

Understanding Risks to Synchronous Machines Due to Load Variability

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SPECIALISTS IN POWER SYSTEM STUDIES

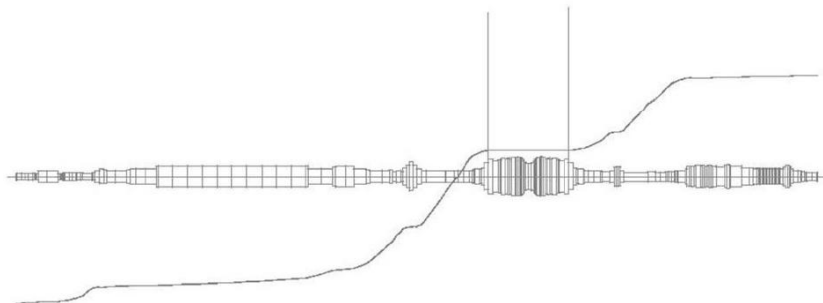
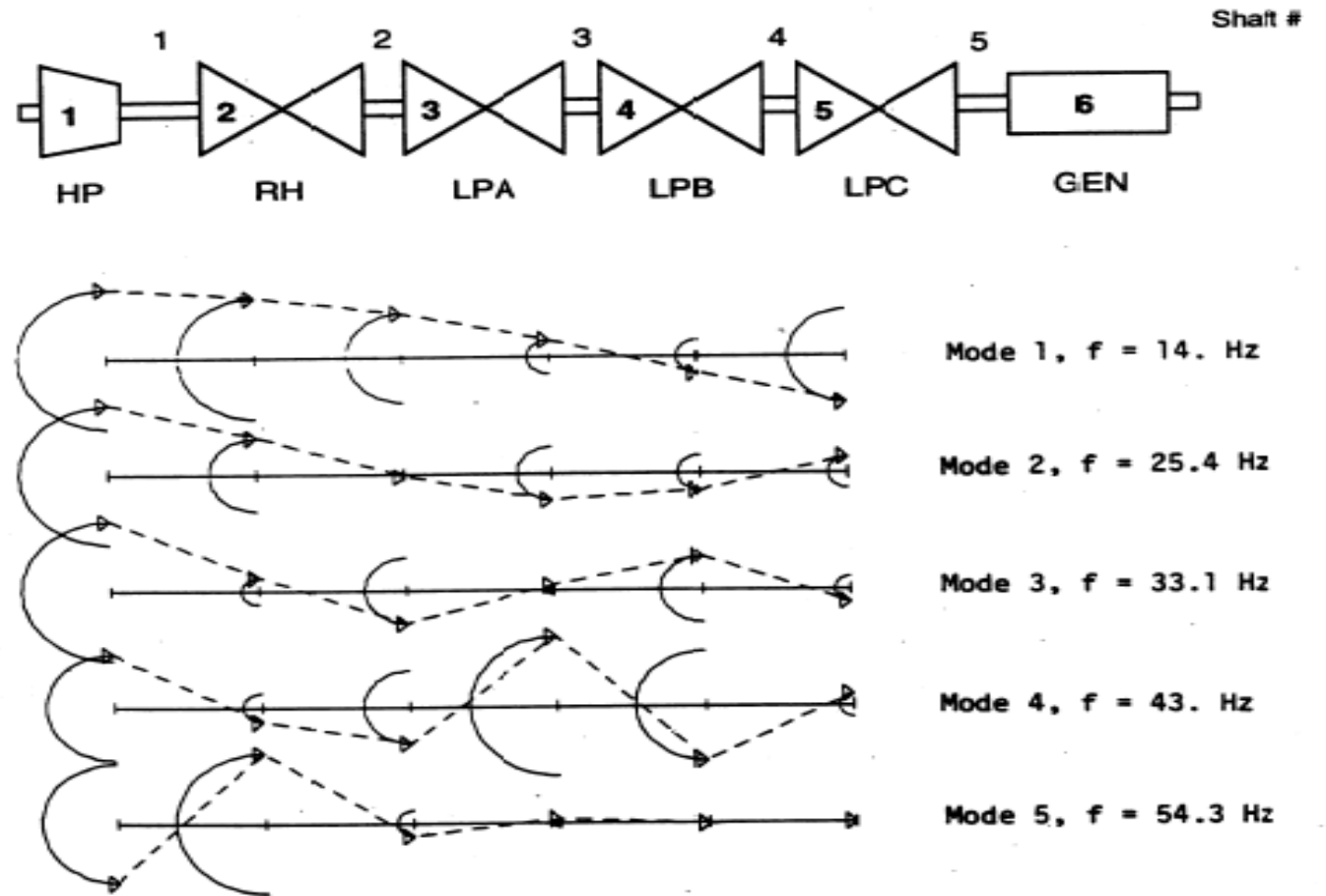
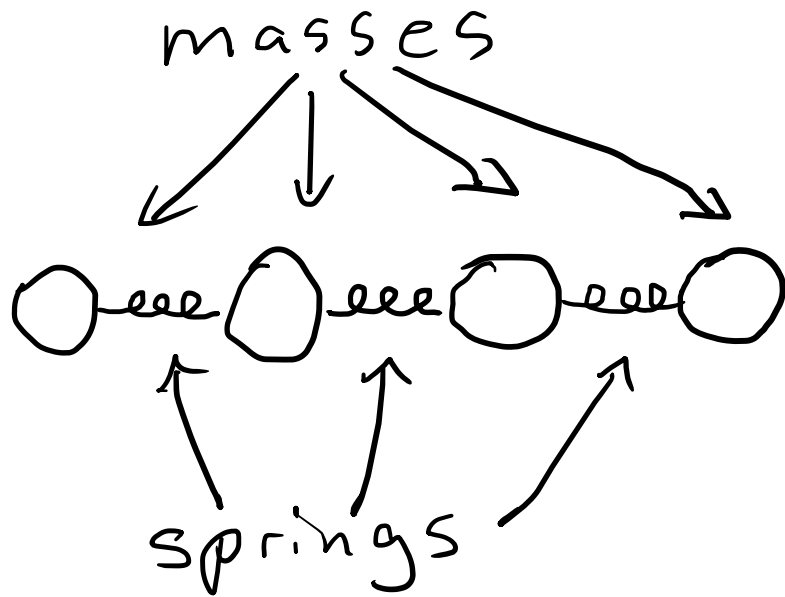
First... a few thank you's!

- Electranix team: Kasun Samarawickrama, Lukas Unruh
- Nick Giffin and Goodarz Ghanavati from Elevate Energy Consulting
- Clients and Customers who will remain unnamed to protect the innocent

Survey of Potential Issues

- Generator damage
- Degradation of system damping
- Power Quality
 - Harmonics
 - Flicker
- Ride-through failure impact
 - Voltage impact
 - Frequency impact
- IBR interaction
- Machine mode instabilities
- Interarea oscillations
- Resource Adequacy
- Steady state constraints
 - Thermal
 - Voltage
- Dynamic VAR margin

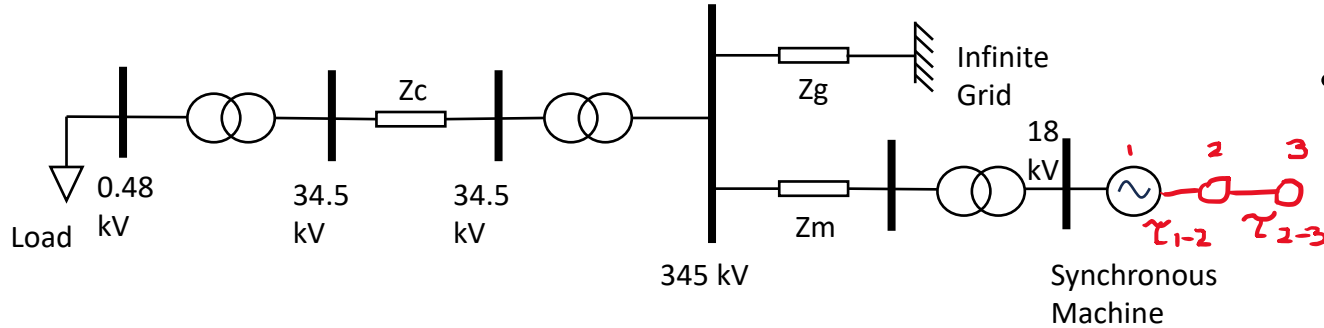
Reminder... Synchronous Generator Shaft



What is the concern with loads and synchronous machines?

- Broken or fatigued shaft... due to:
 - Resonant condition with nearby series compensated network
 - Lowered system damping at a shaft torsional mode due to load controls
 - Forced oscillations from nearby load processes
 - Periodic transients due to software cycling
- Other turbine-generator stresses due to fluctuations in terminal current, especially outside of nominal machine ratings
- Degraded damping of conventional machine oscillations

Example (ERCOT study)



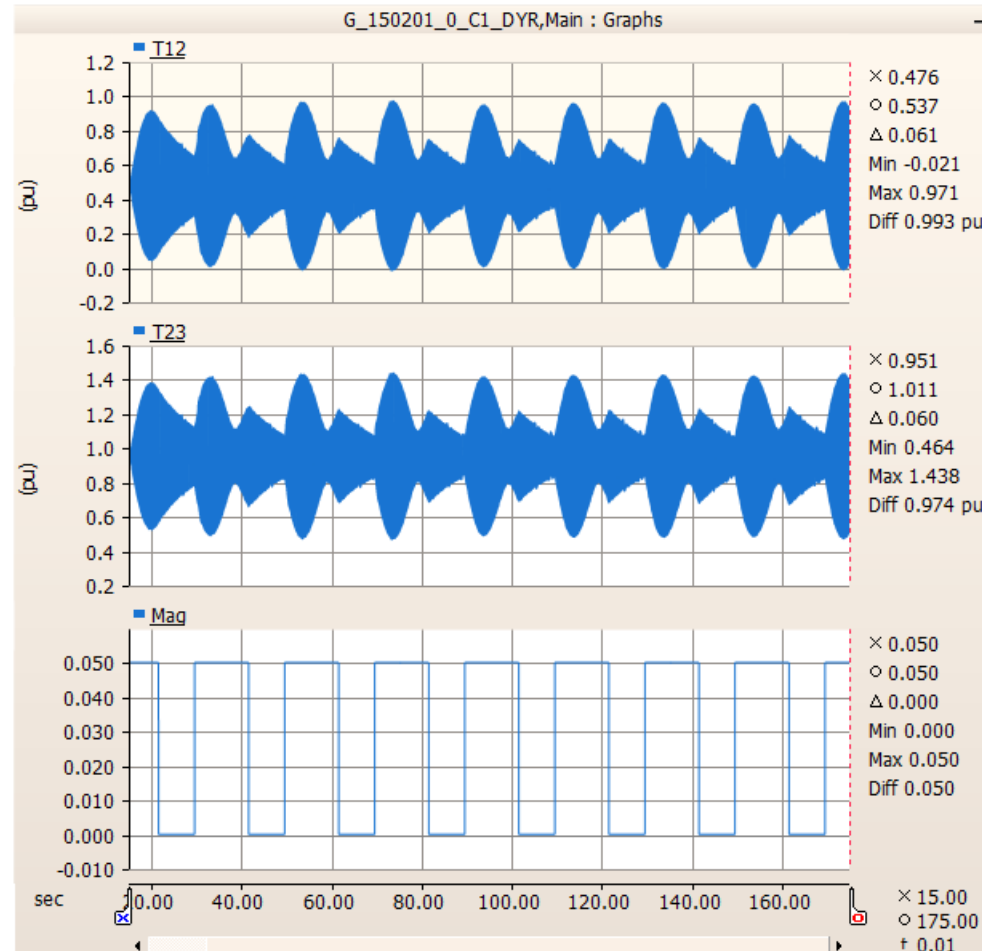
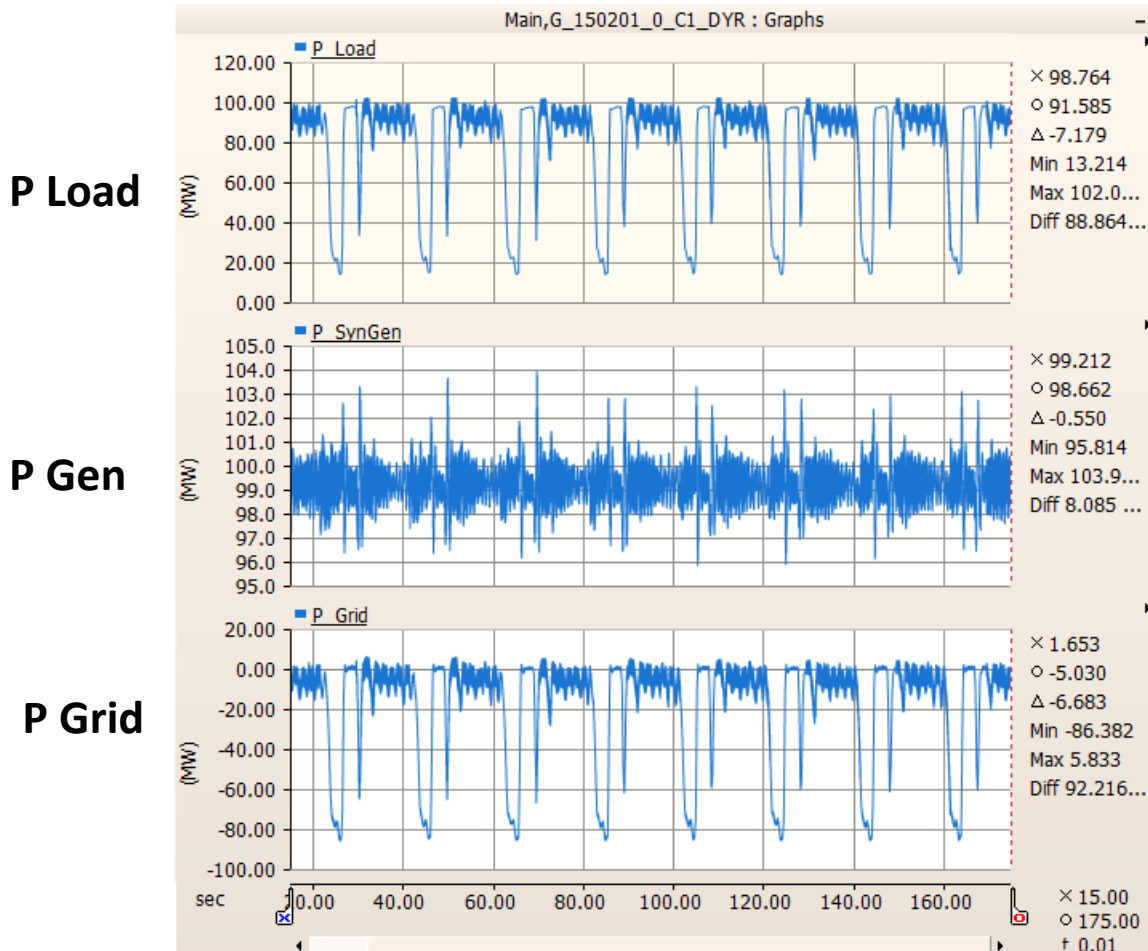
Key Parameters:

- Machine Rating = 100 MW
- **Synchronous machine key torsional mode: 12 Hz**
- Load profiles:
 - Profile 1 (S1 – S8): Fixed frequency square wave varying between 25 MW and 100 MW with a ramp rate of 10 MW/1ms
 - Profile 2 (S9 – S16): Proxy waveform mimicking measured AI training load profile

| Scenario No. | Load Variation | Max Pk-Pk Active Power Variation* (Generator electrically close: $Z_m = 0$) | | | Alternating Torque | |
|--------------|--|---|----------------|-------------|--------------------|------------|
| | | At the Load | At the Machine | At the Grid | Tau12 (pu) | Tau23 (pu) |
| | Hz | MW | MW | MW | | |
| S1 | Load profile 1 at 2 Hz | 76.81 | 32.98 | 77.81 | 0.233 | 0.234 |
| S5 | Load profile 1 at 12 Hz | 77.61 | 11.89 | 82.55 | 5.124 | 5.028 |
| S9 | Load profile 2 | 85.55 | 6.21 | 87.44 | 0.042 | 0.042 |
| S13 | Load profile 2 with 12 Hz oscillations | 88.86 | 8.09 | 92.22 | 0.993 | 0.974 |

*Note: Split of active power between machine and grid is initially determined by impedance split, and the final variation will depend on the frequency of the variation and other machine characteristics over time. Ref. ERCOT LLWG October 24 meeting:

Load profile 2 with 12 Hz Additional 1pu Torque... strong Torque Amplification!



Torque 12

Torque 23

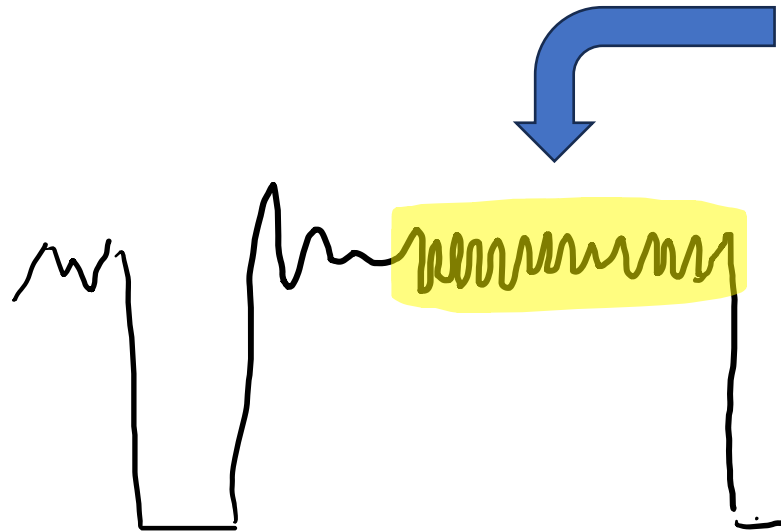
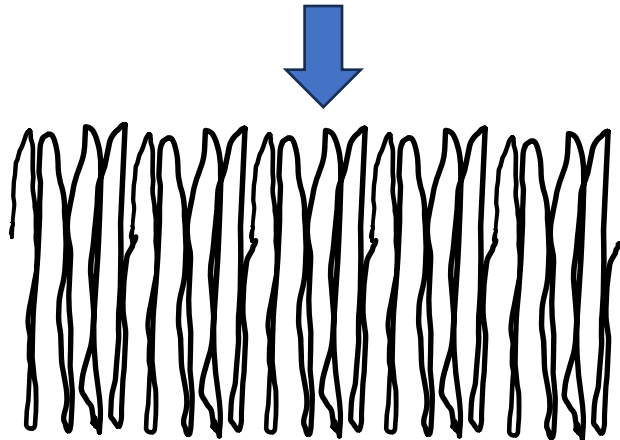
**Per unit 12 Hz
Component**

Is it really that bad?

- When we ask the question “Is it *possible* that your load will look like this?” The answer is **YES**. No one knows or is willing to guarantee what the GPU load will look like into the future.

- **HOWEVER: Is it likely?**

- If we see full rated oscillations at a torsional mode, we're in **big trouble**:



- BUT, actual measured load profiles (so far) contain sub-synchronous components, usually here:

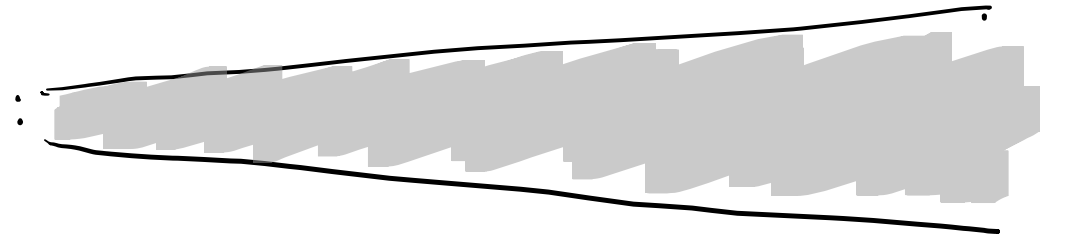
- If we analyze that portion...

Magnitude, frequency, phase, and duration matter!

Continuous, constant phase, off-torsional frequency



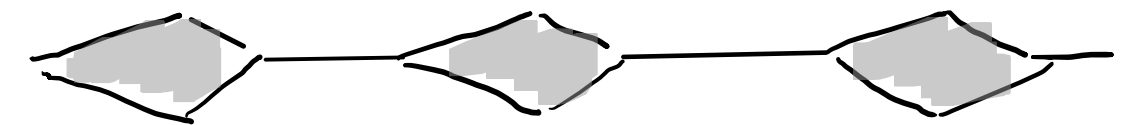
Continuous, constant phase, on-torsional frequency



Continuous, phase shifting, on-torsional frequency



Dis-continuous, constant phase, on-torsional frequency



What can we do?

- Write requirements to limit active power variation
 - Can be either surgically with frequency domain analysis, or bluntly with active power bands.
 - Note: These will need continuous tuning and updating for a while!!
- Quantify probabilities of *in-phase, long duration, constant frequency* components. We need help with this!
- Protect generators! Subsynchronous monitoring at the least, and maybe even protective action. Consider increasing depth and frequency of machine inspections until more is known.

Questions?

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