Modeling of Data Centers: Ride-through Impacts, Slow oscillations, and SSR risk screening

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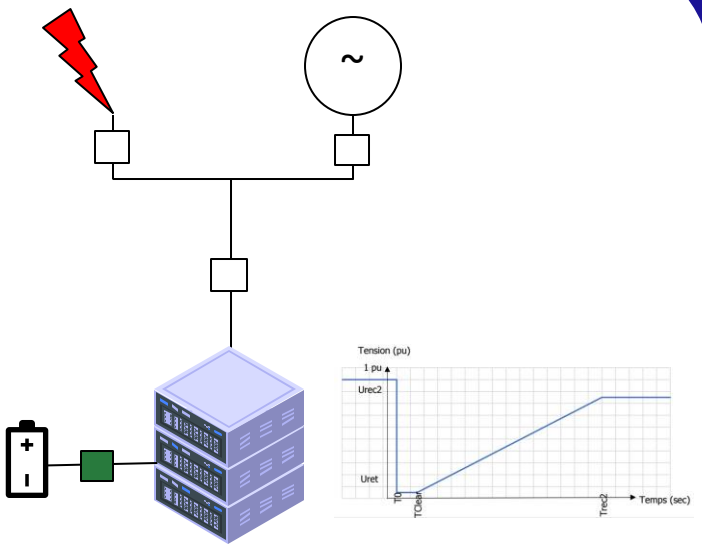
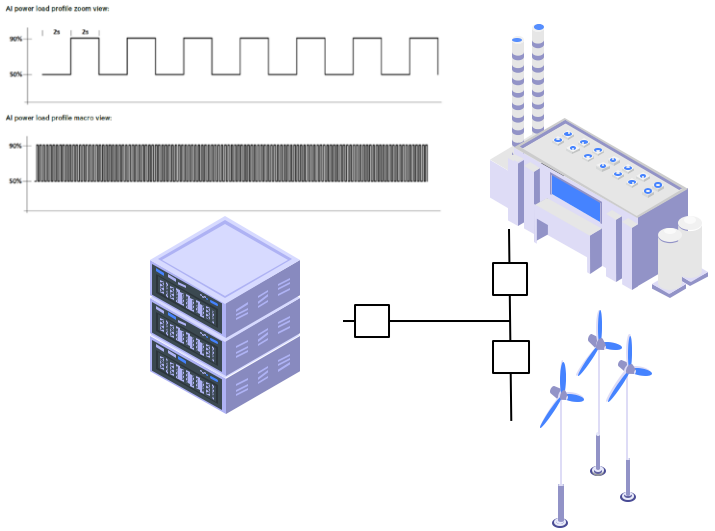
Key Data Center Challenges Impacting BPS Stability



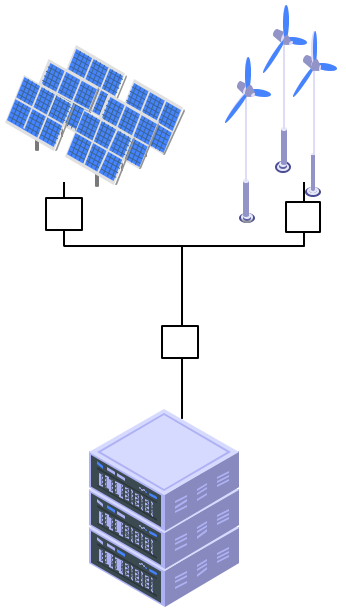
Unanticipated Data center load disconnection after a disturbance in the grid

Phasor Domain Assessment



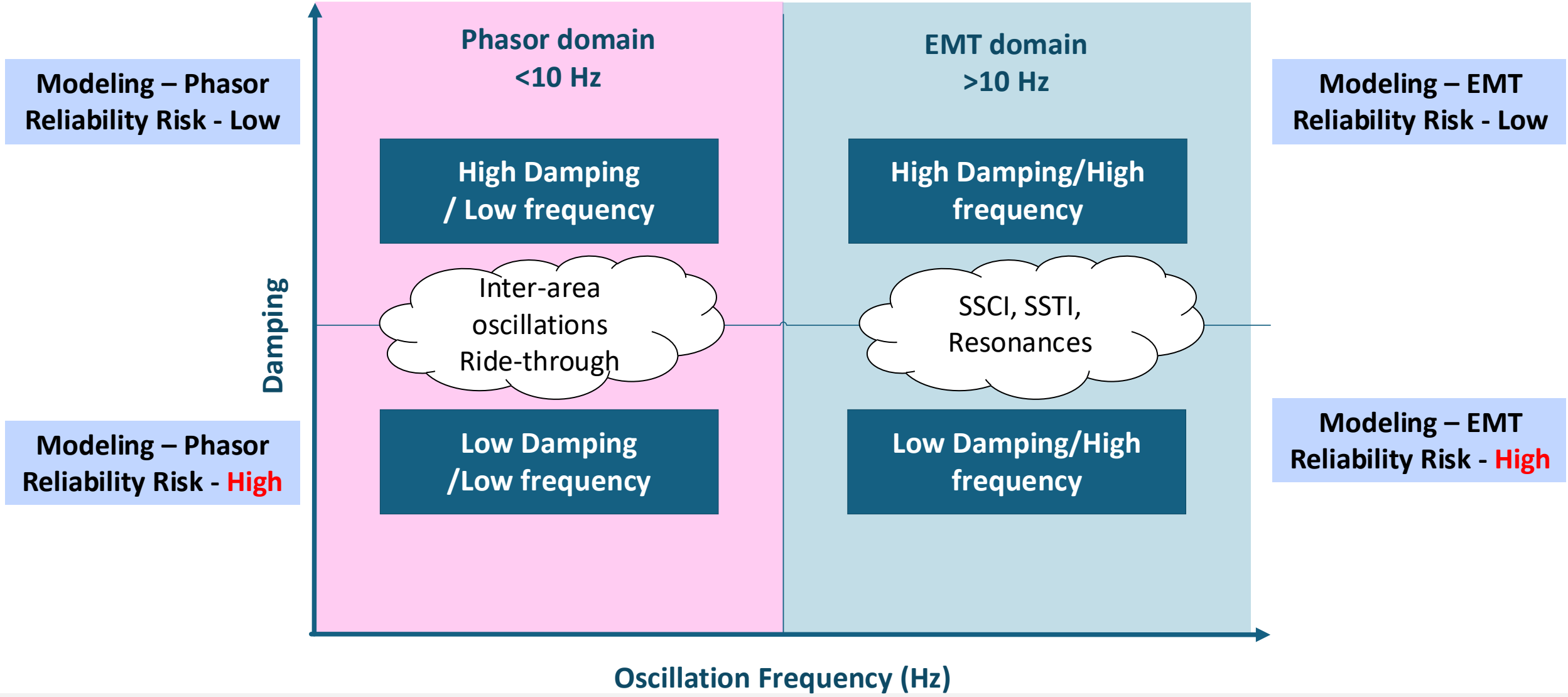
AI training and its impact on BPS stability

Phasor Domain Screening

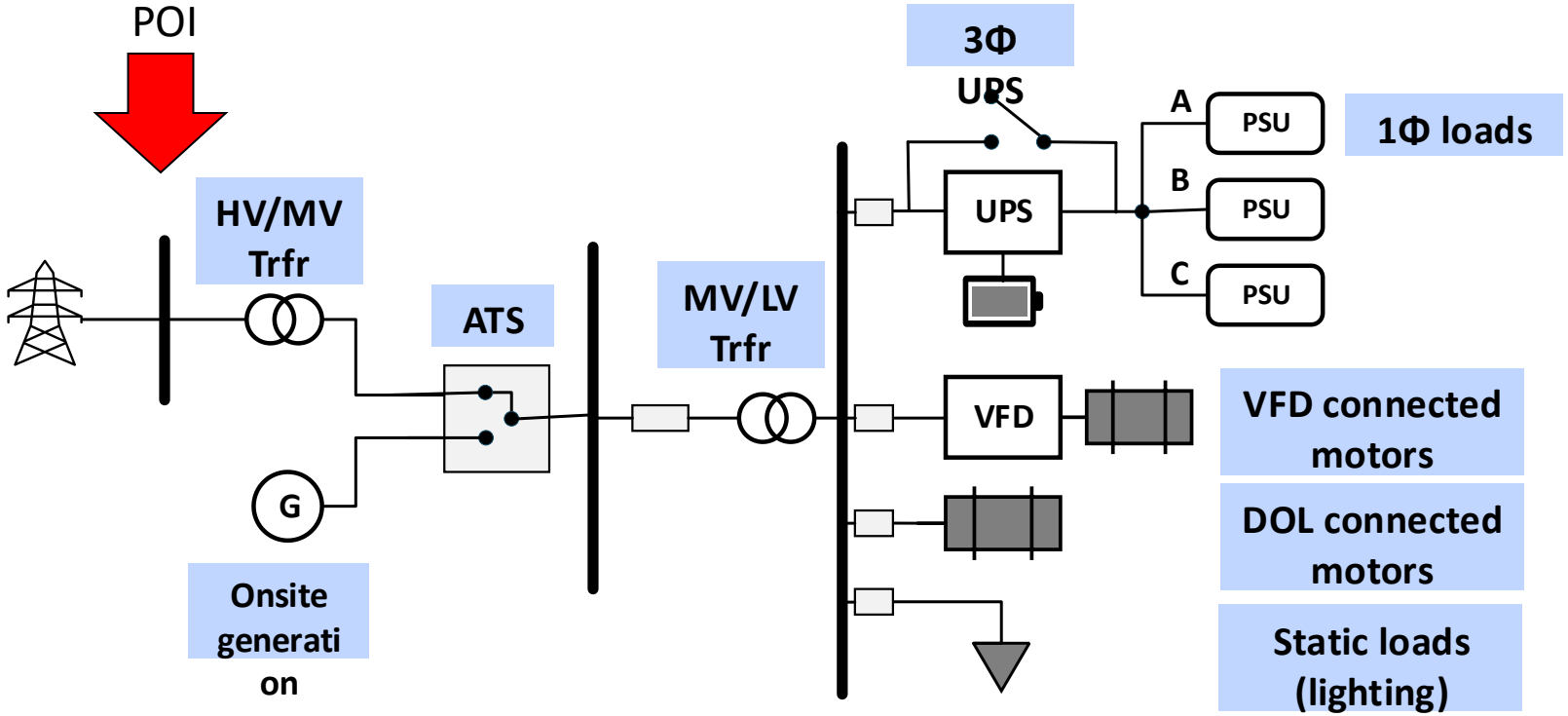


Data center control interactions with IBRs and close by generation

Suitability of EMT/Phasor domain models



Key components of data center

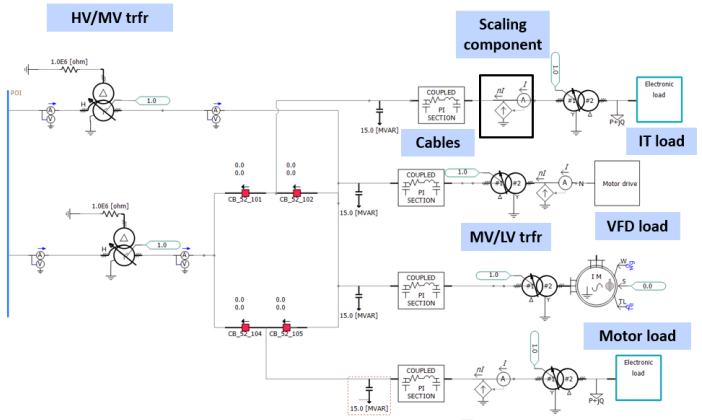


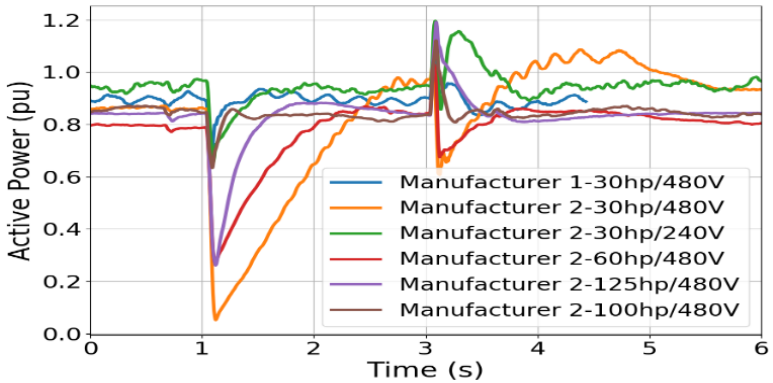
About 90% of the total load is electronically driven (Switched Mode Power Supplies and Electronic Drives)

The main electrical equipment that interfaces with the grid are:

- ***Uninterruptible power supply***
- ***Single phase power supply units (*)***
- ***Variable speed drives/direct connected motors***
- ***Lighting (LED)***
- ***Battery Energy Storage/Power Conditioning Equipment (*)***

Phasor Model Development

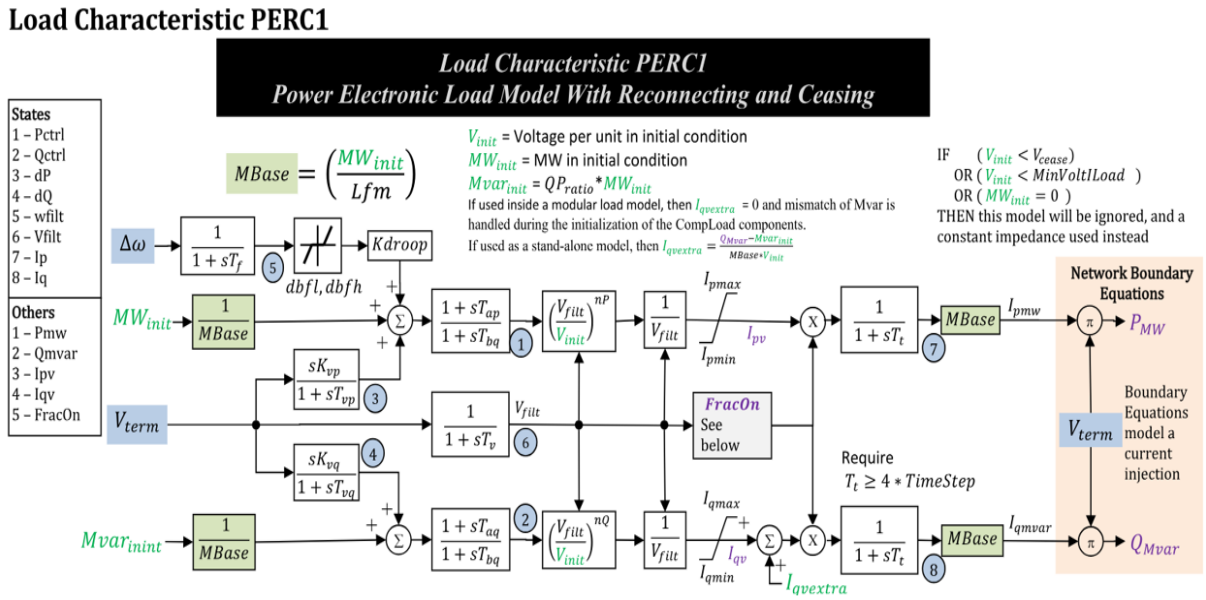




- EMT model with all controls modeled in detail provides us an understanding of aggregated responses
- Lab tests and measurements provide us confidence in model behavior being able to replicate real device

Capture slow dynamics

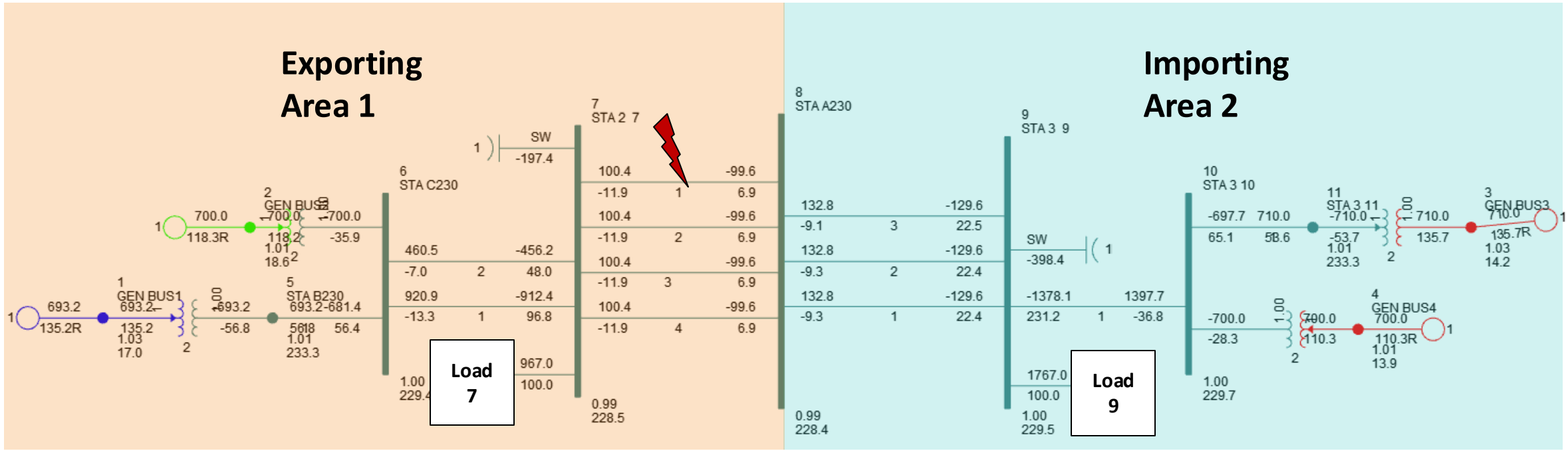
Phasor Domain Model



- **Phasor domain models are effective for studying load disconnection and reconnection impacts on the bulk power system.**

Capability of the Phasor Model

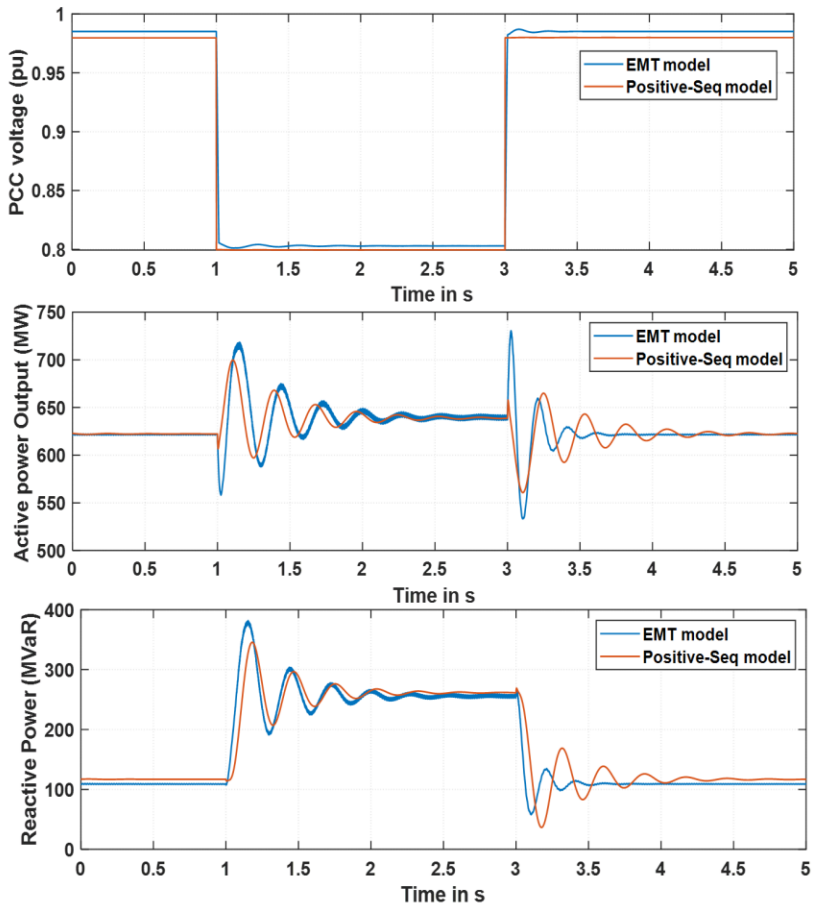
2-area Kundur Test system: Created in EMT and PSLF



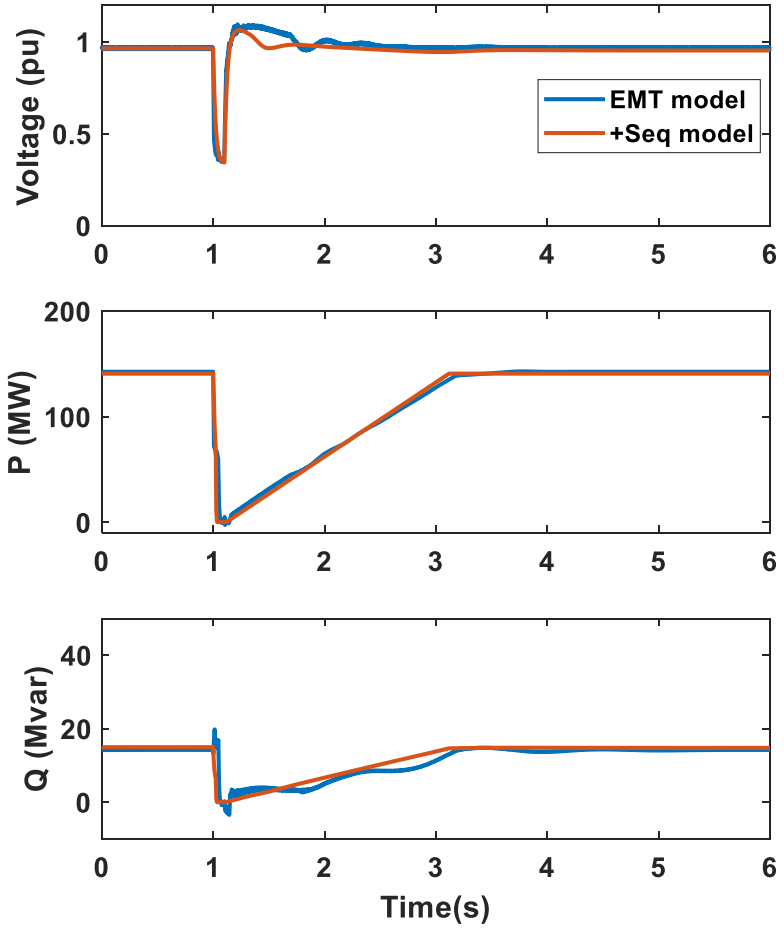
- **Response to minor disturbances – Linear control responses**
- **Ride-through and Ramp behavior**
- **Reflect load's impact on electromechanical modes (aka – local and interarea oscillations)**

Small Disturbances and Ride-Through

The model can be used to capture dynamics due to process control



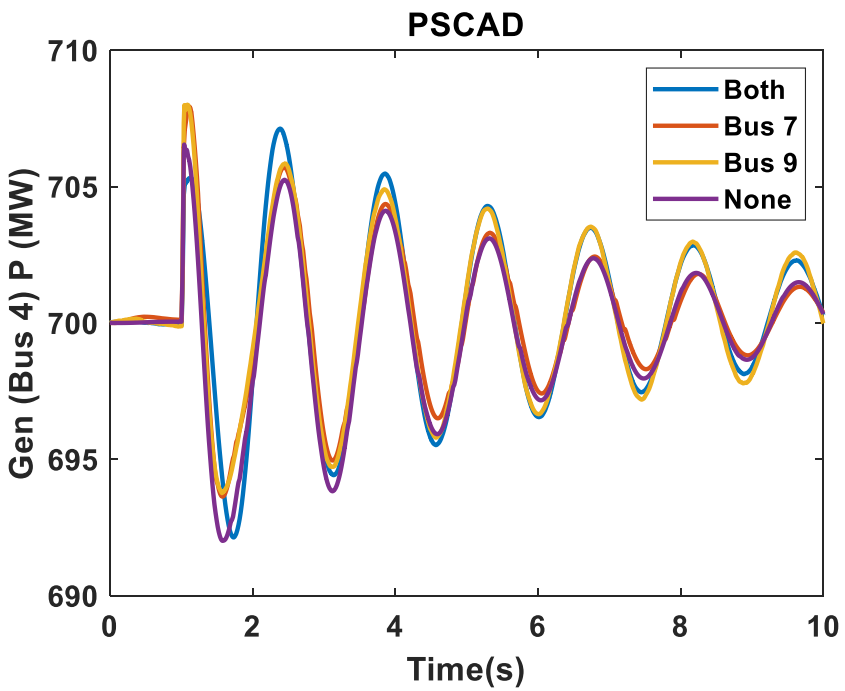
Model can be used to study impact of load disconnection/reconnection

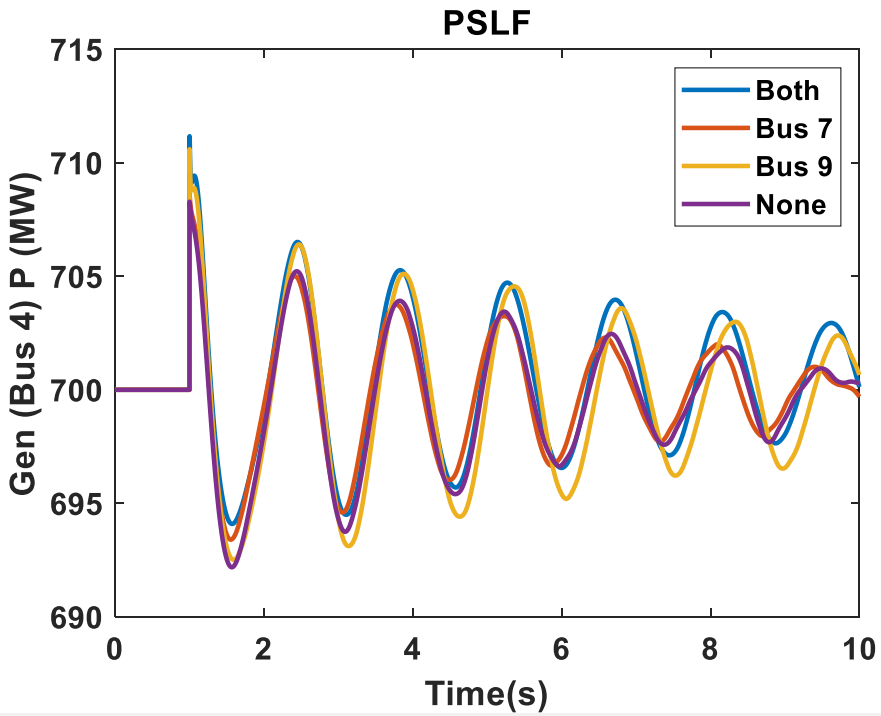


Electromechanical Oscillations

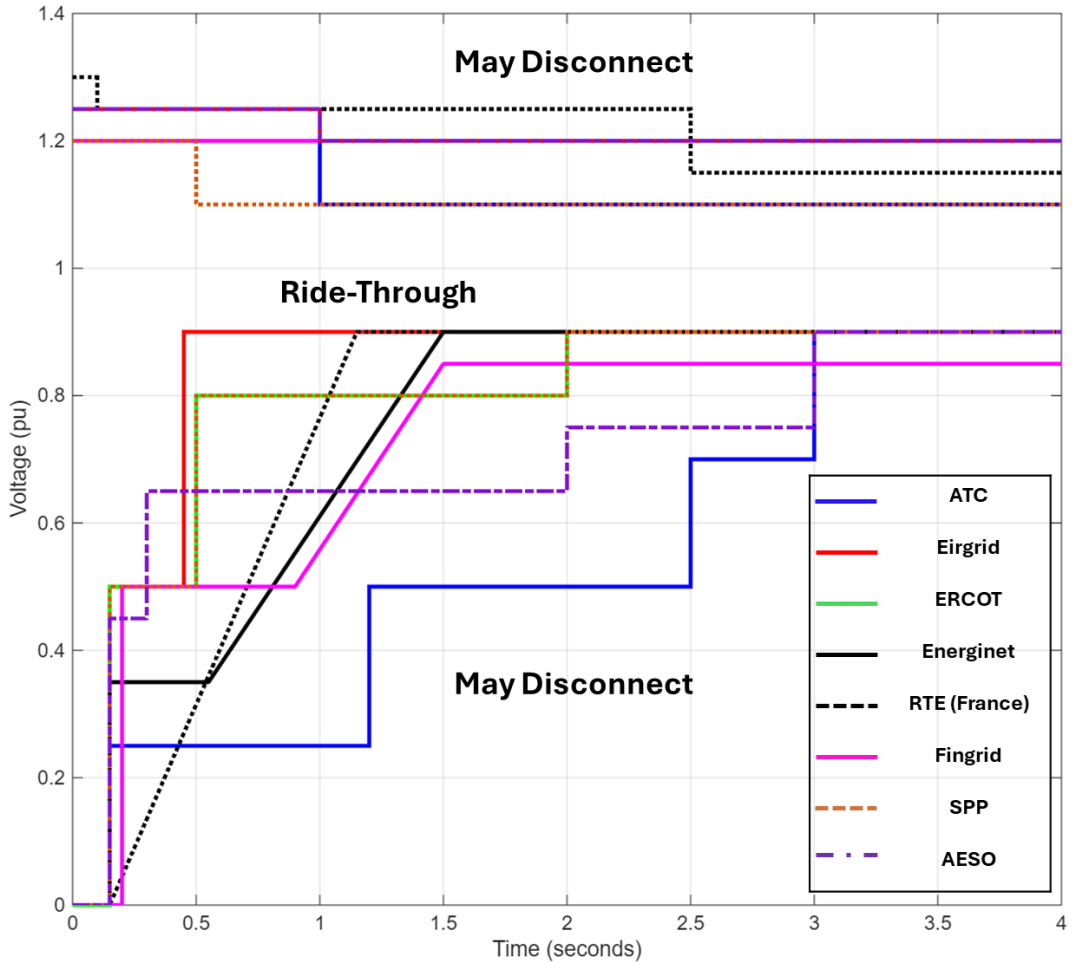
Cases	Description
Scenario 1	Both loads are modeled as data center
Scenario 2	Bus 7 is modeled as data center (Exporting area)
Scenario 3	Bus 9 is modeled as data center (Importing area)
Scenario 4	Both loads are modeled as constant current loads

- The location of the data center loads has a significant impact on the inter area mode
- Whether it improves/worsens the damping depends on the prevailing conditions
- ***The trend of damping is consistent across EMT and phasor domain tools. Highlight effectiveness of both platform and model***



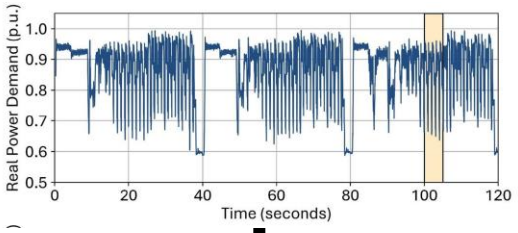


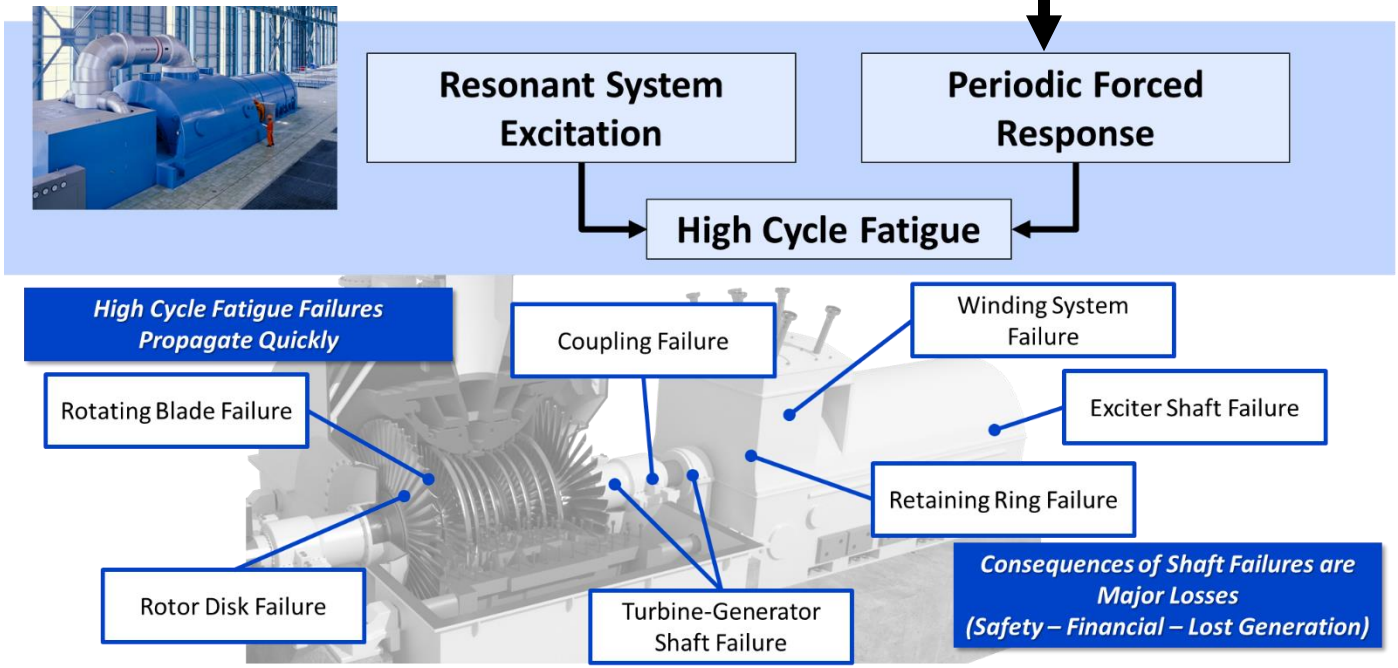
PERC2 Development



- PERC 1 was developed much before ride-through curves were developed.
- It lacks the ability to have multi-point ride-through behavior modeling
- PERC1 is still very much usable and EPRI recommends using this model for data center compute as well as cooling loads
- PERC2 will incorporate a multi-point ride-through representation ability
- Some additional ramp rate capabilities

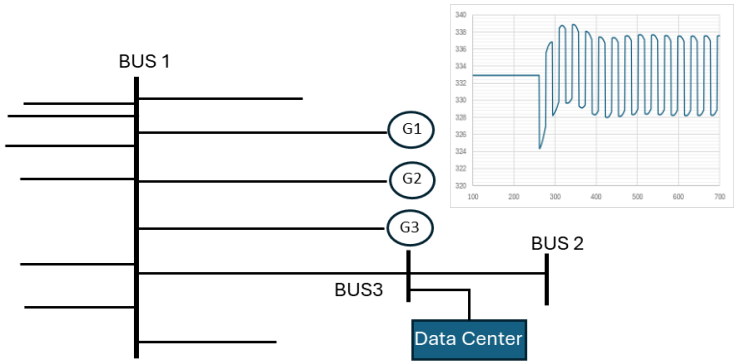
Forced Oscillations and Screening

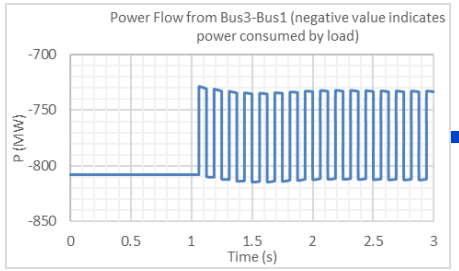




- Continuous perturbations create stress on turbine shaft and other coupled systems
- **Perturbations at resonant frequencies** can cause **disproportionately high stress** on the shaft
- **Perturbations at non-resonant frequencies** can **damage the shaft as well** (above 10% rated torque will be a problem. Can be even tighter for some generator designs)
- **General guidance**: **Avoid torsional modes as much possible** and **keep perturbations within limits**
- **Assessment –** EMT with Multi-Mass model created with guidance from turbine-generator OEM
- **Screening – Phasor Domain with the goal of understanding how much perturbation at a load site shows up at each generator's terminal**

Forced Oscillations and Screening





- Perturbations can be injected in a PSS®E type tool and used to identify how much of the injected perturbations show up at nearby generators
- Main advantage – Faster simulation using power flow cases typically available for planning studies.
- ***Goal is screening only***. Only load shape needs to be injected and no detailed models needed
- Works in PSS®E/PSLF™/PW/DSATools and others for most systems that don't have significant series compensation or shunt filters

Could be simplified more using static approaches.

$$Current\_Gain = \frac{\partial I_{gen}}{\partial I_L} = 1 - \frac{\boldsymbol{SCMVA\_i}}{\boldsymbol{SCMVA\_tot}}$$

EPRI guidance on data center modeling

- **Existing phasor models are recommended for transmission planning studies.**
  - Focus: Ride-Through, Inter-area oscillatory events.
- **Multiple instances of the phasor model can be used to represent the computation and cooling load**
- For SSO assessments, Phasor domain tools and methods will help

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