Data Center Loads Analysis and Mitigation

Lessons learned and thoughts on EMT

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What characteristics are we concerned with, and **which of these may require EMT to analyze?**

Most of these are especially interesting because to the *large size* of the load. Assuming the basic transmission and resource capacity is acceptable, we need to also consider:

1. Significant percentage of the load may cycle in a quasi-periodic way, at a range of frequencies and duty cycles
2. Load ride-through characteristics may be very sensitive
3. UPS components of load may take significant portions of the load and return it to the system
4. Load may come up and down at relatively fast ramp rates
5. Load may contain various dynamic components, including significant HVAC
6. Harmonic content may be unknown and significant
7. Subsynchronous damping characteristics may be negative
8. Load may be connected via software processes across multiple plants

Specific concerns and mitigation: Load Cycling

1. Significant percentage of the load may cycle in a quasi-periodic way, at a range of frequencies and duty cycles

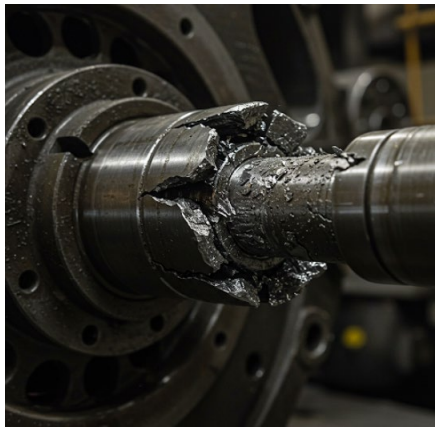
- Cycling can contain significant frequency content at machine torsional frequencies. Introduces risk of generator shaft fatigue or breakage.
  - If needed based on screening, EMT analysis includes explicit representation of shaft tortional data, and requires detailed fatigue characteristics of turbine-generator shaft system.
  - Mitigation may include cycling magnitude reduction (via software, low level hardware or external devices such as ESTATCOM), special measurement and dispatch action, and torsional stress relays.

- Cycling can contain significant frequency content at machine swing frequencies or interarea swing frequencies. Introduces risk of transient instability or reduction in system damping.
  - Mitigation may include cycling magnitude reduction (via software, low level hardware or external devices such as ESTATCOM), special measurement and dispatch action, and torsional stress relays.
- Variation in load can induce flicker violations locally and remotely (depending on how active power flows through the connecting system)
  - Mitigation may include STATCOM or cycling magnitude reduction.

SSR? SSTI? SSTA? SSFR? Other SSO?

(or just plain old broken shaft?)

- Turbine-Generator shafts are mechanical systems. Applying torsional stress beyond their design limits results in a reduction in shaft life, also known as **permanent shaft damage.**
- Put another way: Torsional stress limits are often defined in terms of cyclic torque magnitude vs duration. If you choose a torsional modal frequency and rock the system back and forth on that frequency at a high enough magnitude for a long enough time, the shaft will break.



How do we know if damage will occur?

A given change in P will result in a corresponding change in Torque.

Torque magnitude can be compared to damage over time curves for generator shaft systems.

Specific concerns and mitigation: FRT

2. **Load ride-through characteristics may be very sensitive**
3. **UPS components of load may take significant portions of the load and return it to the system**
4. **Load may come up and down at relatively fast ramp rates**

- Minor voltage depressions in the external network may cause the load to trip, or cause a UPS to take the load temporarily away from the system. May lead to over-frequency, or balancing concerns.
  - EMT analysis may be required to identify the type of voltage or frequency disturbance which may result in protection or UPS load take-up.
  - Mitigation may include BESS, improved ride-through characteristics, or carrying additional spinning reserve.
- Large, fast changes to powerflows in the system may drive voltage excursions through the transmission system.
  - Fast, variable VARs (eg. STATCOM) may be needed for operators to automatically handle voltage variability.

Specific concerns and mitigation: Harmonics

6. Harmonic content may be unknown and significant

- These loads can have significant injection of common “problem” harmonic currents, and this can interact with regional harmonic impedances to cause power quality issues.
  - Analysis is typically performed using multi-port harmonic powerflow studies, but characterization of harmonic sources may require detailed models to be created in EMT.
  - Mitigation may include passive or active filters, or improved harmonic specifications at the design stage.

Are harmonics a problem? Study!

- Some events are being recorded of large harmonics associated with data centers…
- What is needed is a frequency dependent Norton equivalent source
- Perturbation techniques can be used to derive impedances, and currents can be measured in strong testbeds (EMT and/or site measurement)

Study!

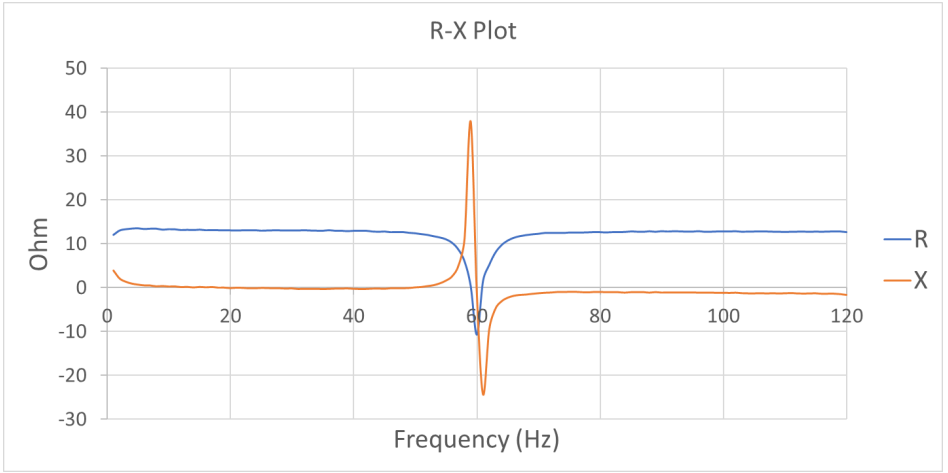
- Frequency-dependent impedance characterization is done for the external system under many operating conditions
- Harmonic sources are added
- *Multi-port* harmonic "powerflow" is calculated to create a family of possible voltage amplification, add existing measured background harmonic voltage distortion, and check harmonic voltage distortion, and harmonic current ratings of equipment

Specific concerns and mitigation: Damping

7. Subsynchronous damping characteristics may be negative

- Just like IBR plants, converter interfaces to the grid may have regions of negative damping in the sub-synchronous region. This can degrade existing system damping and exacerbate SSCI issues driven by IBR generation.
  - Analysis requires extremely detailed EMT models (possibly OEM specific), or lab testing of component devices to characterize damping,
  - Mitigation via control adjustments or external hardware such as GFM batteries or ESTATCOMs.

- Eg: 240V, 5700 W Power Supply, generic controls…
- Positive resistance. Good!
- Negative X >60 Hz?
- Is it real???



Specific concerns and mitigation

8. Load may be connected via software processes across multiple plants

- Large loads connected at different locations with different parties involved may be connected via software processes to make up a type of “super CPU”. This means that any of the prior issues may be amplified and spread through a wider geographical area.
  - Load modeling and impact assessment may need to be grouped and considered in aggregate.

What type of EMT models are needed?

- The specific EMT models required for each of the above criteria differ based on the issue. Models required may include:
  - “Flexible” EMT models that can evaluate generator shaft torsional impact. These may be non-OEM specific, but configurable to represent possible load variations.
  - “Detailed” EMT models that can correctly represent damping for SSCI evaluation and characterize vulnerability to ride-through failure. These need specific control information about grid-facing power electronic equipment.
  - Harmonic models that can be used to evaluate network harmonic impact and design harmonic mitigation. These also need specific control information or hardware specific mitigation.

Requirements as a supplement to EMT analysis

- In cases where strict limits on variation/oscillation are imposed, and where ride-through standards exist, it may be possible to reduce the need for detailed analysis.
- If your load can guarantee and demonstrate how they will not violate the requirement, you may no longer have to provide detailed models of loads and nearby generators to do an SSO analysis.

What could such a requirement look like?

Questions?

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