Pacific Northwest NATIONAL LABORATORY

EMT Modeling of Data Centers: Fault Response

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Brett Ross
Electrical Engineer

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Agenda

- Summary of open-source library (0:02)
- Fault response of data center devices (0:06)
- Impacts to electromechanical generation (0:06)

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Library Overview

Library Overview

- The data center model library (DML) is a collection of generic models for representing data centers in PSCAD/EMTDC
- 30 custom components, 6 example systems
- Free download: https://ieee-dataport.org/open-access/data-center-model-library-electromagnetic-transient-analysis-pscad
- Intended for grid-level studies, individual devices highly aggregated
  - Average-value models recommended
  - Not suitable for harmonics studies
  - Not suitable for simulating faults within data center itself
- Alpha release—consider these a rough draft:
  - Require enhancement and validation before use in real-world studies
  - Open and early release meant to accelerate consensus building

Preview: Beta Release

- Available online in **July 2026**
- **Improvements to existing models:**
  - Rack-level power supply control more flexible RE: fault behavior
  - Improved sophistication of UPS Vdc control during LVRT
- **New components:**
  - Multi-layer GFM inverters, droop and VSM—represent BESS, SST front-end
  - Complete cooling models—drive and mechanical load
  - On-site generation—combustion engines
- **New system models:**
  - Benchmark with phasor model (PERC1)
  - Semi-aggregated model—simulate partial tripping, curtailment, transfers

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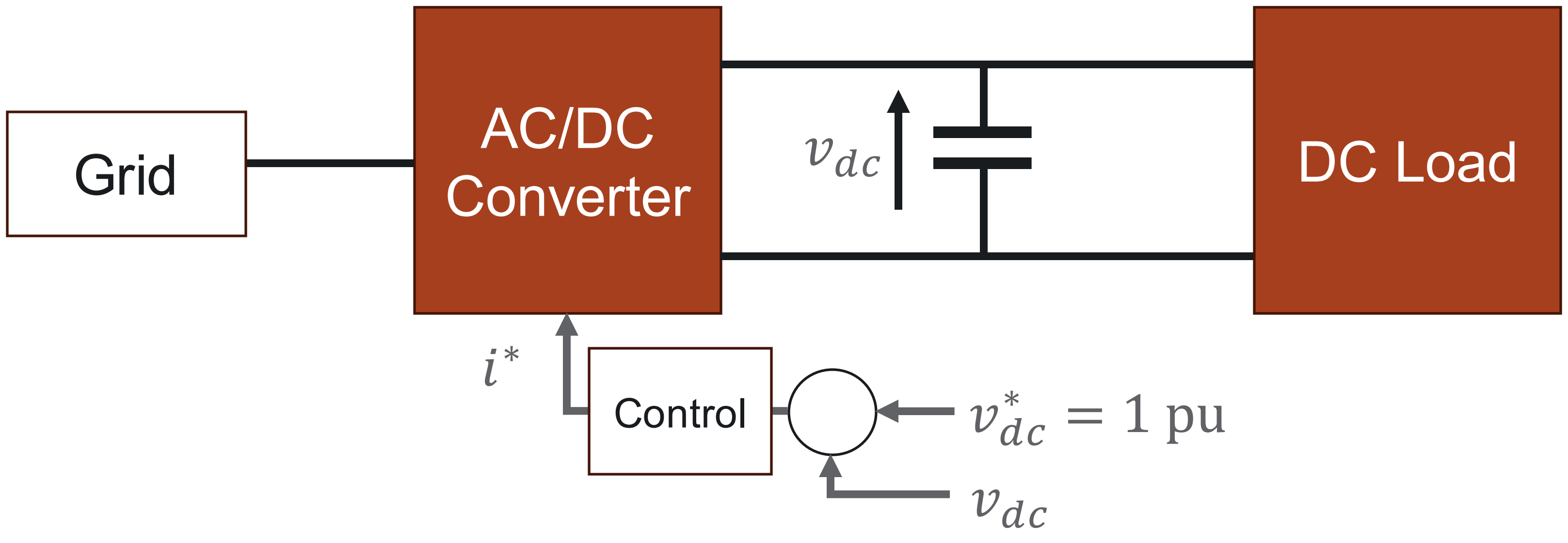
Fault Response

Role of DC Link Dynamics

- These common design elements apply to almost all data center load



$$E_{dc} = \frac{1}{2} C v_{dc}^2$$

$$\frac{d}{dt} E_{dc} = P_{ac} - P_{dc}$$

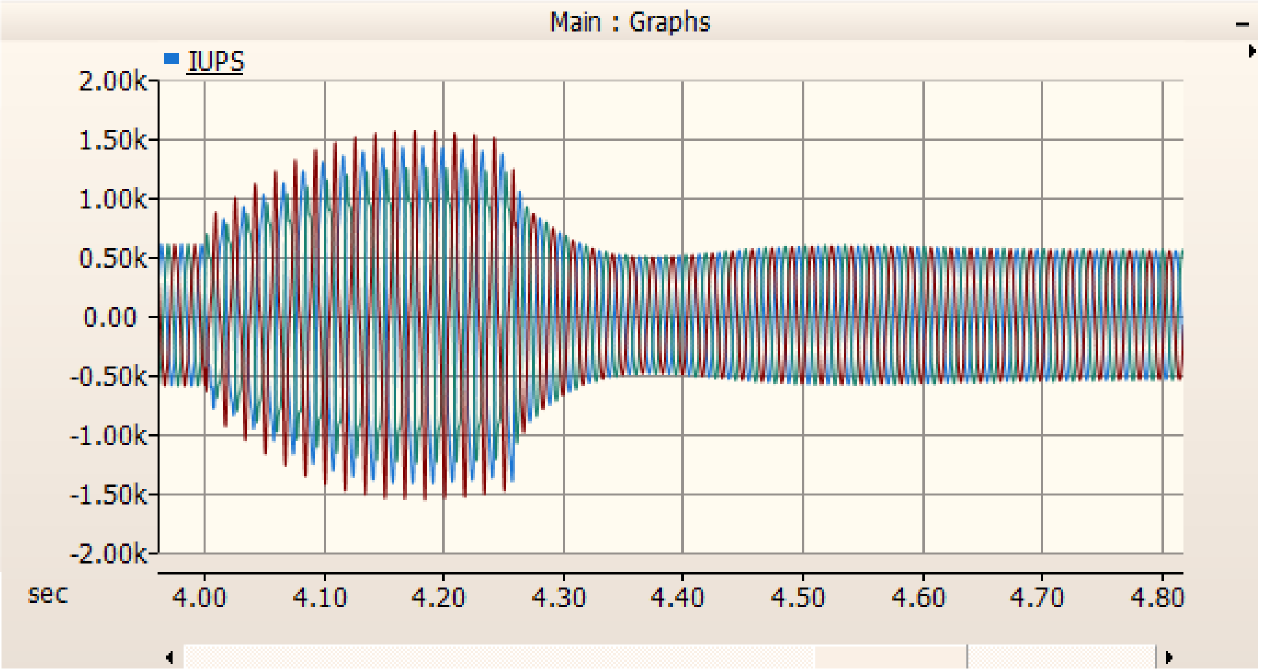
<u>Key nuances:</u>

- Constant power behavior is the natural consequence of DC voltage regulation
- Tripping may result from AC overcurrent, DC link voltage fluctuation, or AC voltage fluctuation
- Rate of capacitor discharge dictated by P_{dc}—varies by application, operating condition
- Presence of a battery **does not** trivialize DC voltage control
- Motor drives are still mostly diode-based, don't exhibit this behavior.

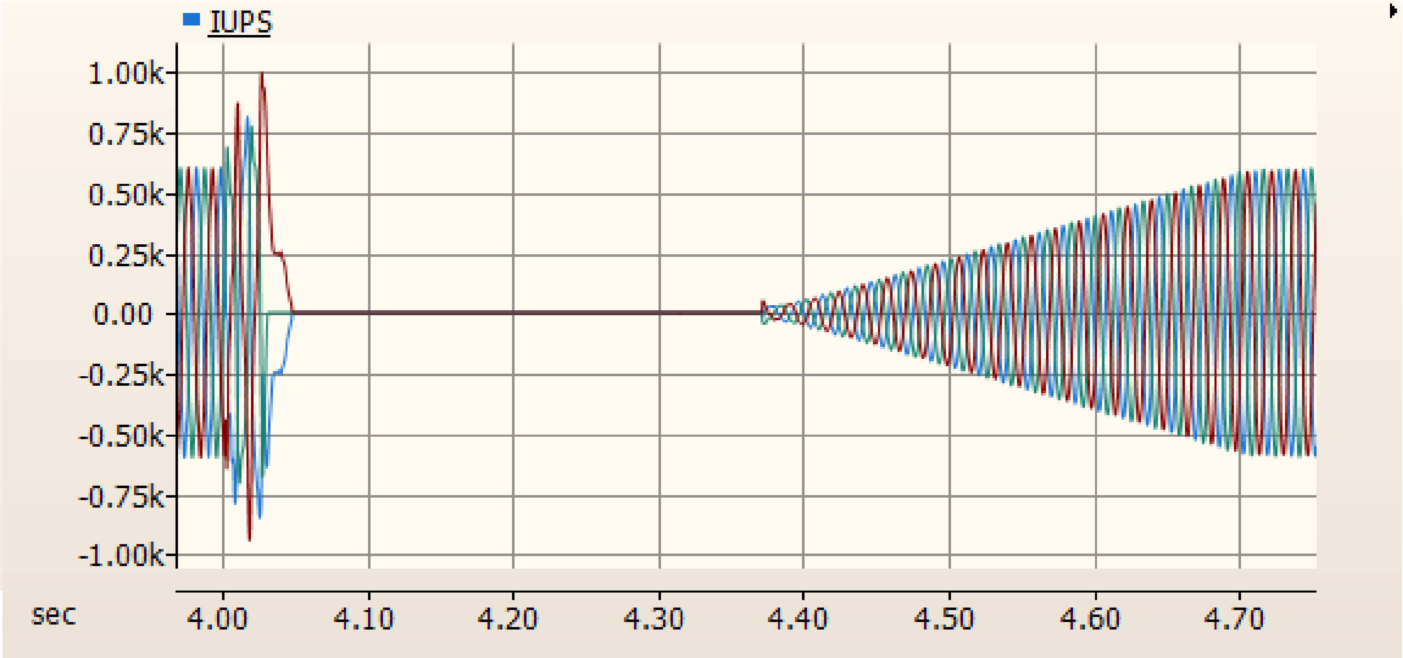
Double-Conversion UPS

- Primary grid interface for ~2/3 of traditional data center capacity
- Actual ride-through capability varies by make and model, sophistication of fault and DC voltage controls a major factor.
- Constant power, unity power factor, minimal I_2 consumption during voltage unbalance; momentary cessation below V = ~0.6 pu

Line-to-line grid fault at t = 4 s, UPS at 50% load:



(No momentary cessation)

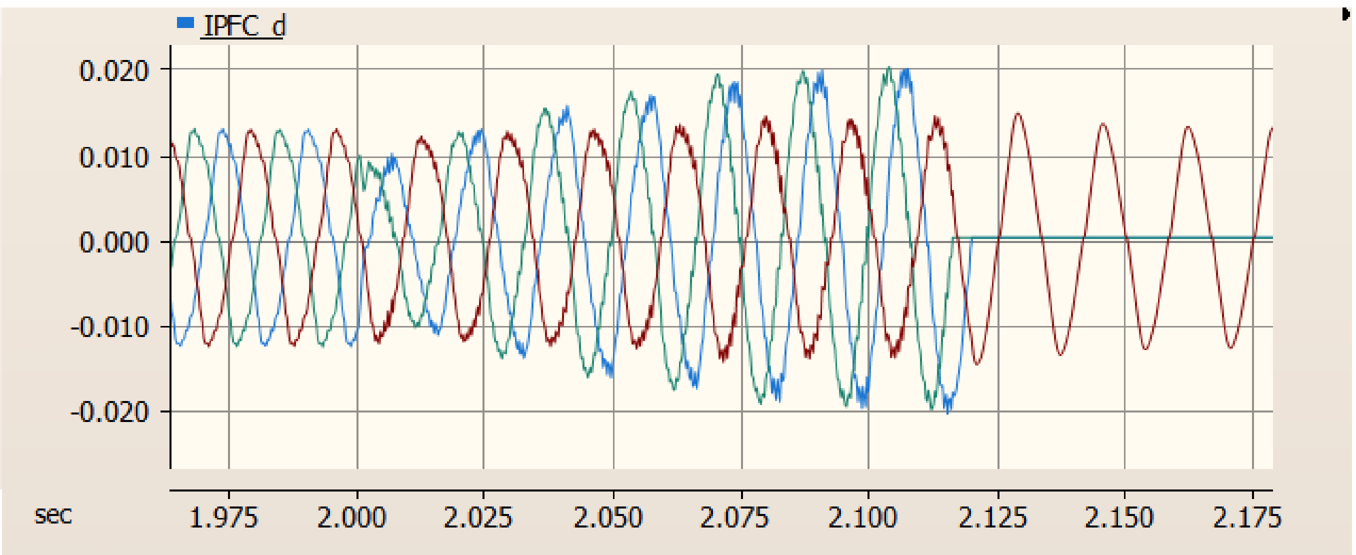


(Momentary cessation)

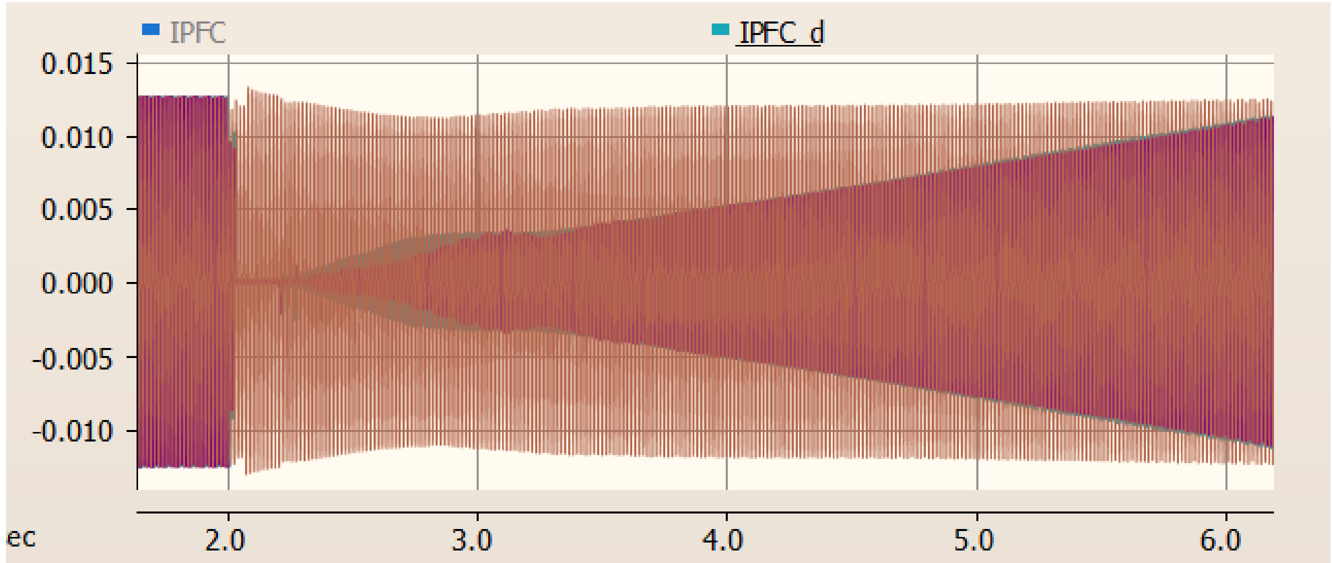
Rack-Level Power Supply

- Primary grid interface for cryptominer, distributed UPS data center
  - ~1/3 of traditional data center, most current AI data centers
- Today, mostly a single-phase 240 V inverter
  - AI applications on rapid (>2 yr) transition to 3-PH converter at rack level

Line-to-line grid fault at t = 4 S



(Constant power, trips on AC overcurrent)



(Enters momentary cessation, ramps afterwards)

Restart behavior:

Cryptomining applications—manual or automatic restart after several minutes

Distributed UPS—automatic ~4 s ramp after delay to come back up on backup generation

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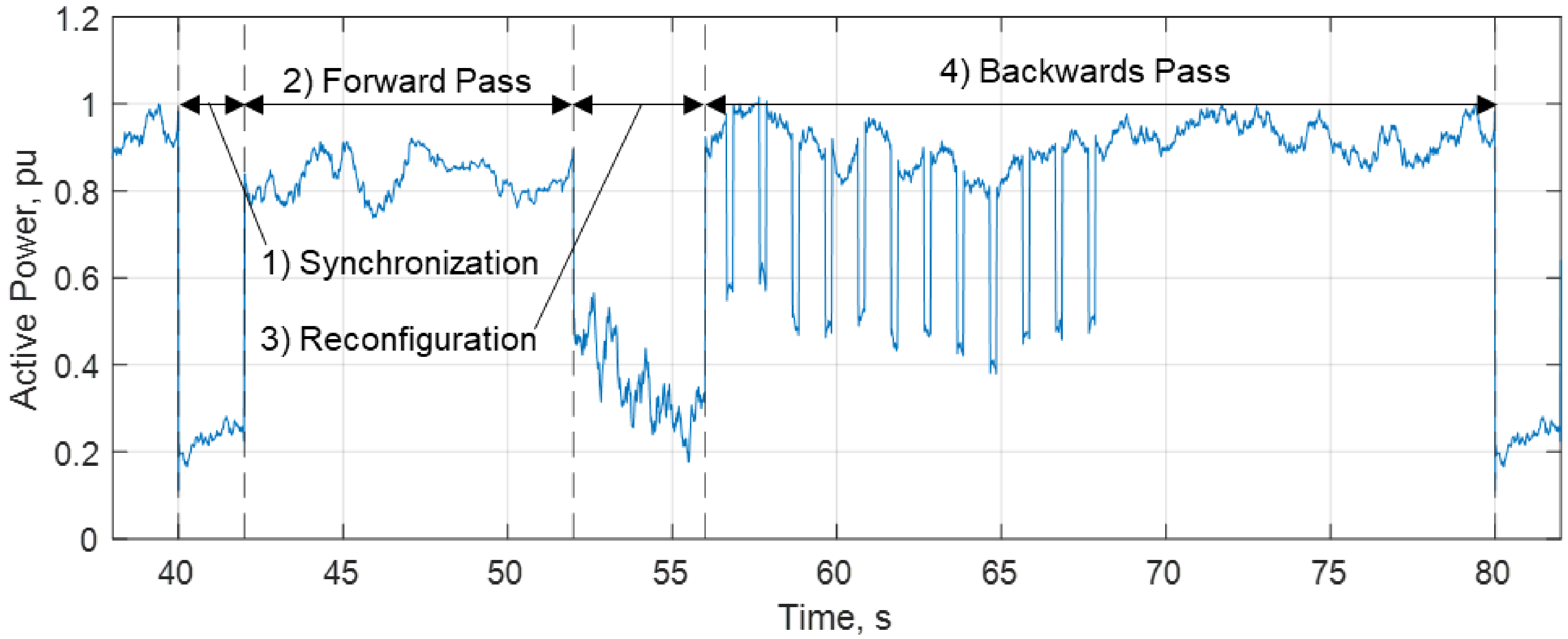
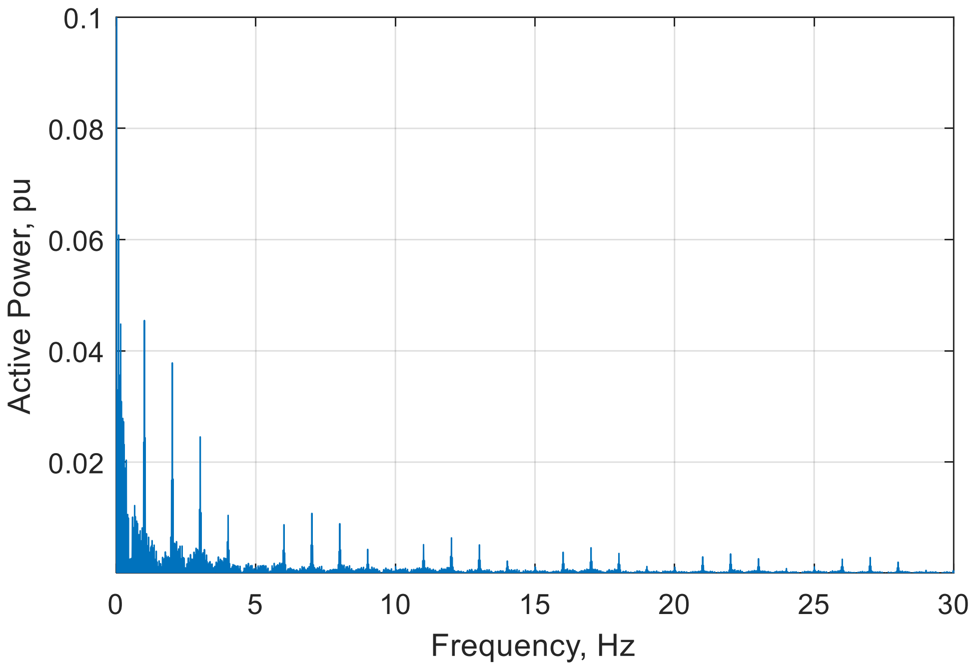
Electromechanical Impacts

Motivation

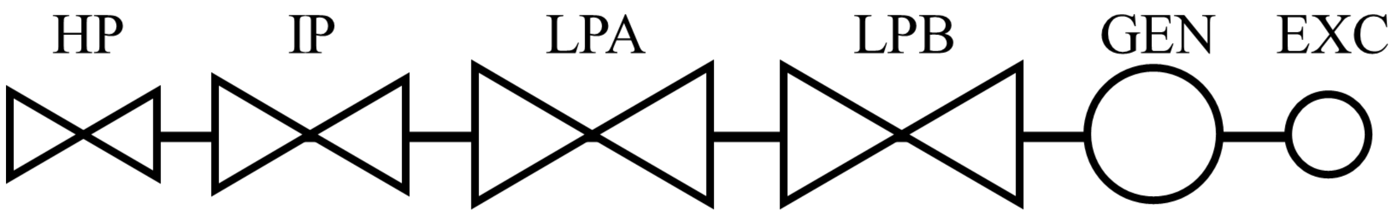
- Massive, synchronized compute loads cause rapid active power fluctuations
- Software-level controls (e.g., NVIDIA's minimum power floor) reduce # of GPUs that can be installed per site.
- Energy storage is expensive, space intensive
- **EMT study objective**: simulate torques on generator and prime mover components

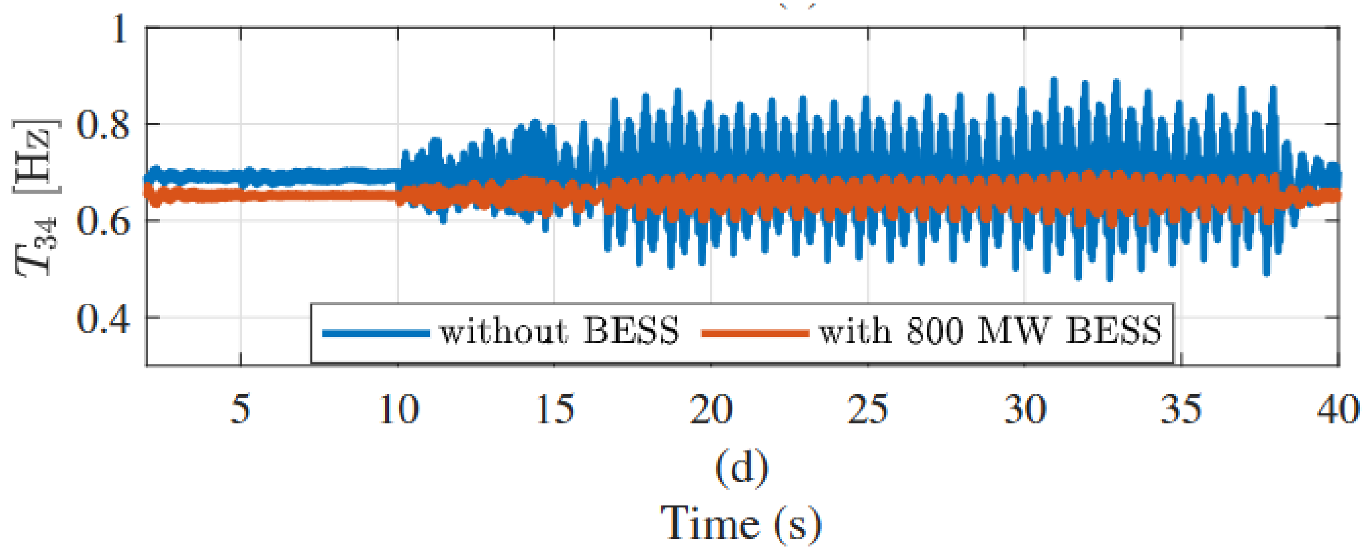




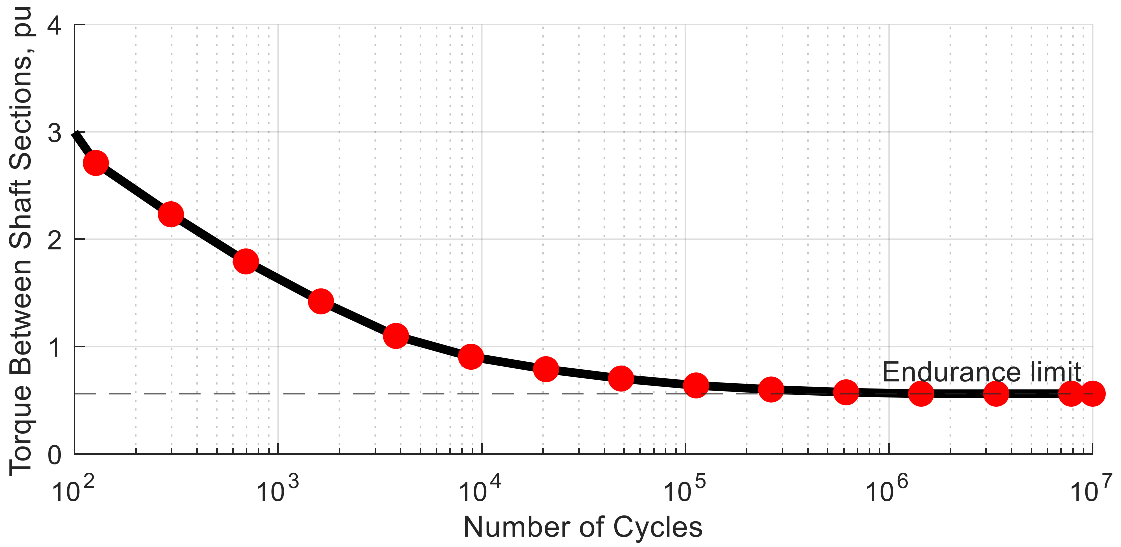
Methodology

- Data center load profile treated as a controlled active power source
- Phasor studies (e.g., unit interaction factor) recommended to identify at-risk generators, EMT for simulating torques internal to specific machines
- For machine modeling, current practices for SSR studies, arc furnaces being used



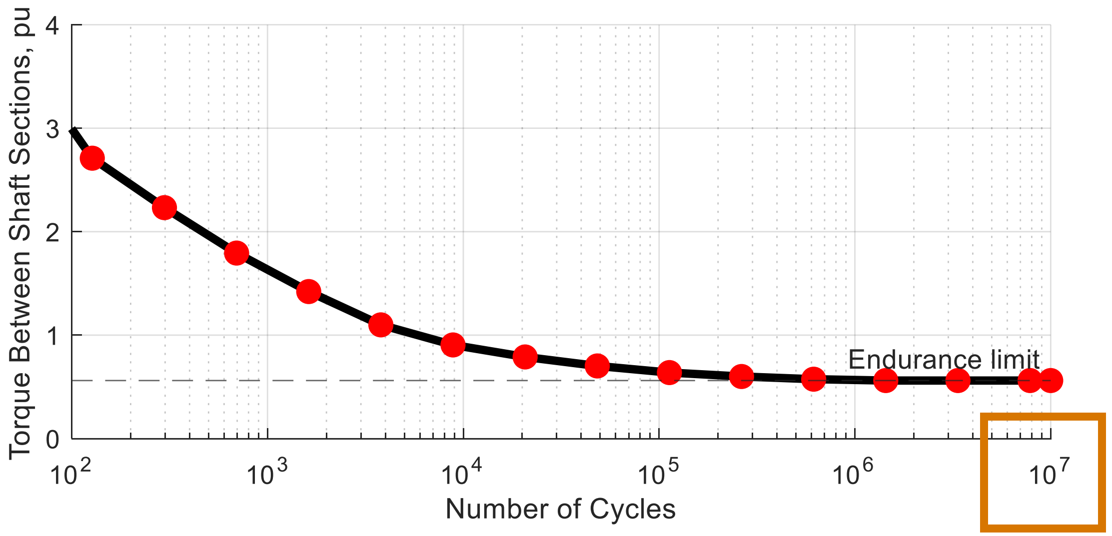


(d)



Outstanding Questions

- Applicability of existing SN curves—continuous AI loads induce very high cycle counts
- Capabilities of reciprocating engines—increasingly common for bridging power
- Suitability of existing generation monitoring—if exceeding endurance limit, will we know?



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Thank you