TPS
49TH TURBOMACHINERY & 36TH PUMP SYMPOSIA
SEPTEMBER 14-17, 2020 | HOUSTON, TX | GEORGE R. BROWN CONVENTION CENTER
TEXAS A&M UNIVERSITY
TEES TURBOMACHINERY LABORATORY
TEXAS A&M ENGINEERING EXPERIMENT STATION

SUB-SYNCHRONOUS TORSIONAL INTERACTION (SSTI) CASE STUDY: GENERAL APPROACH APPLIED TO A REAL LNG PLANT

D. Sgrò - M. Guidi - M. Frattoni - L. Bongini

Baker Hughes

Authors

Daniele Sgrò
Technology Leader - Electrical Power Management
Plant and Module Technology
Baker Hughes, Florence, Italy

Michele Guidi
Engineering Manager
Electrical System Engineering
Baker Hughes, Florence, Italy

Michele Frattoni
Consulting Engineer
Electrical System Engineering
Baker Hughes, Florence, Italy

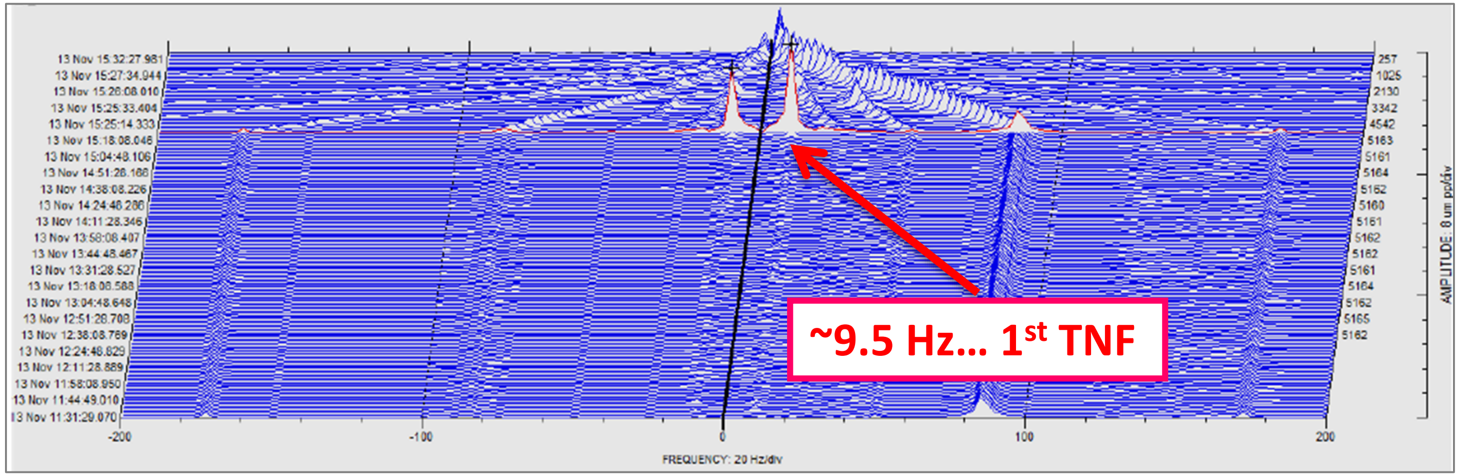
Lorenzo Bongini
PhD Student
Electrical and Automation Engineer
University of Florence, Italy

Abstract

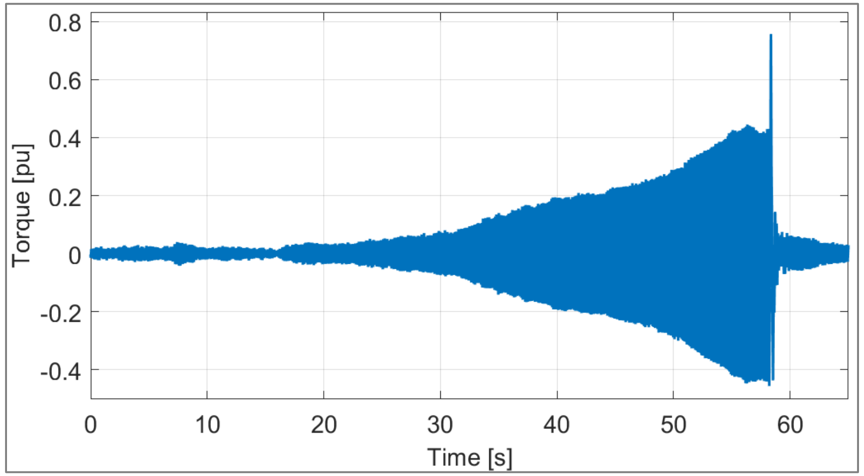
Scope of this Case Study is to apply a general approach used for Sub-Synchronous Torsional Interaction (SSTI) studies to a real Liquefied Natural Gas (LNG) plant, where severe SSTI events have been observed during commissioning and start-up activities. The results obtained by using a commercial simulation platform are compared to field data acquired during an SSTI event. The importance of this type of analysis during the plant design phase is emphasized, showing how it can help plant owners in addressing the implementation of proper monitoring and mitigation actions against unexpected SSTI events in the field.

Problem Statement

- **Sub-Synchronous Torsional Interaction (SSTI)** phenomena observed during plant commissioning activities, resulting in power-gen train trips;
- The trips cause was **high lateral vibrations on the power-gen train gearbox, induced by torsional vibrations**… 1st Torsional Natural Frequency (TNF) in gearbox spectrum;



Example of measured power-gen train gearbox full spectrum during an SSTI event



Example of measured alternating torque on the generator shaft during an SSTI event

Case Study Targets

Site Issue:

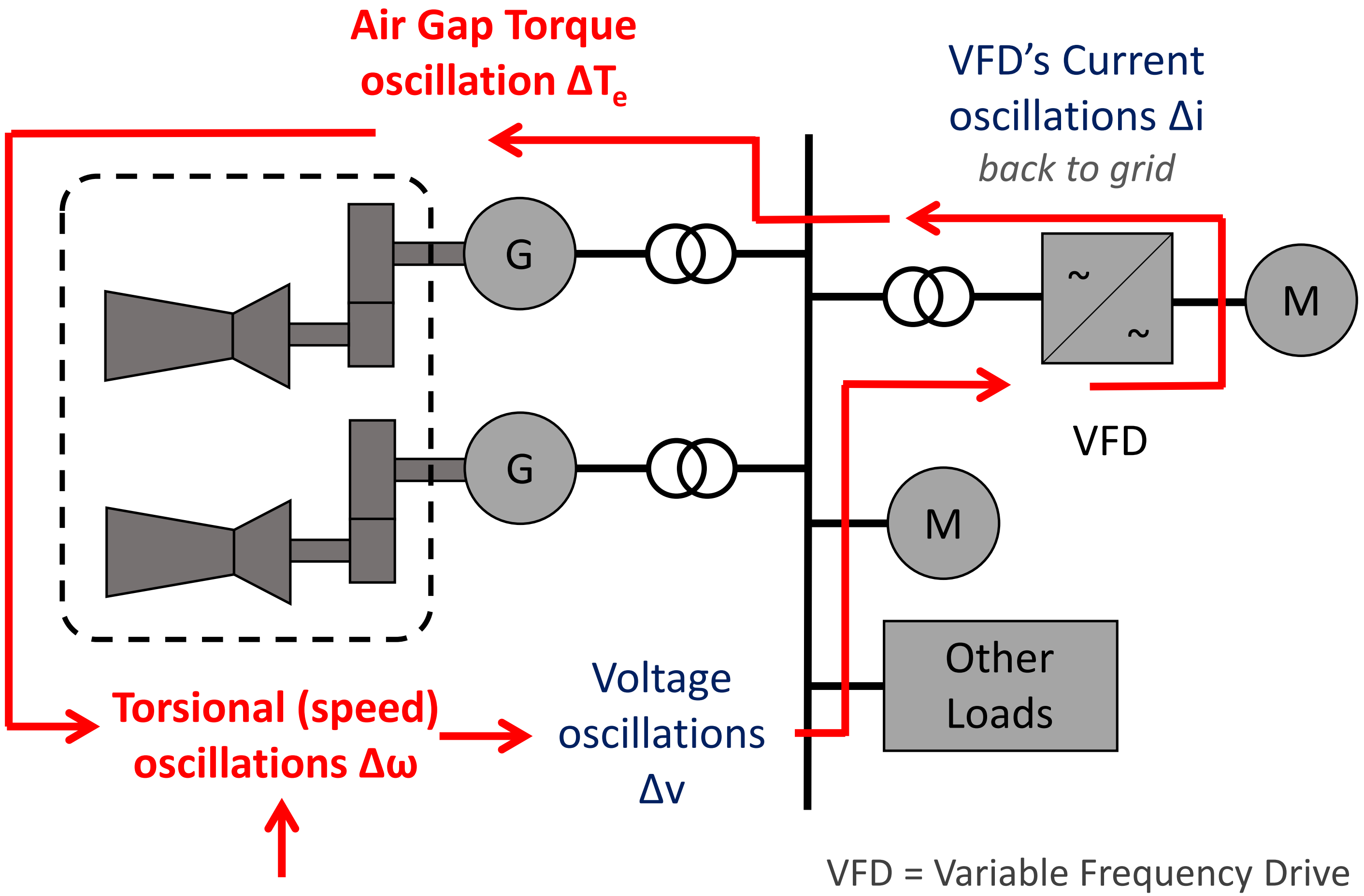
- **No SSTI Study was performed during engineering phase…**
- **Months of delay** to understand and address the phenomenon;
- Trips avoided by adding n.1 power-gen train in operation, with **additional operating costs**;

→ ***Lesson-Learned****: a structured approach to perform a* ***detailed SSTI Study*** *was developed.*

Targets of this Case Study:

- Provide **SSTI Basic Background.**
- Define a **step-by-step general approach** to perform an SSTI Study.
- **Compare simulated and measured results** for a specific SSTI field event.
- Highlight the importance of performing an **SSTI Study during engineering phase** to identify corrective actions in advance… avoiding surprises at site.

SSTI Background



Grid transient event
(e.g. load steps, motor start-up, etc.)

VFD = Variable Frequency Drive

The torsional **Electrical Damping *D_e*** is resulting from the **interaction** between the **Speed oscillations Δ*ω*** of a shaft-line with an electric generator and the resulting **air gap Torque oscillations Δ*T_e*** of the same machine, and it is function of frequency *(f)*:

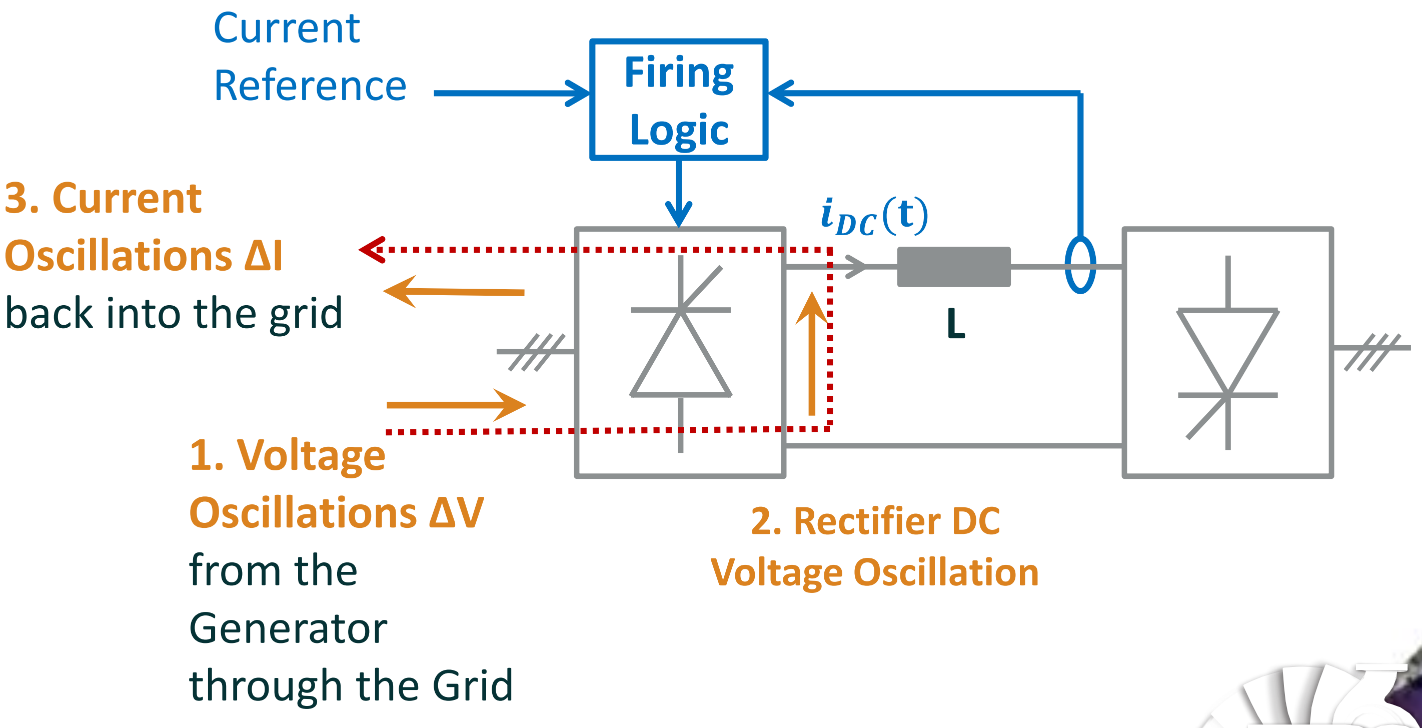
$$D_e(f) = -Re\left\{\frac{\Delta T_e(f)}{\Delta\omega(f)}\right\}$$

SSTI Background

The **Electrical Damping** can be either **positive** or **negative**, based on the ***phase shift*** between generator speed oscillation and the resulting torque oscillation...

This is depending on the **entire grid configuration and VFD key control loops**.

Example - **DC Link Current (i_{DC}) Control Loop of a VFD** (Load Commutated Inverter Type):



SSTI Background

The **Overall torsional modal Damping** $\boldsymbol{D_{tot}}$ is the sum between mechanical (D_m) and electrical modal damping (D_e) :

$$D_{tot} = D_m + D_e$$

Sub-Synchronous Torsional Interaction (SSTI) events occur when $\boldsymbol{D_{tot}}$ is negative for a specified TNF... i.e. when D_e is negative and D_m is not sufficiently large to have a positive overall damping.

The **Mechanical Damping $\boldsymbol{D_m}$** can be *estimated* from field measurements... and, for SSTI analysis, a suitable range can be defined for a specific type of machine.

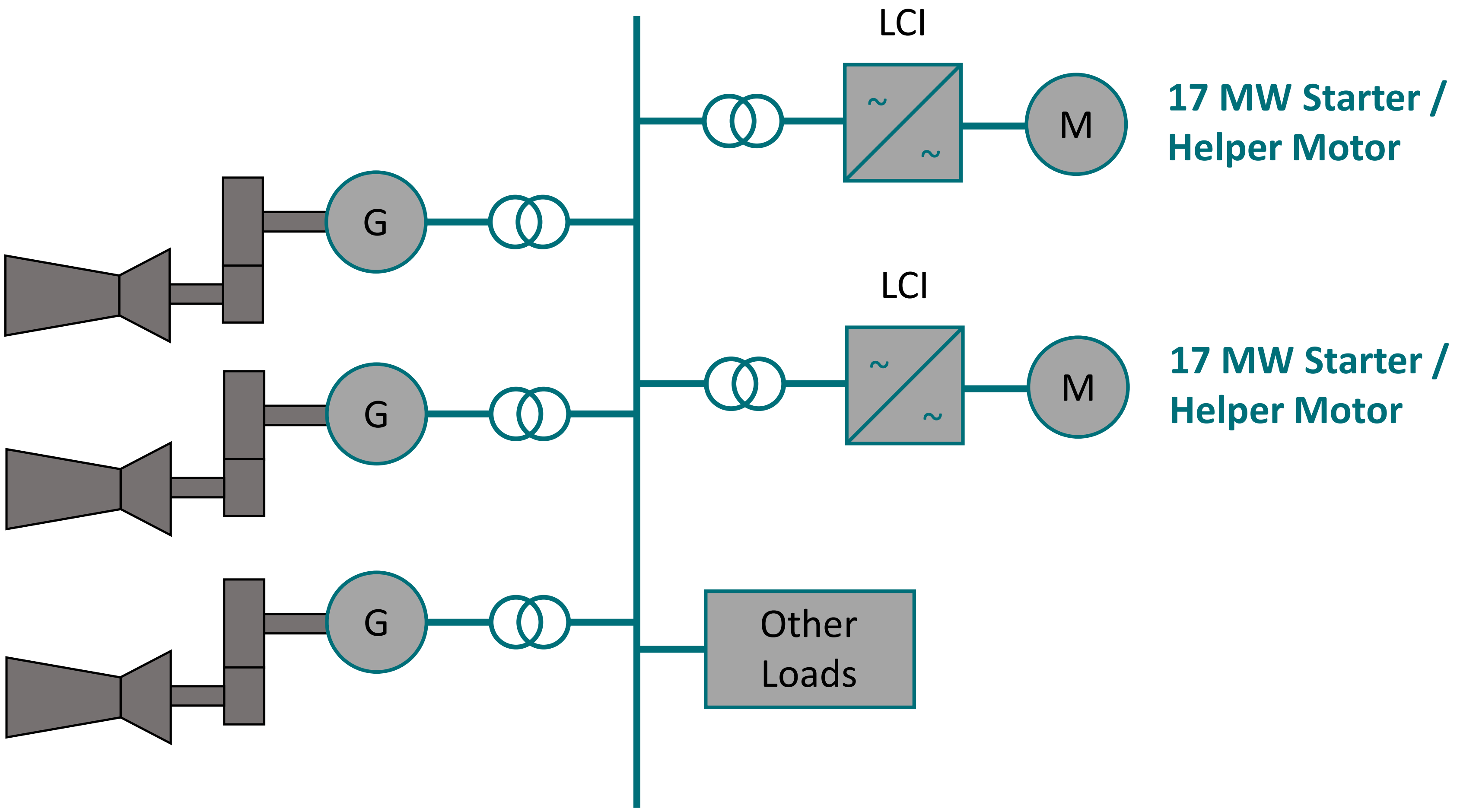
Electrical Damping $\boldsymbol{D_e}$ can be quantified for each grid operating scenario, and each electric generator in the plant, by means of a **suitable simulation model**...

Case Study

MS6001PA Gas Turbine Generators (GTG)

35 MW Generator Rated Power

(tot. 105 MW for 3 GTG)

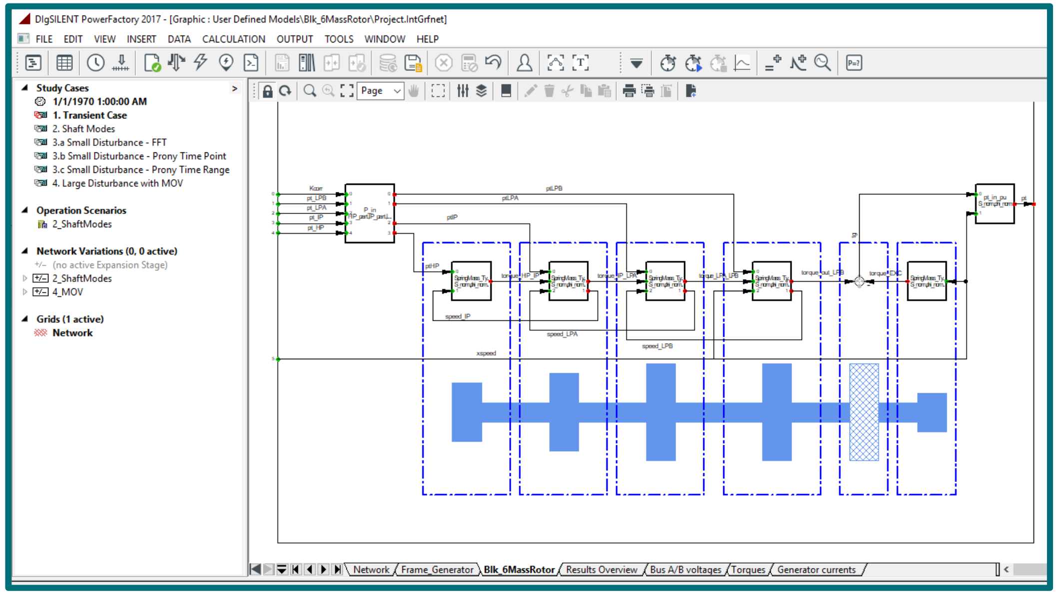


LCI = Load Commutated Inverter

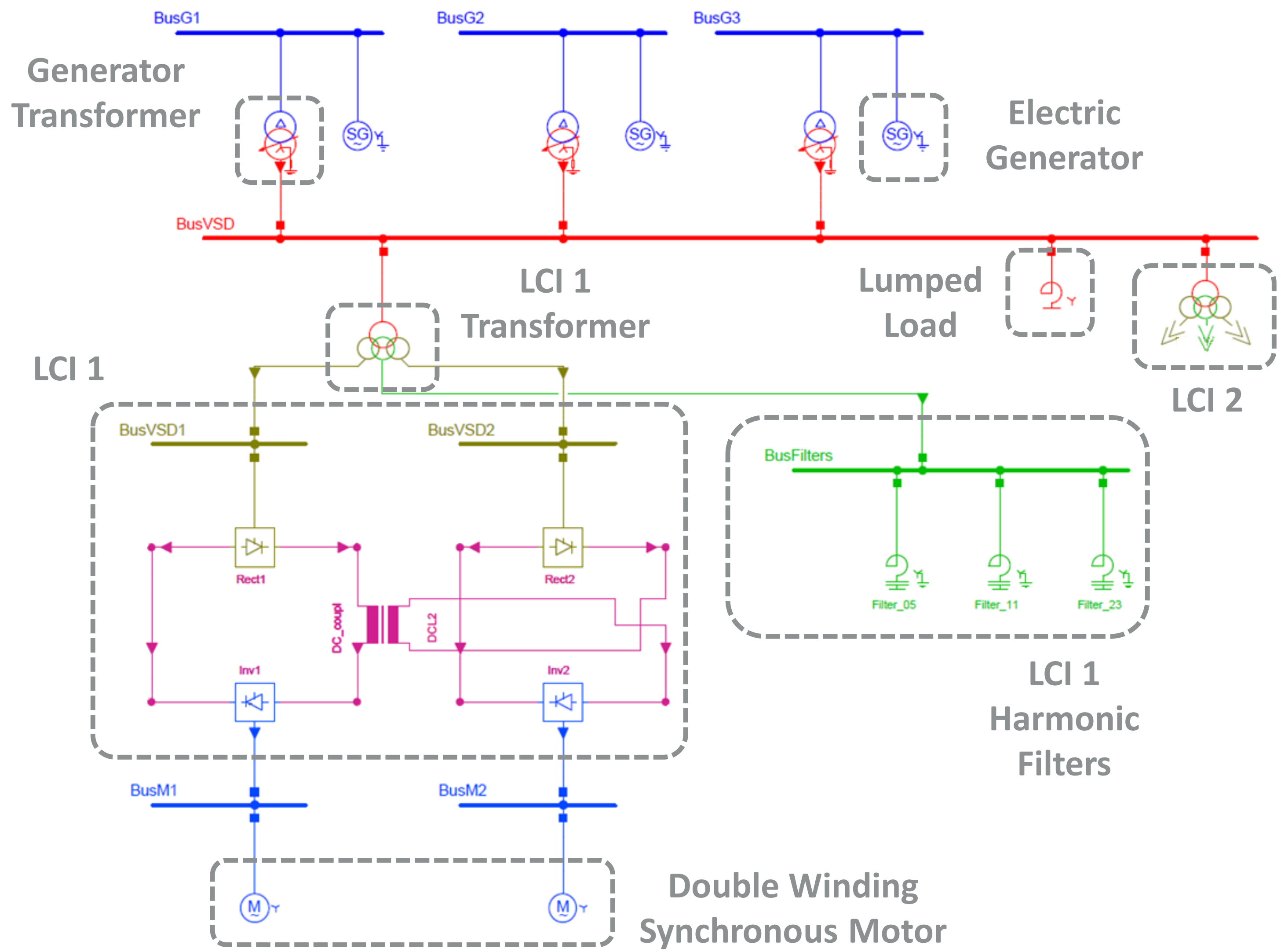
SSTI Study Approach

Key steps:

- **System modelling** with an appropriate simulation platform
- **Stability analysis** of the turbine-generator units' torsional modes
- Impact of **VFD's current pulsations** on the turbine-generator units' torsional behavior
- **Monitoring** and potential **mitigations**



SSTI Study Approach: System Modelling



Simulation model including:

- Electric **Generator** model, with Automatic Voltage Regulator (AVR) and Power System Stabilizer (PSS);
- Turbine speed Governor;
- Turbine-Generator unit torsional model;
- VFD's electrical and control model;
- Main electric networks elements (e.g. loads, transformers, etc.)

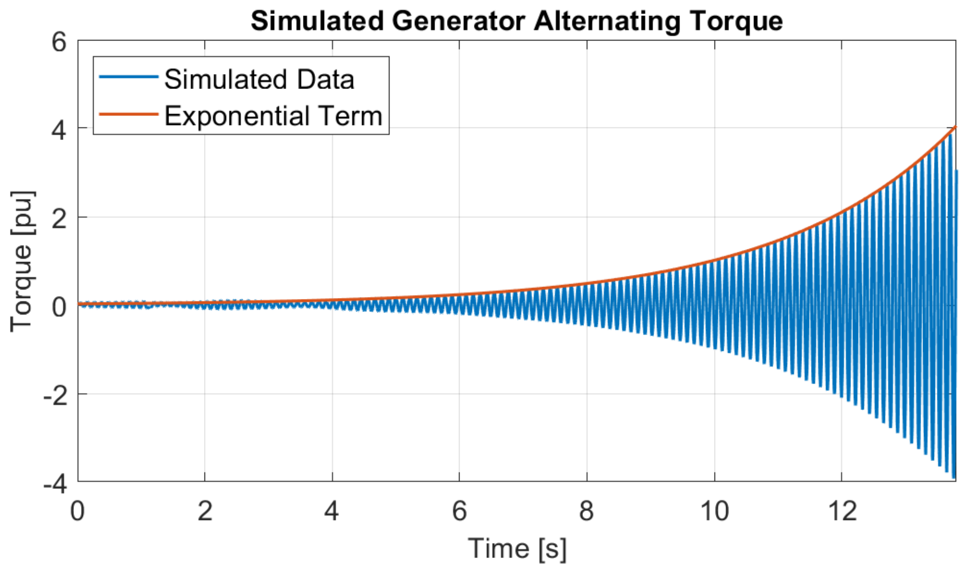
SSTI Study Approach: Stability Analysis

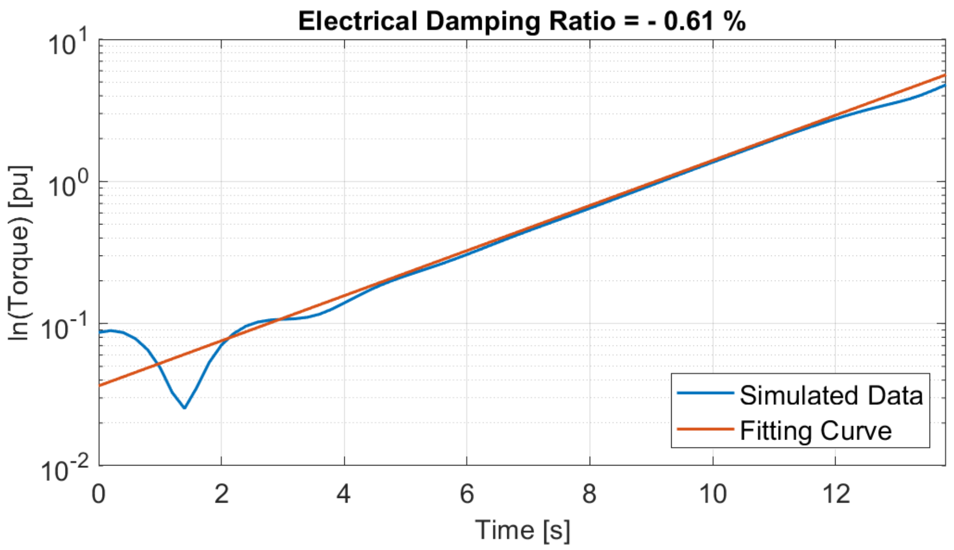
For each normal operating condition and contingencies, the following steps are followed:

1. **Initial Conditions:** Load-flow analysis to get a steady state condition;
2. **Transient torque disturbance** added to generator shaft;
3. **Zero mechanical damping** initially introduced in the model;
4. **Time-domain simulation**(*) run;
5. **Electrical Damping** calculated from the resulting **generator mechanical alternating torque (log dec)**
6. **Sensitivity to Mechanical Damping:** SSTI risk evaluation

(*): Electrical system's dynamics are highly non-linear, making time-domain transient simulations more practical than trying to linearize the system to perform the more typical *eigenvalues* analysis…

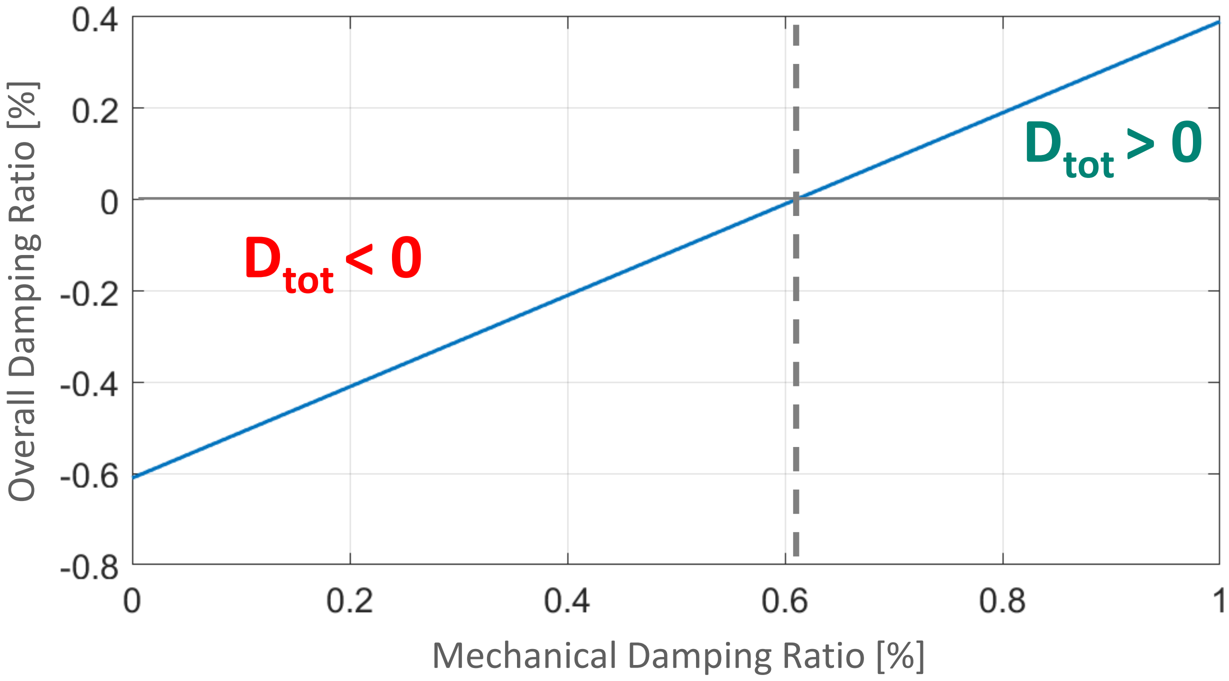
Simulated Electrical Damping Results





Electrical **Damping** Calculated from a Log Dec Analysis on post-processed Data of **Simulated Generator Alternating Torque**

Simulated Overall Damping Results: Sensitivity to Torsional Mechanical Damping



From the Electrical Damping calculated…

D_e = -0.61%:

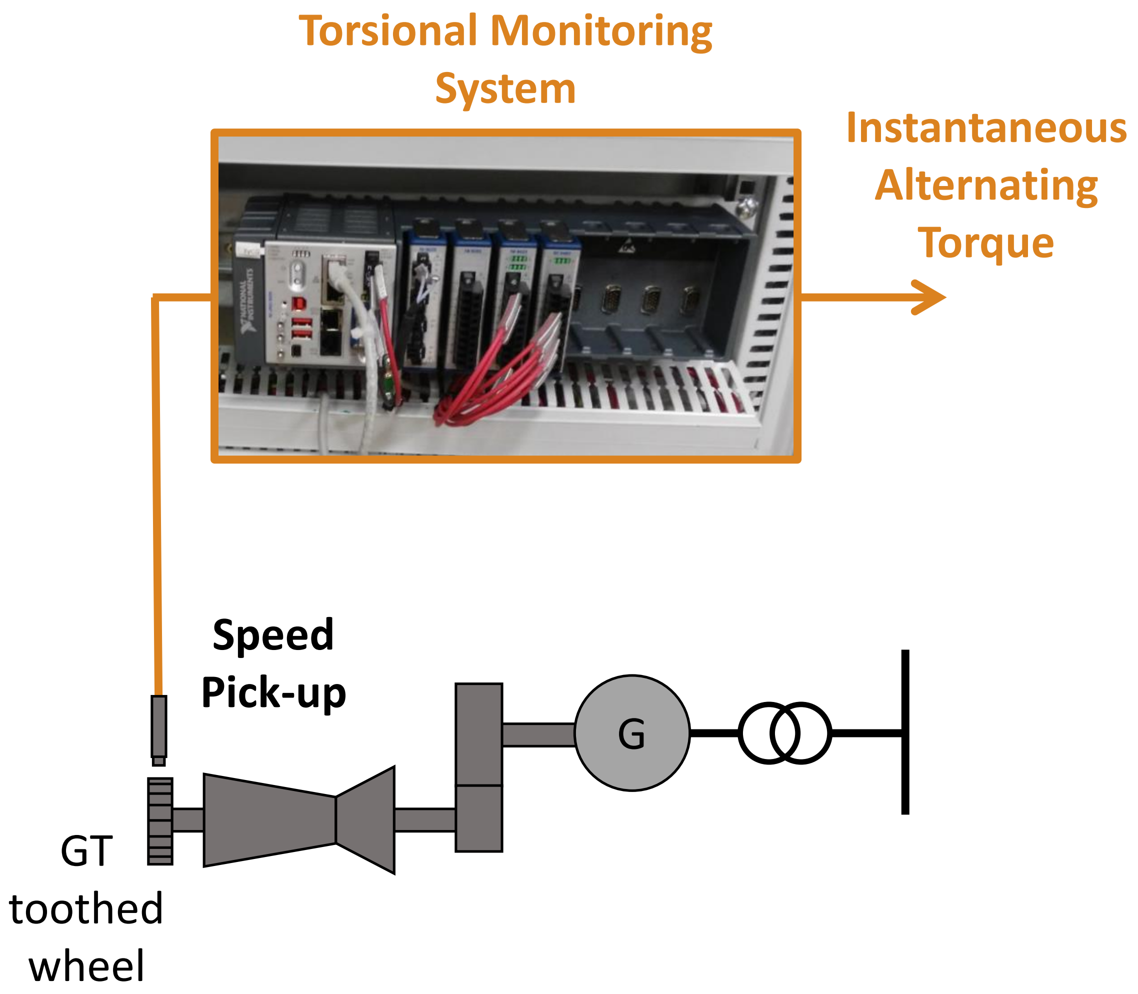
the **Overall Torsional Damping** from simulations:

$D_{tot} < 0$

for Mechanical Damping ratio:

$D_m < 0.61\%$

Alternating Torque Field Measurement

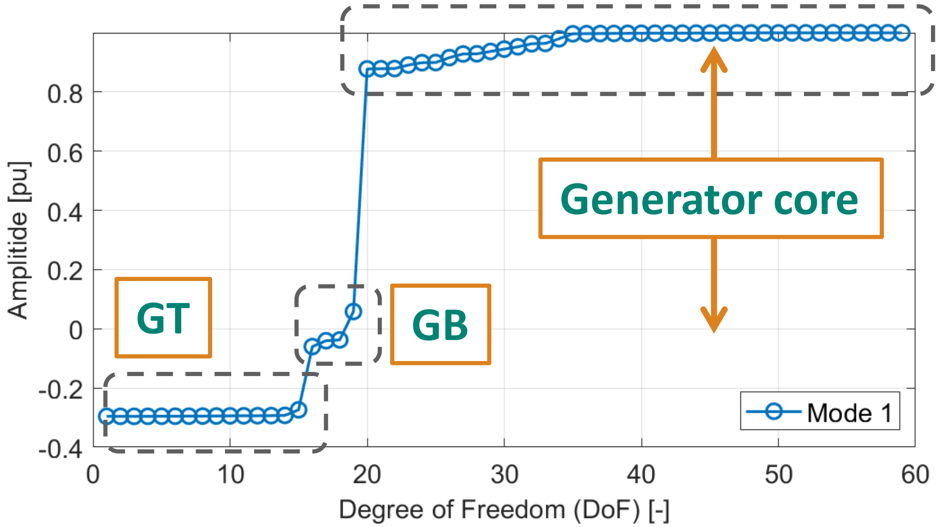


- **One single Speed pick-up** raw data
- **Angular oscillation** extrapolated using a dedicated software and control system
- Knowing the **shaft-line torsional mode shapes and torsional stiffness**, the alternating torque at generator shaft-end is calculated *for each torsional mode of concern.*

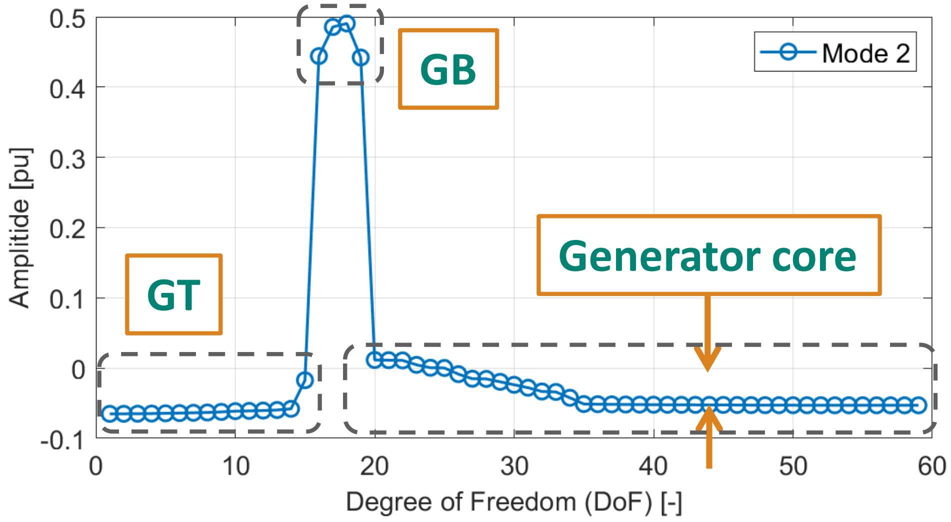
Alternating Torque Field Measurement

Based on the **torsional mode shapes amplitude at generator core sections**, only the 1st Torsional Natural Frequency (TNF) is affected by SSTI phenomena for this machine.

1st Mode Shape (TNF 1 = 9.5 Hz)

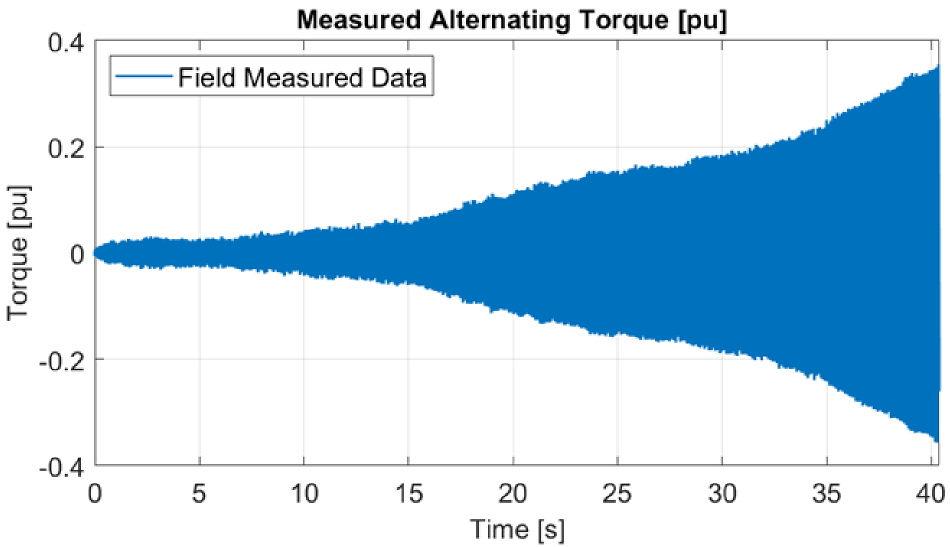


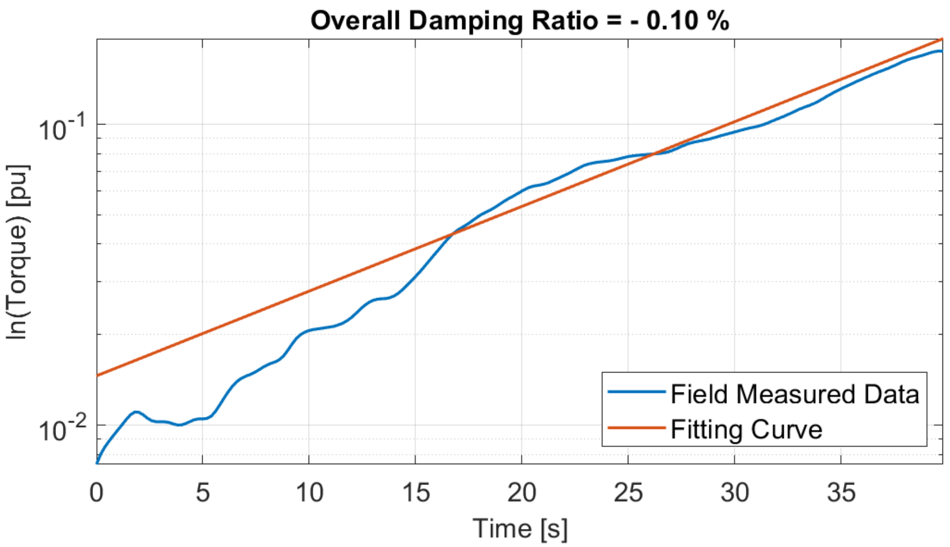
2nd Mode Shape (TNF 2 = 29.4 Hz)



GT = Gas Turbine; GB = Gearbox

Measured Overall Torsional Damping





Overall Damping Calculated from a Log Dec Analysis on post-processed Data of **Measured Generator Alternating Torque**

SSTI Study Approach: Model Tuning

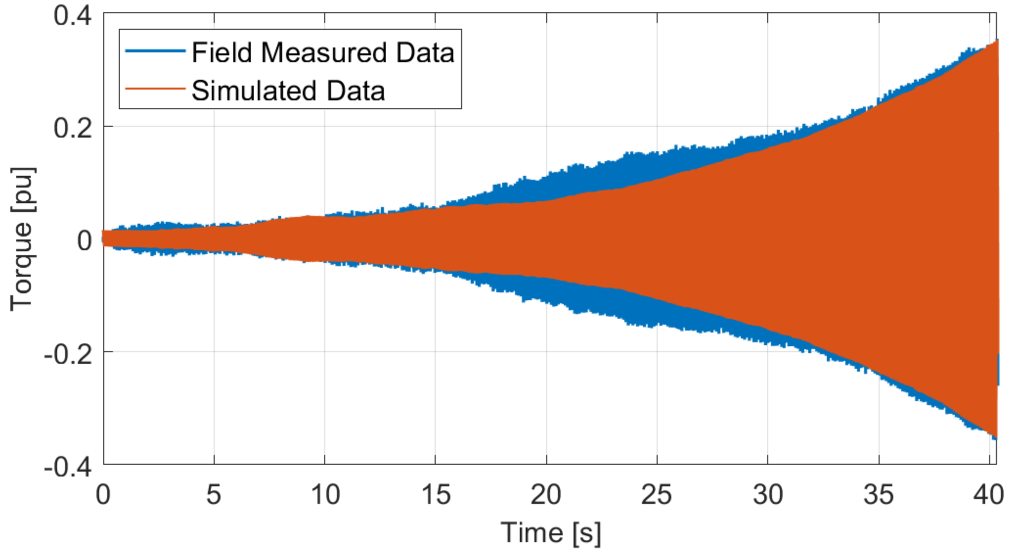
From the measured Overall Damping $\boldsymbol{D_{tot}}$, in order to match the field measurements, the torsional mechanical damping D_m^* of the power-gen unit, for the specific study case, has been derived:

$$D_m^* = D_{tot}^{meas} - D_e^{sim} = -0.10\% - (-0.61\%) = 0.51\%$$

D_{tot}^{meas} = Measured Overall Damping

D_e^{sim} = Simulated Electrical Damping

Simulation re-run including the estimated mechanical damping



Conclusions

- Severe **SSTI events observed at site caused months of delay** to understand and address the phenomenon
- Adding one power-gen in operation avoided to reach trip limits due to SSTI events… **additional operating costs**
- **Lesson-learned from such field experience… analyze SSTI phenomena during engineering phase** to identify corrective actions in advance… avoiding surprises at site
- The **electrical damping can become highly negative**, overcoming any positive mechanical damping, and driving the mode unstable
- Due to **uncertainties on the actual mechanical damping**, a *sensitivity analysis is recommended* to get a range of possible overall torsional damping

References

- D. Sgrò, P. Rotondo, F. Meucci, F. Svetti, **Practical Guidelines for Oil & Gas Plant Design Against Sub-Synchronous Torsional Interaction Phenomena**, Proceedings of the 44th Turbomachinery Symposium, Turbomachinery Laboratory, Texas A&M University, 2015
- IEEE Subsynchronous Resonance Task Force, **First Benchmark Model for Computer Simulation of Subsynchronous Resonance**, IEEE Transactions on Power Apparatus and Systems, Vol. PAS-96, no. 5, 1977
- IEEE Subsynchronous Resonance Working Group, **Second Benchmark Model for Computer Simulation of Subsynchronous Resonance**, IEEE Transactions on Power Apparatus and Systems, Vol. PAS-104 no. 5, 1985
- P. Kundur, **Power System Stability and Control**, McGraw-Hill, 1994
- B.K. Bose, **Modern Power Electronics and AC Drives**, Prentice Hall PTR, 2002
- **DIgSILENT PowerFactory® User Manual**, v2017