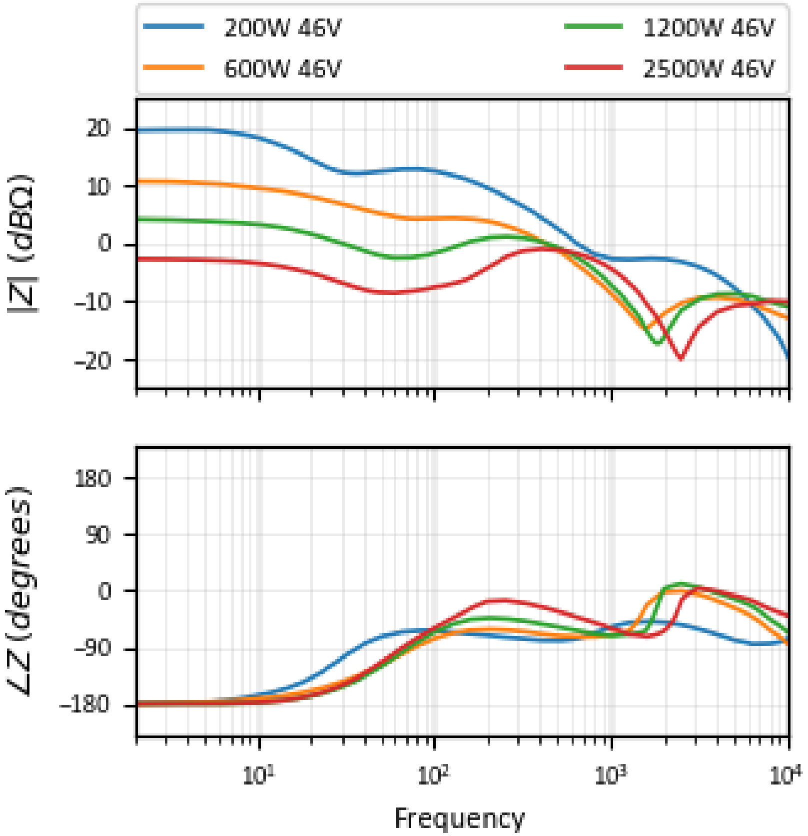
Theory | Load Impedance of the PSU – Bode Plot we need



The load impedance magnitude of this PSU, measured at its input terminals, shows a dip between 30 and 80 Hz at high load.

Note this frequency range coincides with phase of -90 to -180 degrees (lower left quadrant of polar plot).

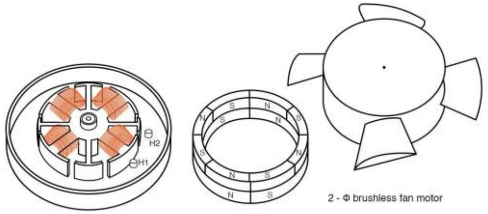
Frequency analysis of the PSU's impedance at the input terminals is crucial for anticipating resonance events based on the specific source impedance at a given site.

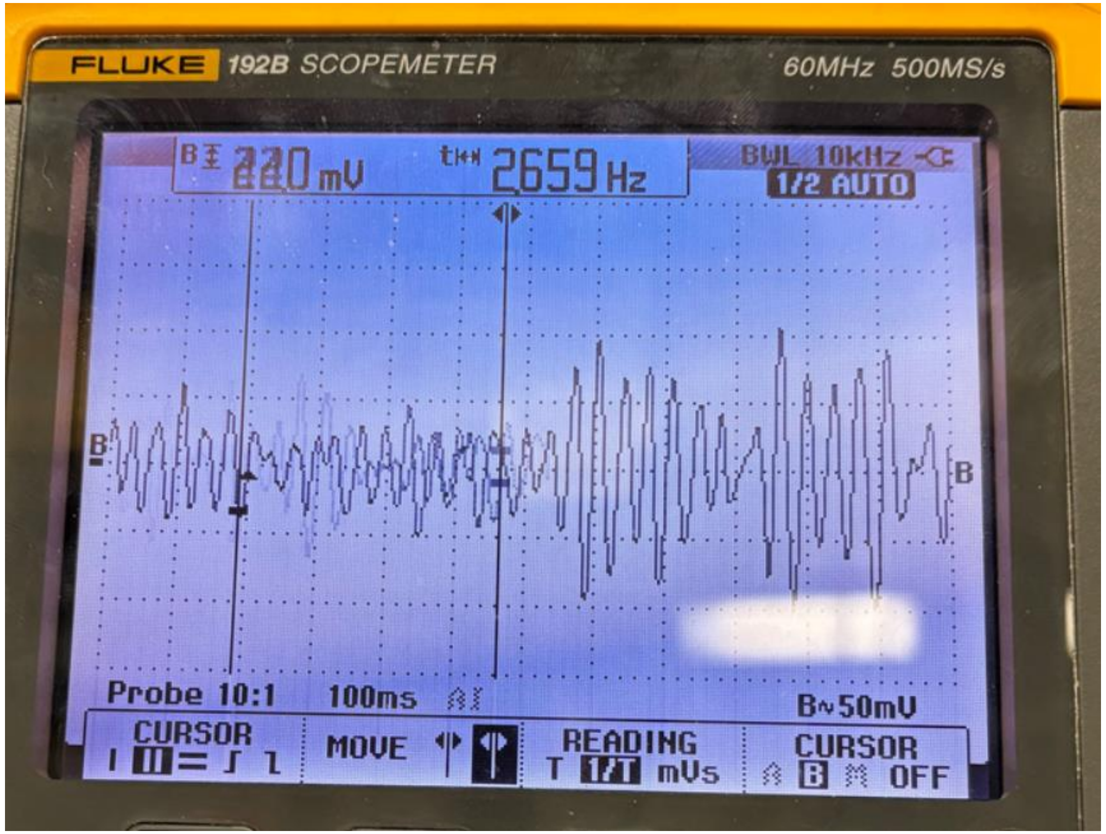
Key variables include:

- Voltage
- PSU load
- Number of PSUs deployed
- Source impedance

- Source: TPI Engineering, AT&T

Theory | Source of AC – dc brushless fans in the servers





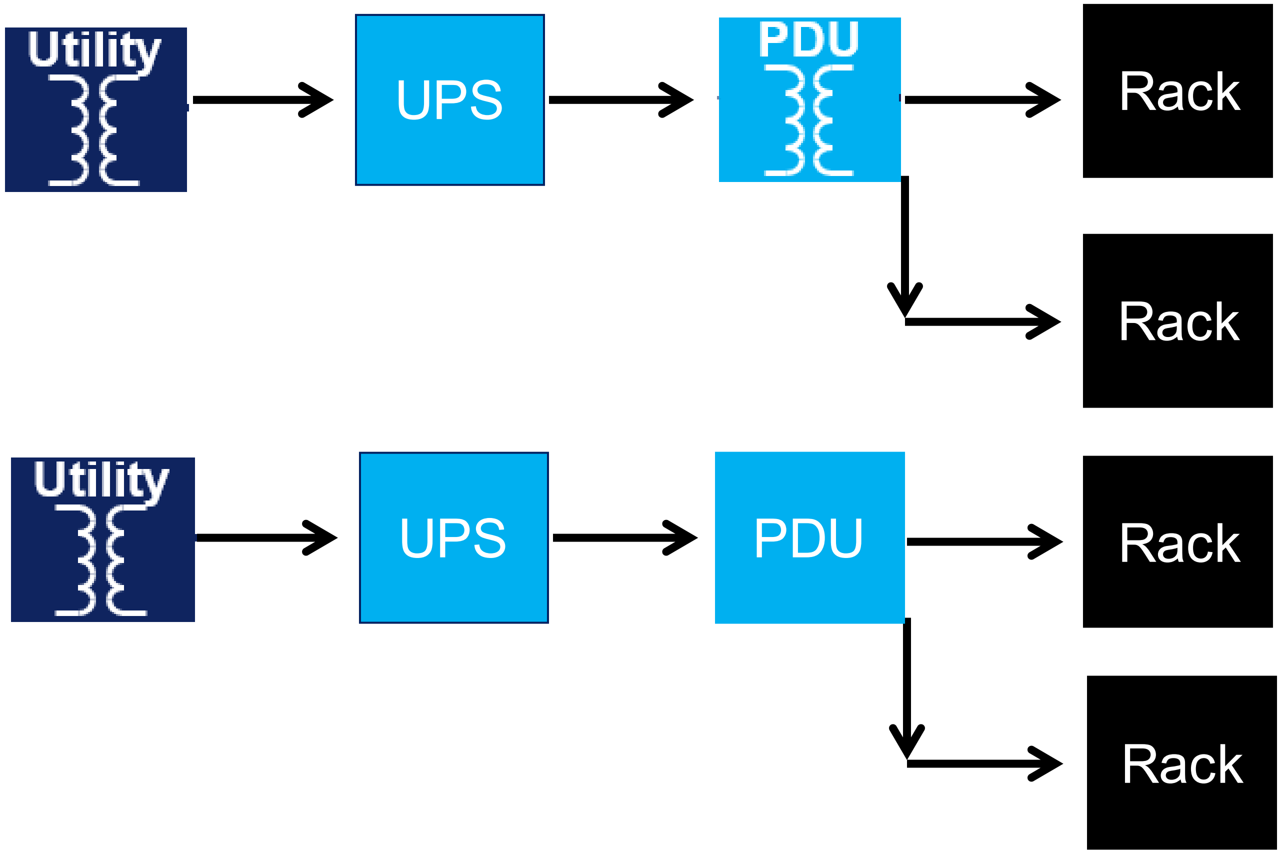
DC brushless fans generate the AC signal.

Fans produce an AC sine wave on the internal 12V DC bus, which is then transferred and amplified via the dc-dc converter feedback loop back to the -48Vdc bus.

This is supported by oscilloscope images displaying AC voltage spikes on the -48Vdc bus as fan speed increases.

- Source: AT&T

Theory | Why Does This Not Happen in AC Data Centers?



PSU ***only sees the impedance back to the transformer in the PDU***, or at the output of the UPS

Number of servers is limited by PDU capacity, A&B PDUs.

Higher input voltage = higher load impedance at low frequency

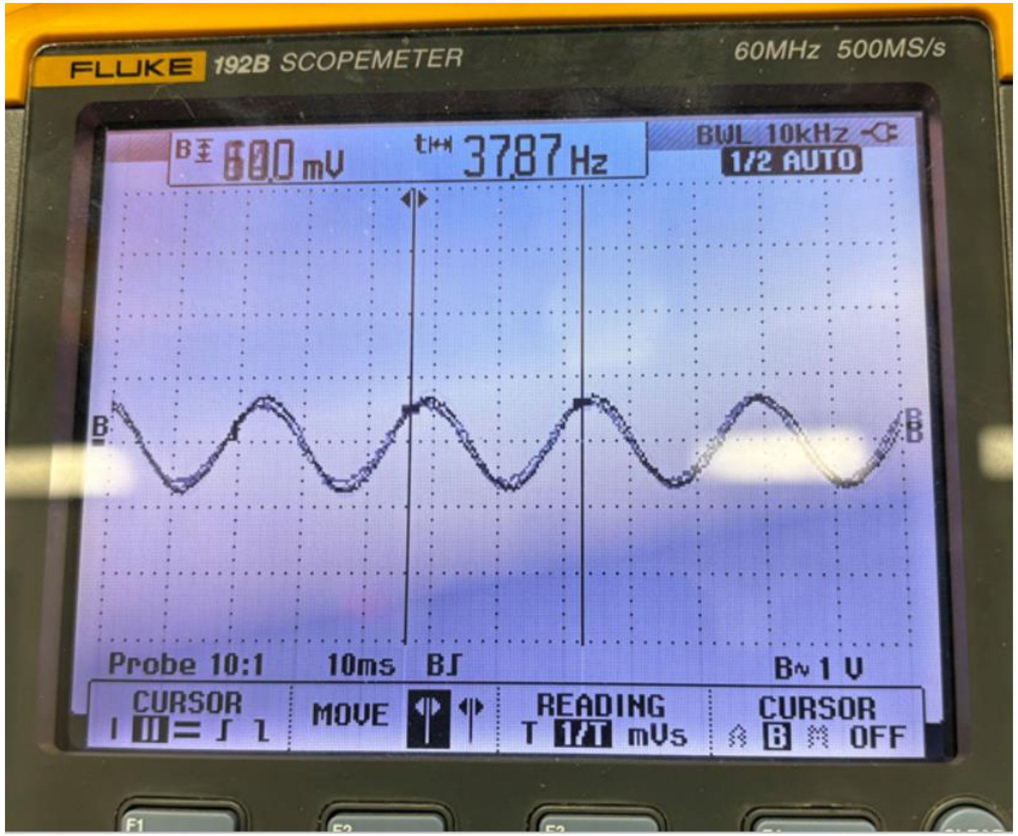
When can oscillations occur?

- Native 208Vac UPS (transformer-less UPS)
- No UPS

Servers see impedance back to utility transformer

Meta, Open Compute Project

Example | Resonance / Sync



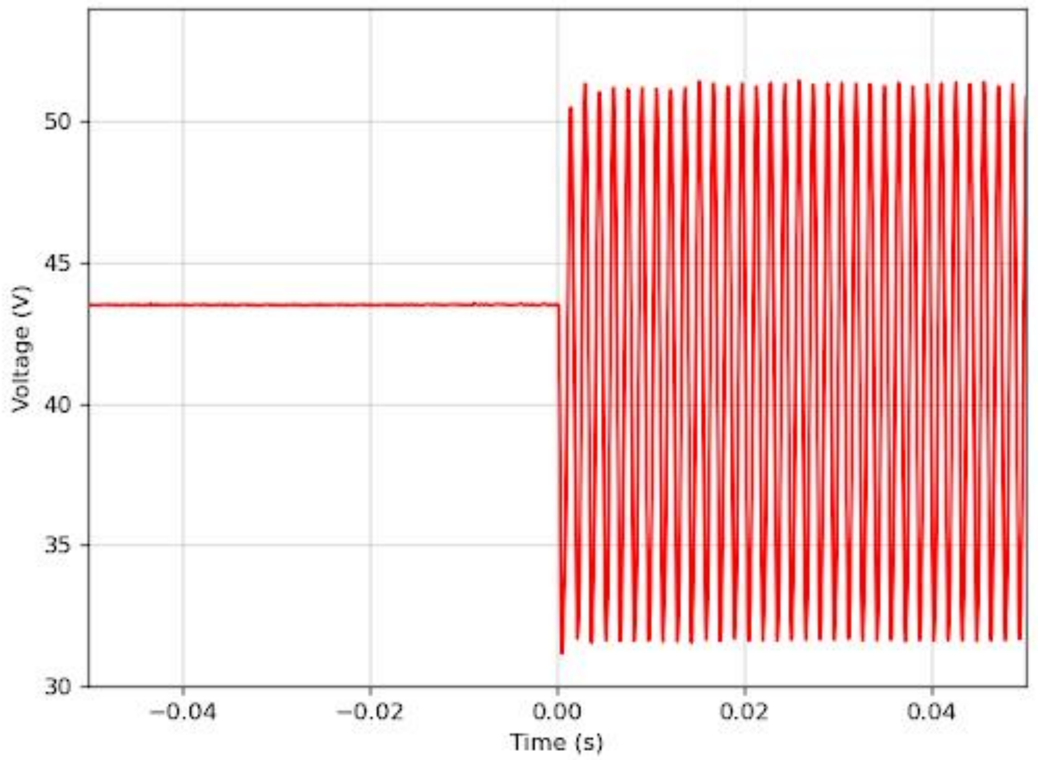
Scope image of resonance, but not "avalanche"

For this specific site condition:

- Resonance occurred @ -52Vdc, 100% fan speed
  - Looks like ac ripple
  - Voltage relatively low, < 2Vac in this case
  - Current can be significant
  - Can remain stable if no changes in voltage or load
- Avalanche occurred @ -48.5Vdc, 100% fan speed
  - Voltage becomes significant, PSU shutdown
  - Current can be thousands of amps
  - How much current does it take to cause 10,000A busbar to audibly "chatter"?

- Source: AT&T

Example | Avalanche



- Image is a single PSU
- Created by increasing load via load bank, while holding voltage constant, with a series inductor
- < 100mV$_{p\text{-}p}$ noise "avalanches" to ~ 20V$_{p\text{-}p}$ sine wave
- PSU shutdown occurs in milliseconds
- Frequency of avalanche sine wave matches the frequency where PSU instability occurs, not the natural frequency of the fan noise
- Only fan in this case is the fan internal to the PSU

- Source: AT&T, TPI Engineering

Example | Source Impedance – Busbar Contribution

•Source: AT&T

Busbar is T shaped with a number of 90 degree bends

- Ls (busbar) = 100x > Ls (cable) for this site, 10x > Ls (cable) at other sites
- Only true because all cabling was run “closely coupled” at this site

Solutions | How to achieve stability

Source Impedance

What can we control:

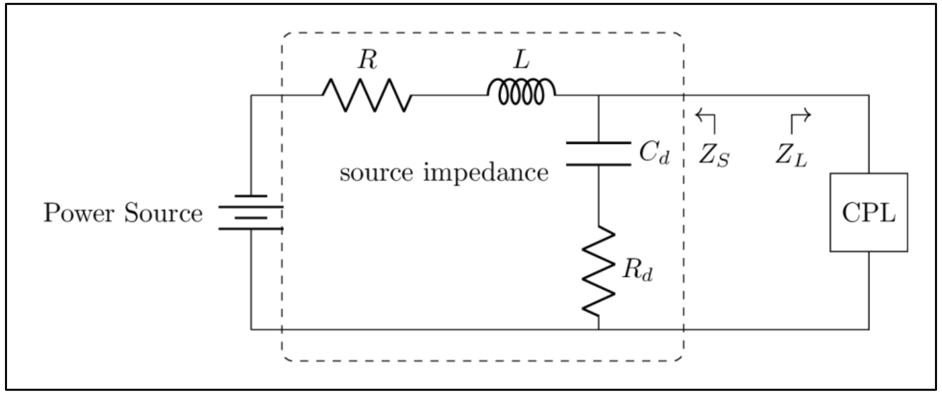
- **Add external parallel cascade damping filters**
- **Closely couple BATT – RTN cable pairs**
  - Limit BATT and RTN separation
- **Deploy DA plants located near the equipment**
  - Minimize busbar, distance
- **AC powered servers, UPS (w/ output transformer)**
  - Less battery reserve
  - Incur UPS maintenance cost

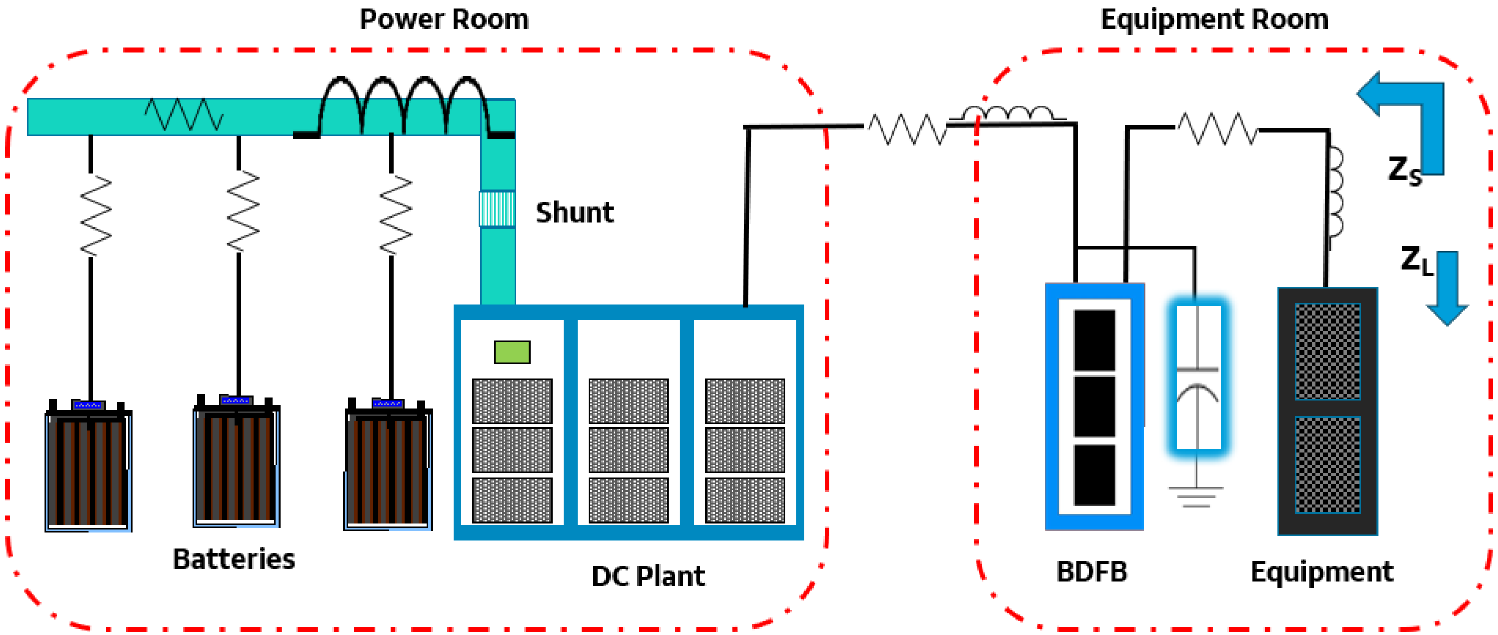
Load Impedance

What can we control:

- **Number of servers deployed per power plant**
  - Will vary by PSU load and source inductance
- Direct to chip (DTC) / liquid cooling may reduce number of fans
- 800Vdc (Project Mount Diablo / Open Compute) may assist with stability for future high loads

Solution | Add External Parallel Cascade Damping Filter

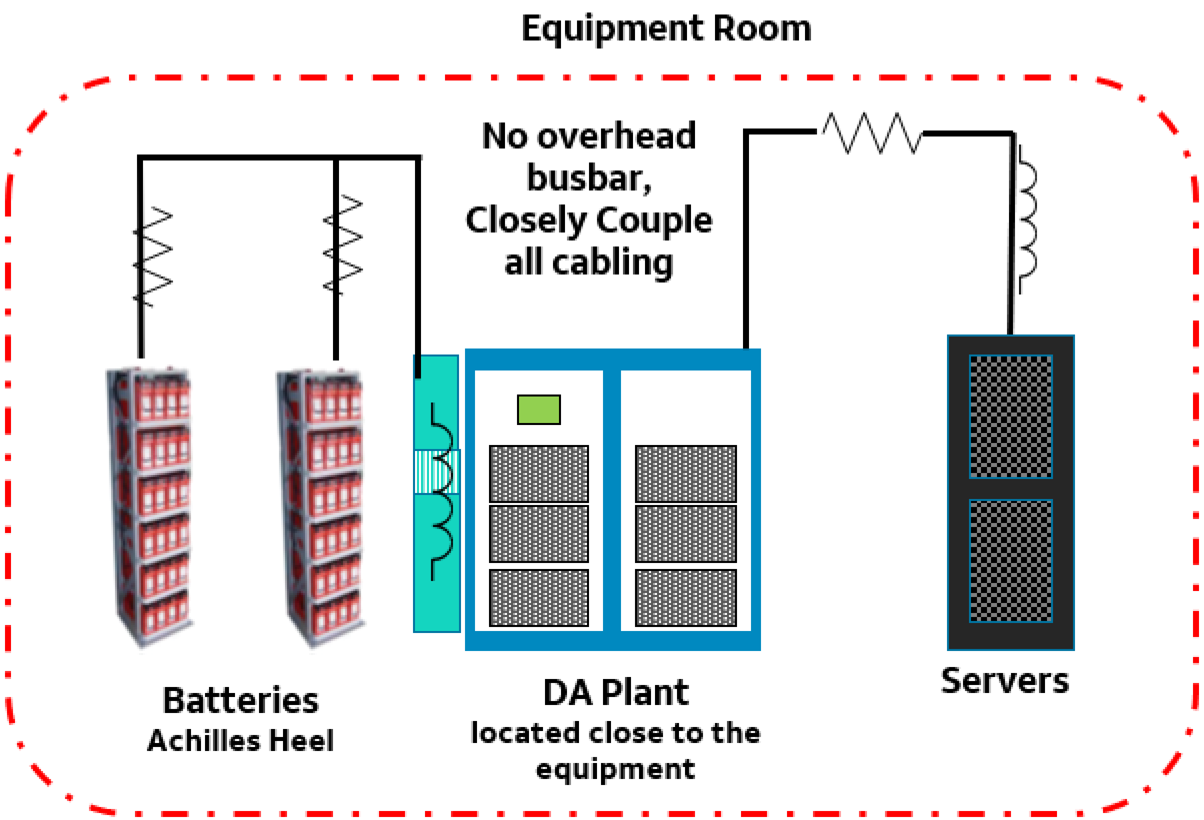




- Source: TPI Engineering

Solution | Lower Inductance, Lower PSU Quantity per Plant

Smaller Distributed Architecture (DA) Power Plant(s)



- Source: AT&T

Possible ATIS Action Items | Expect Manufacturer Pushback

Establish a Shutdown Voltage

- ATIS establishes a Minimum Operating Voltage, but not a “must shutdown” voltage. Shutdown voltage is left to the PSU manufacturer.
- As voltage drops to -36Vdc and below, PSU load impedance decreases exponentially
- Easy to do, minimal benefit

Require PSU Impedance Bode Plot

- New ATIS requirement to produce PSU Bode Plot impedance frequency analysis at the input terminals for magnitude (in dbΩ) and phase for all new PSUs
- Test requires a frequency impedance analyzer, which can be expensive
- Requires carriers to have expertise to apply the plots to that carrier’s range of source impedances, PSU loads, and deployment plans
- Easy to test, but difficult for carriers to implement

Require manufacturers to demonstrate PSU stability

- Will require a table of standard source inductances vs PSU loads
- Test requires variable voltage source, variable load bank, and inductors to perform the test(s) on a single PSU
- Difficult to predict future carrier equipment deployments and changes in technology
- Difficult to test consistently across various test conditions
- PSUs cannot achieve stability across all possible deployment scenarios.

Contributors