Predictive Modelling of Complex Grid Connected Electro-mechanical Systems

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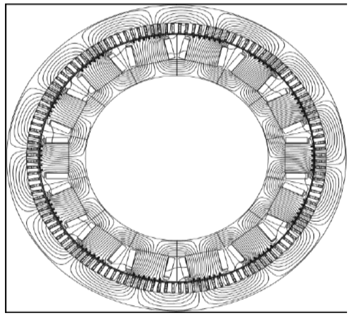
Challenges in Electromechanical Systems

Electrical engineers see electrical problems. Mechanical engineers see mechanical. But many problems lie in the boundary between.

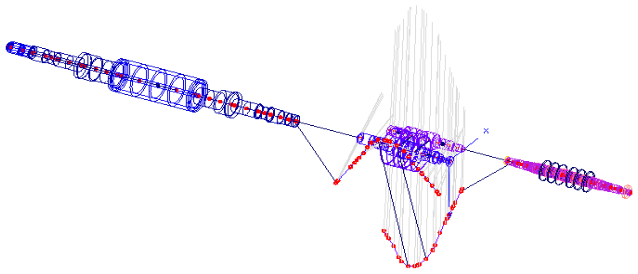
An multiphysics approach reveals the entire picture: the electrical, the mechanical (and the process!) and their complex interactions.

Because the nature of the issue is **physically coupled**, the solution needs to be seeked from a global perspective – one where both the electrical and mechanic sections are seen as integrated parts of the system as a whole and where the interactions between these parts are studied in detail

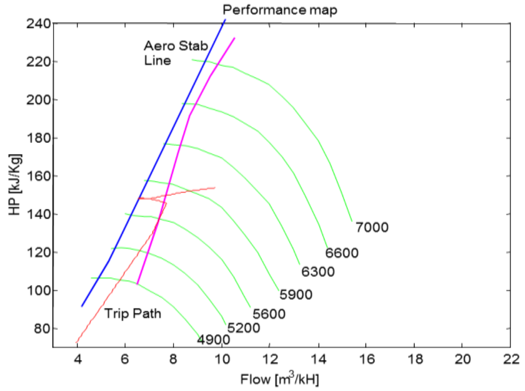
From electromagnetic analysis…



…understanding the mechanical behavior…



…to its effects on the process



Where is it relevant?

There are many problems which require an integrated approach where electrical and mechanical are taken as a full electromechanical system

1. **Islanded power generation in combination with large electrical loads.**

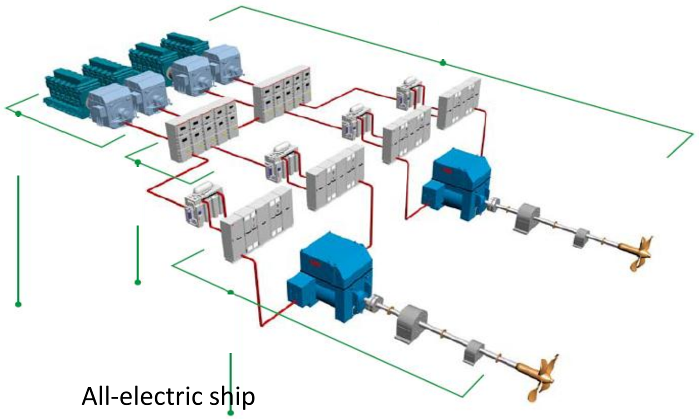
   Electromechanical interactions between power generation and heavy electrical motor powered machinery affecting the mechanical behavior of machines (and vice-versa) in LNG plants, offshore installations, vessels, remote mining facilities etc.

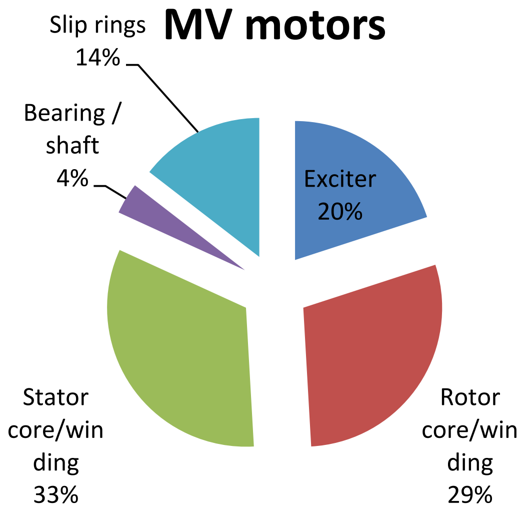
2. **Large VFD driven electric motors which have large failure rates, not delivering the expected reliability.**

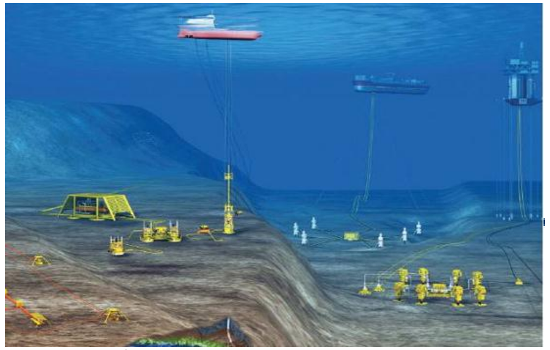
   Not only observed in the energy business but also observed as a similar trend in generators in marine environment.

3. **Large electric motor driven plants in areas with unstable grids.**

   Sites which have a history of voltage dips causing process trips due to the need to the keep system protected


All-electric ship




Subsea gas compression

Assess and resolve potential problems at the design stage

Making predictions requires a multidisciplinary approach

- **Evaluation of interactions between electrical system and rotordynamics:**
  - ✓ Torsion-lateral electro-rotordynamic coupling (especially for geared trains)
  - ✓ Electric drive and control system influence on machine mechanical behaviour (harmonics and subharmonic electromagnetic torques, control loop instabilities, power dips,…)
  - ✓ Large machines: electromagnetic forces effect on stator (unbalanced magnetic pull, 2X ovalisation, support and skid dynamics, etc.)
  - ✓ Closed loop transient simulation (not only short circuit, but other high stress events, such as start-up, synchronzation, load variations…)
- **Fully coupled multiphysics model of plant setup, including electric model of grid, power generation and utilities electromechanics, process dynamics and control.**
  - ✓ Interaction of machines (parallel generators, motors, or combinations) in weak / isolated grid
  - ✓ Process disturbances due to power dips
  - ✓ Subsea applications: reliability, trip dynamics and effect of long transmission lines

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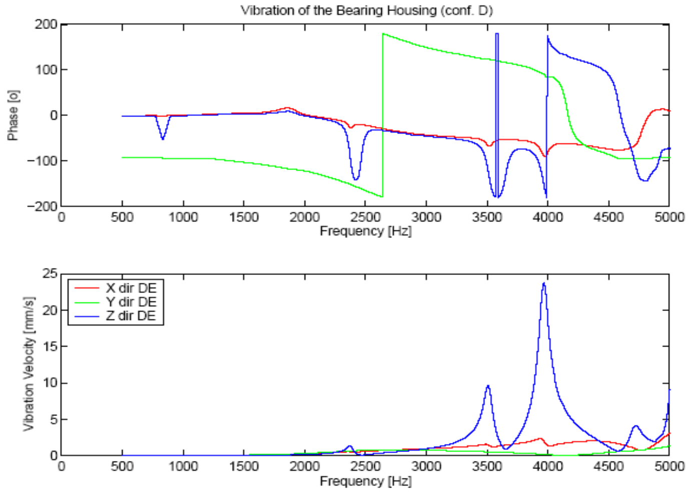
Case study - LNG processing facility with all-electric main compression trains.

Potential issues resolved at design phase through advanced simulation study

- Very large motor: special design and magnetic-rotordynamic-structural coupling
- Isolated location, connection with weak external electric grid (plant can also be operated in islanded mode)
- The power system one-line diagram of the LNG plant gives reason to suspect a certain risk for operational problems caused by torsional dynamic interaction between compressor drive VSDs (Variable Speed Drives) and natural mechanical frequencies within rotating machineries, especially the GTGs (Gas Turbine Generators)

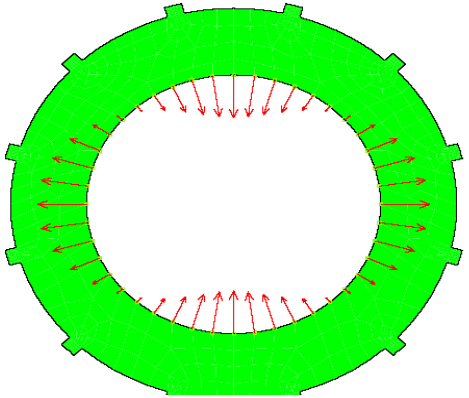
Large Motors – Foundation interaction study

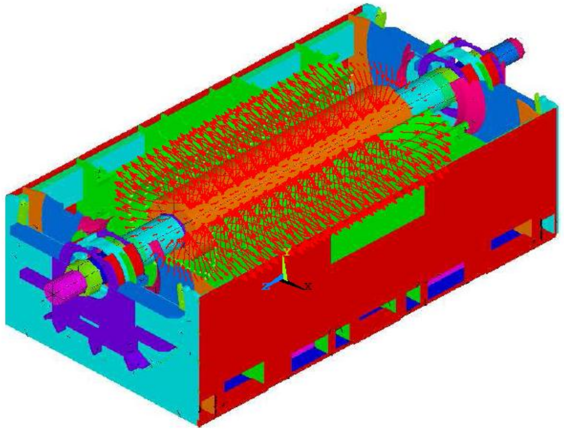
Testing showed 2X vibration due to stator ovalisation forces to be influenced by support impedance.



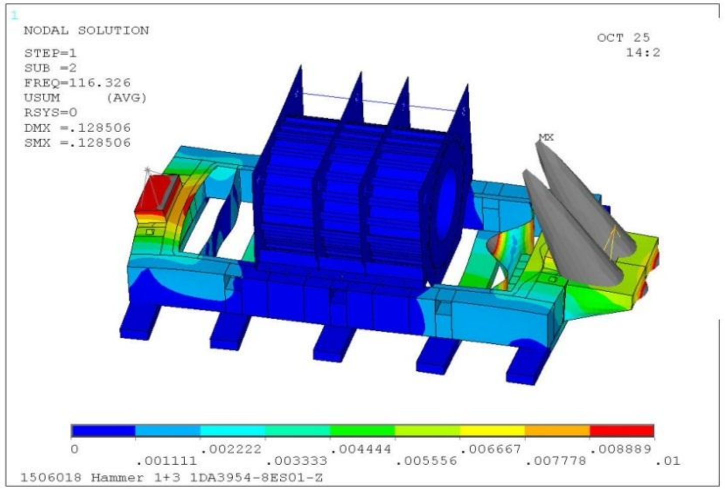
Combined response

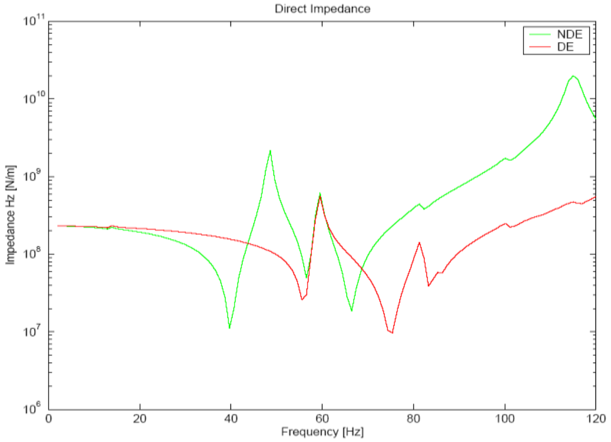
Electromagnetic





Structural





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Electromechanical interaction (grid + rotor systems)

Problem approach

The following approach was taken to address the problem:

1. Identification of possible sources for interaction
   - Interharmonics from VSD to GTGs: lateral coupling in gear translates torque fluctuations into lateral vibrations
   - Effect of converter control: potential negative damping source
   - The role of the power network of the plant: risk of instability in some operating modes
2. Network and components modelling
   - Network and load
   - Generators with detailed modelling of electrical and mechanical dynamics
   - Compressor drives with detailed modelling of electrical and mechanical dynamics
   - Other relevant load (thyristor operated heater, other non-linear loads,…)
3. Simulation of relevant scenarios, provide countermeasures if issues are suspected
   - At SAT (string acceptance test)
   - At commissioning
4. Verification through measurements

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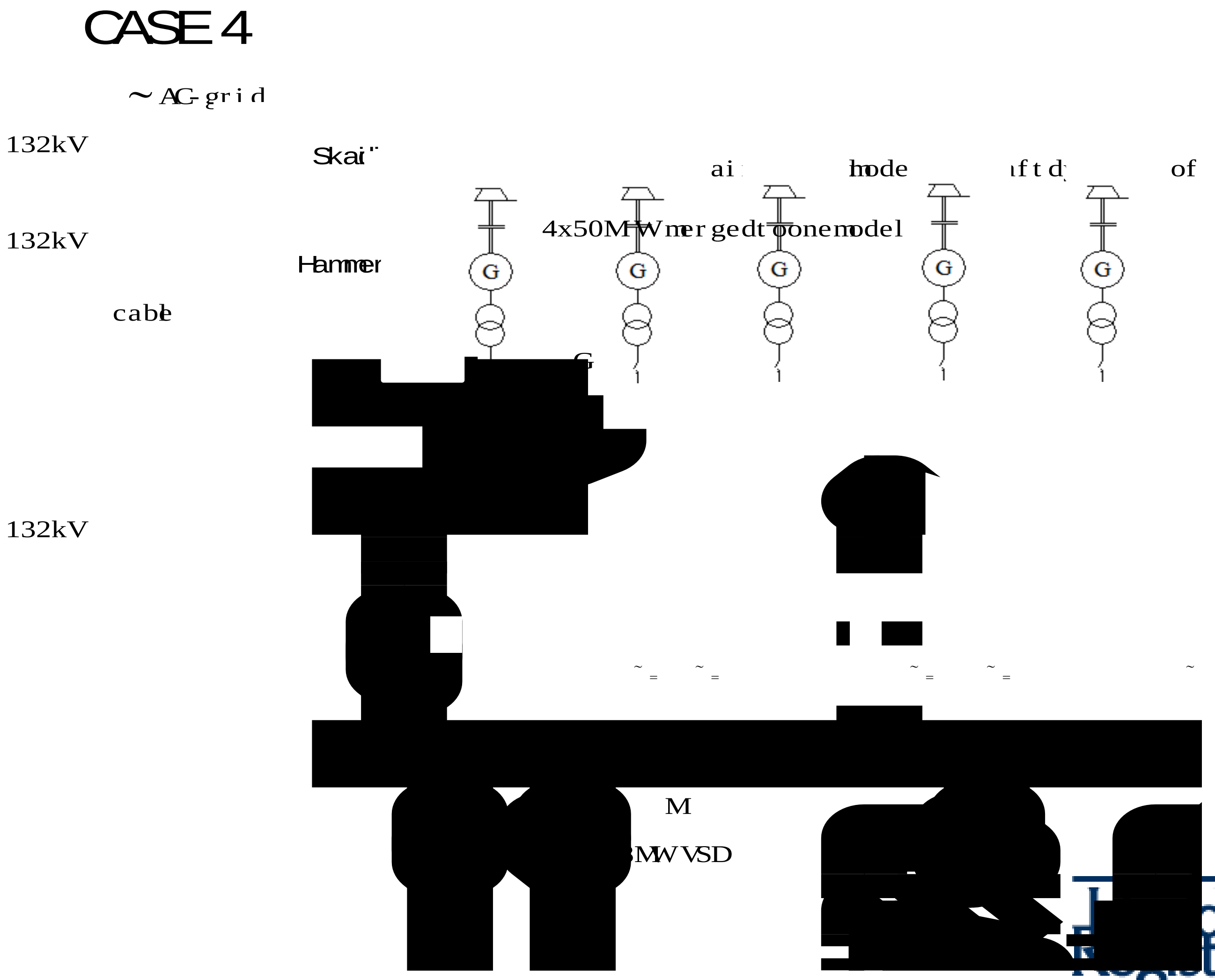
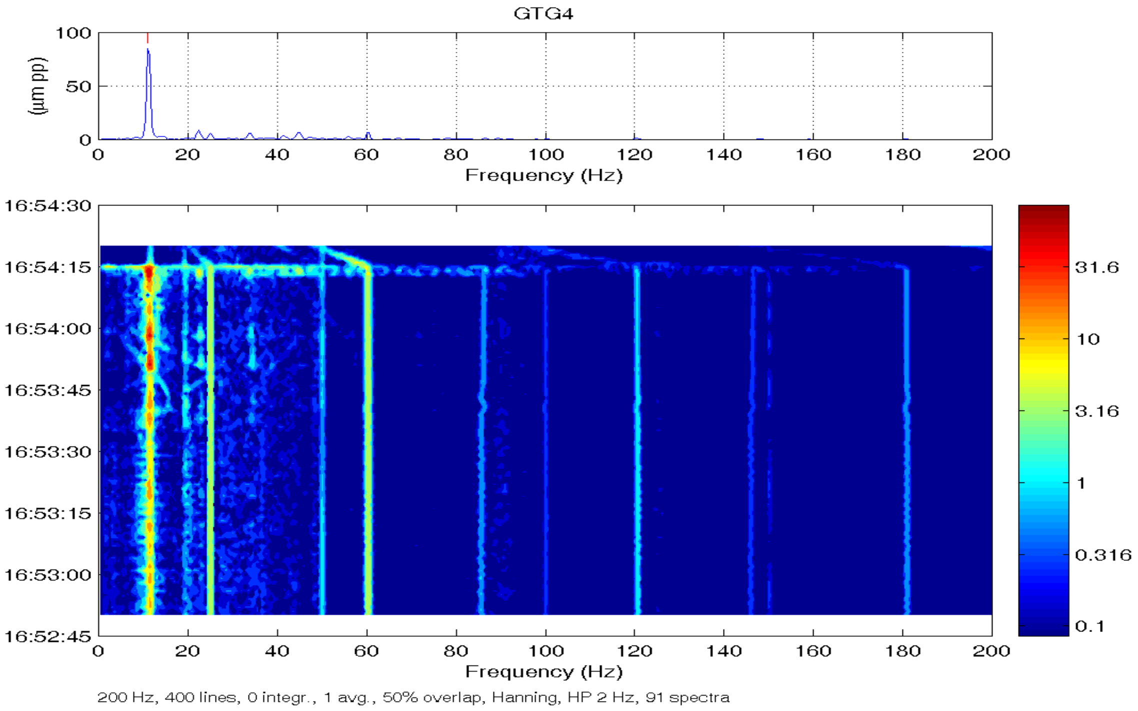
Illustration of interaction

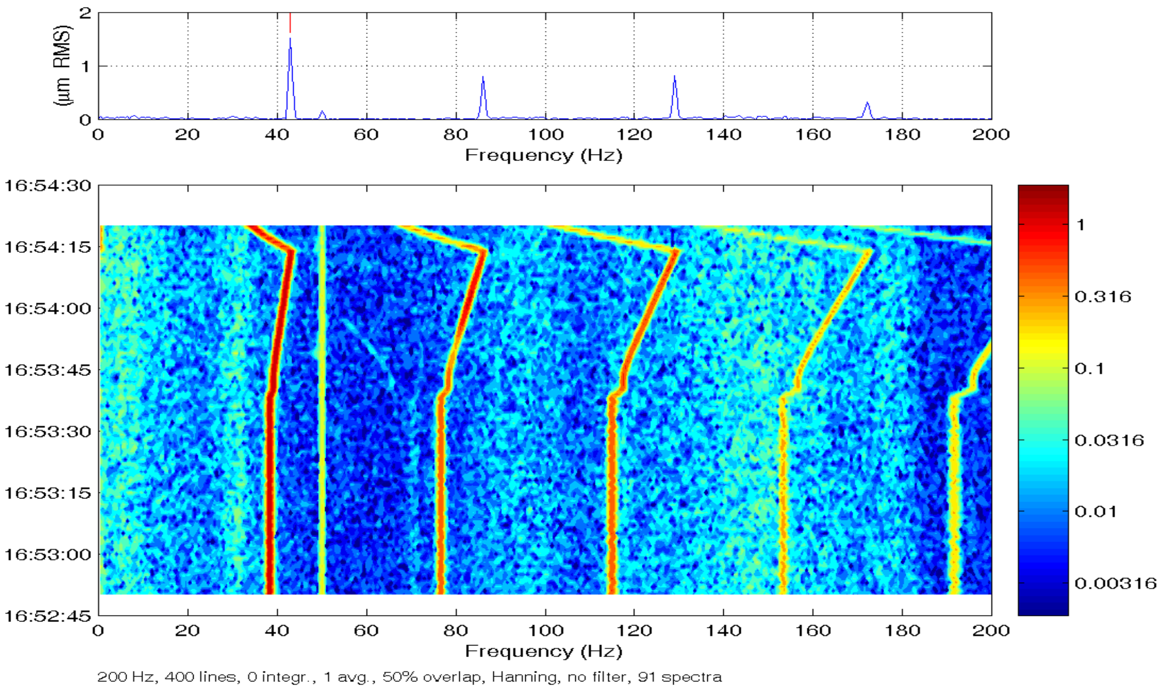
- 5 generators with detailed modelling of electrical and mechanical dynamics
- 4 large compressor drives with detailed modelling of electrical (incl. trafos, filters) and mechanical dynamics
- Underlying grid with e.g. several direct coupled asynchronous motors + other relevant non-linear loads (e.g. thyristor heaters)
- Cables and lines to external grid



Full Load Test

Generator Trip during Compressor Testing





GTG gearbox trip during compressor speed ramps

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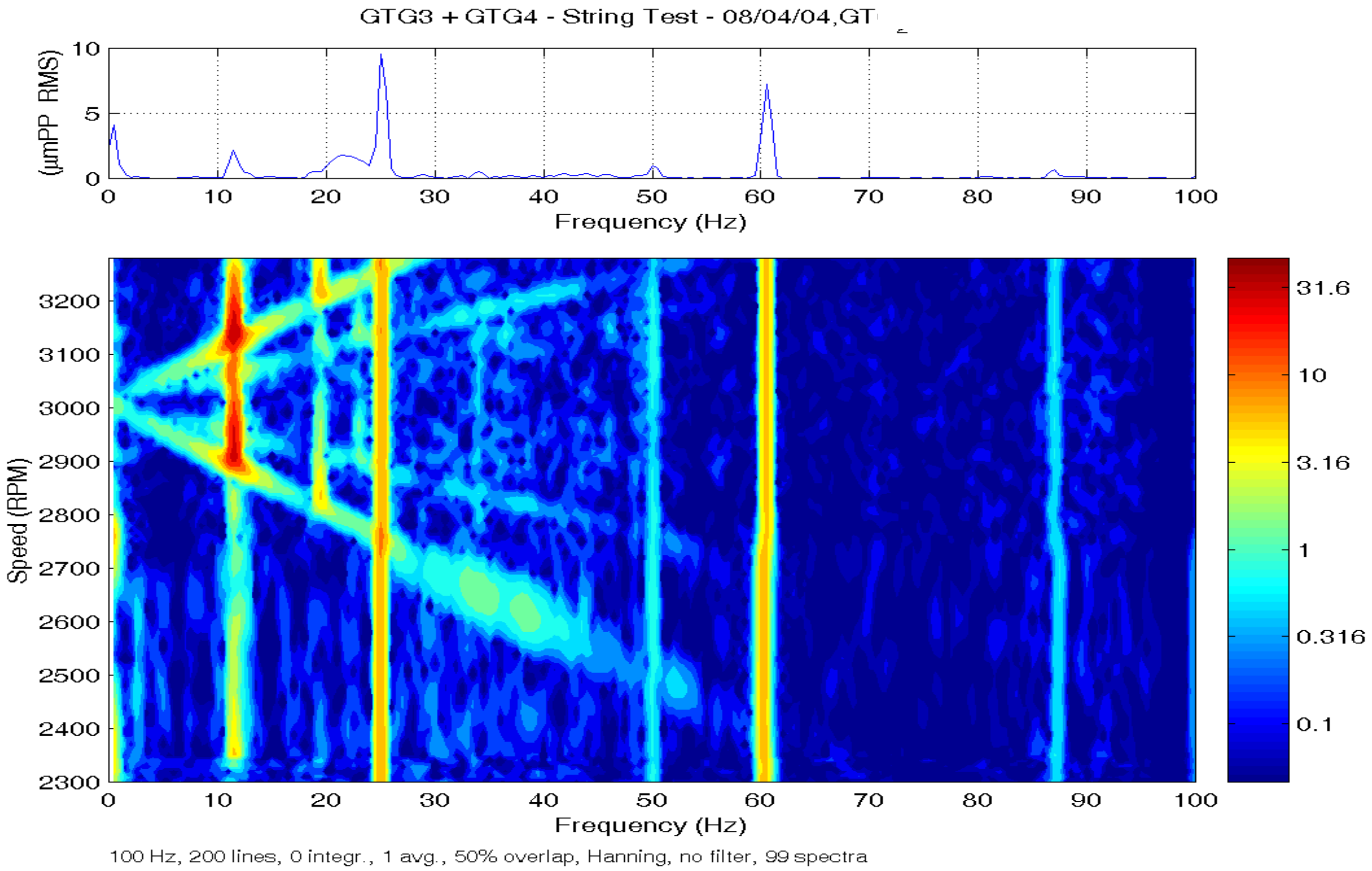
Effect of voltage drop compensator during FAT

With design configuration, not considering the results of the study



Gear vibration vs. VSDS motor speed. Interaction with 6x|f_N-f_M|, does not disappear after resonance

This would have caused problems and delays during commissioning, as the GTGs would have experienced trips during compressor start-ups

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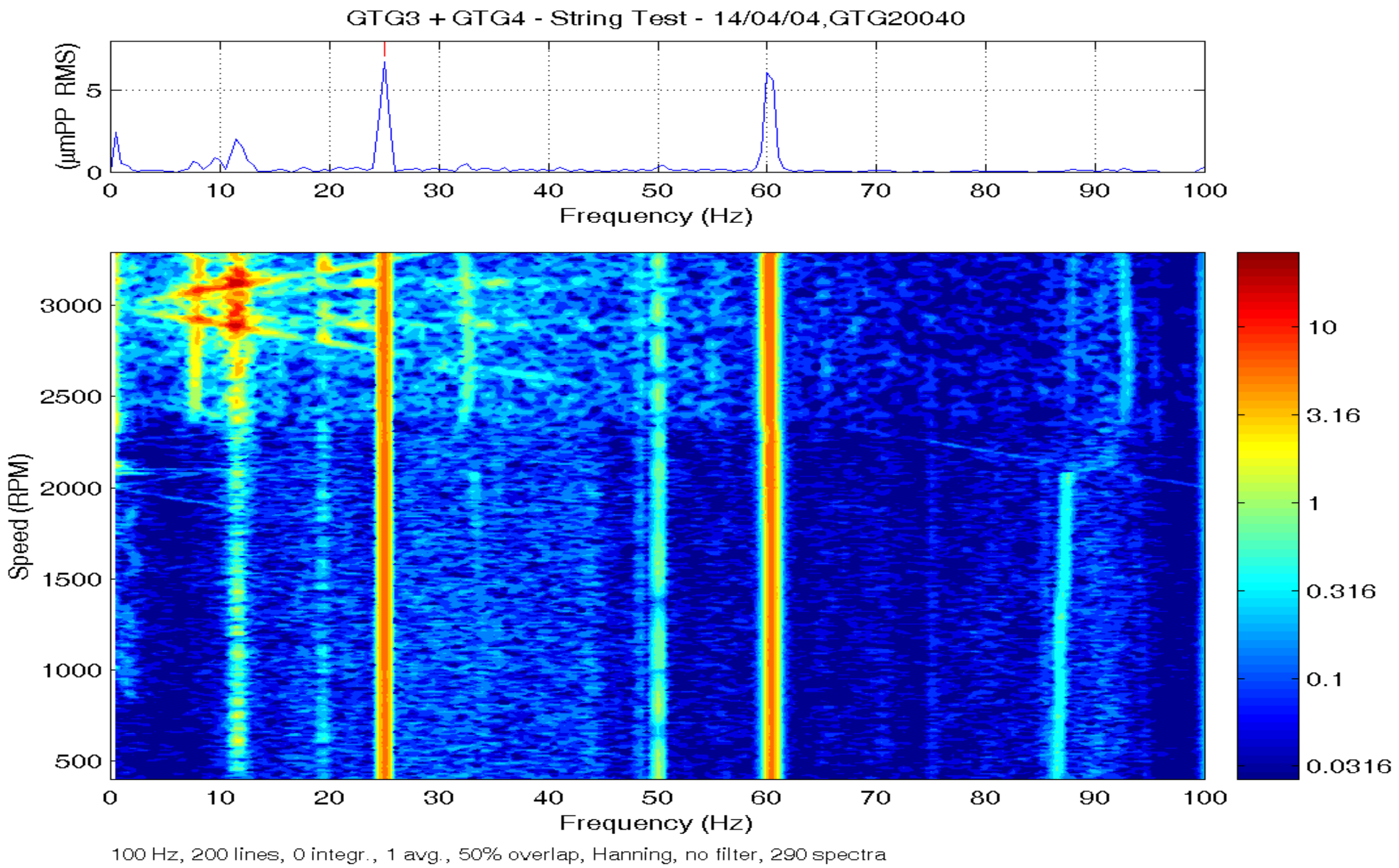
Effect of voltage drop compensator during FAT

Problem solved: tuned parameters after the results of the study



After disabling Voltage dip compensation, max gear shaft vibration was below 60 um pp. Gear vibration vs. VSDS motor speed.

Problem solved (actually, avoided!)

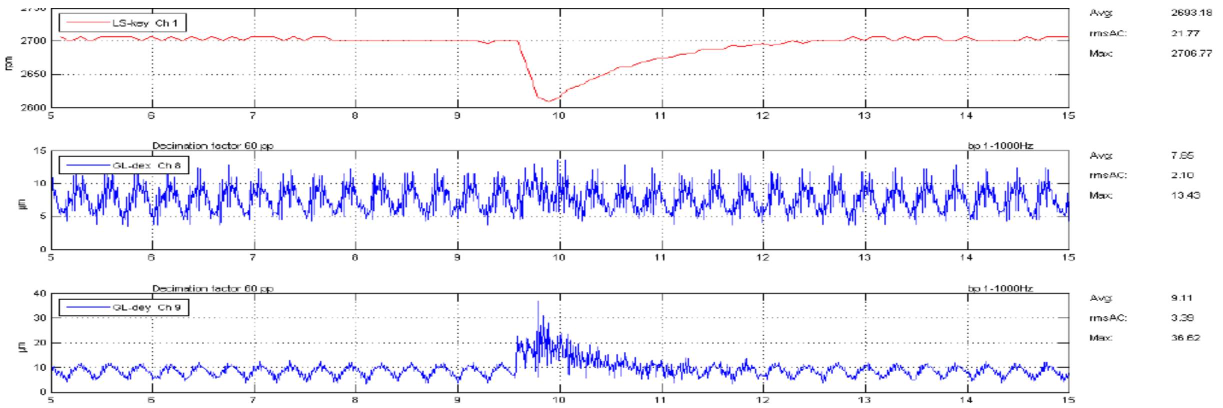
Voltage dip coupled phenomena

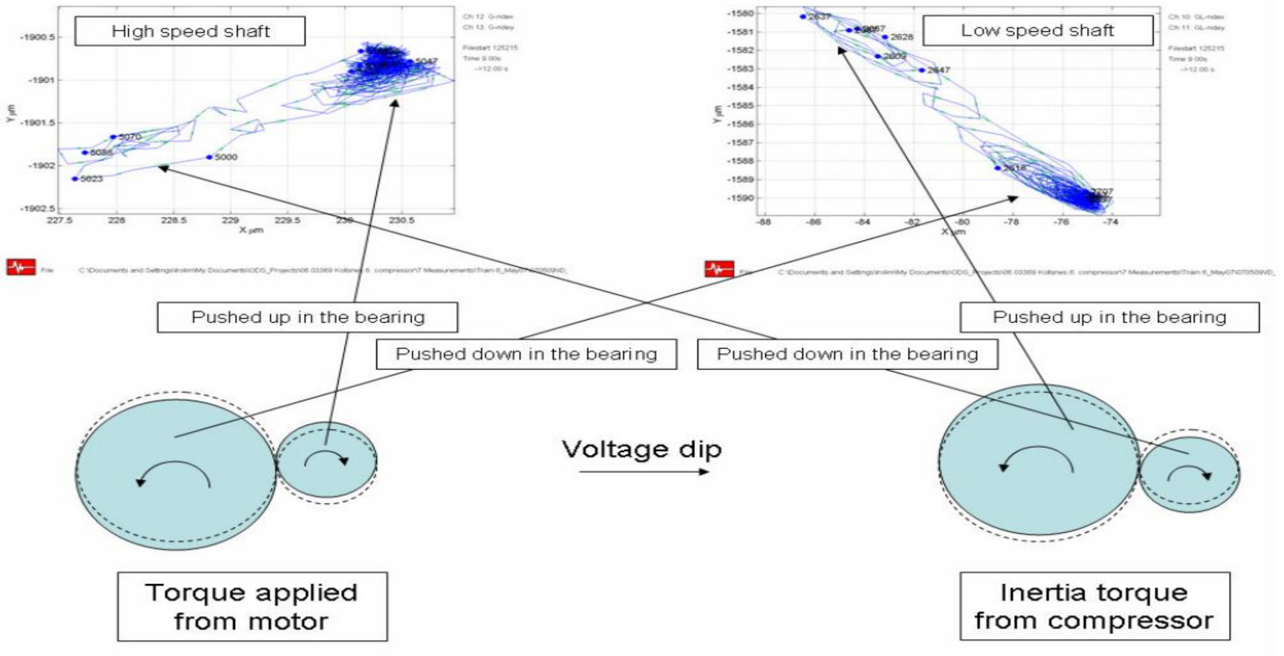
From the drive point of view the following can be said:

- Keep the speed drop as small as possible and fastest reacceleration
- Supply only limited torque ripple even if the line voltage is asymmetrical

Mechanical:

- Some reacceleration strategies may cause increased vibrations / trips
- Isolated events can be tolerated, but permanent changes in drive control should be assessed (gearbox and couplings mech. integrity)





Lessons learned

- Despite the complexity, full electromechanical modeling proved to be a well spent effort, avoiding the need costly delays and troubleshootings during plant commissioning
- The VSD DC link cannot prevent passage of low frequency inter-harmonics from one motor (or other thyristor controlled equipment) to other electrical machinery
- Lateral coupling in gear translates torque fluctuations into gear lateral vibrations (can cause trips due to high vibrations)
- The speed control system needs tuning to minimize torsional response for ”internal” VSD forcing and excitation from grid
- Risk of instability in some operating modes
- 2X stator vibration from ovalisation forces
- High bearing stiffness implies stiffness of the bearing support will influence rotordynamics

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