GENERATOR STABILITY STUDY FOR HIGH ROCOF EVENTS IN A LOW INERTIA GRID

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Introduction

- Background of this Study
- Study Approach
- Model and Input Assumptions
- Simulation Results
- Risk of Tripping
- Mechanical Assessment
- Combustion Assessment
- Conclusions

Background

- Increased penetration of wind and solar energy sources:
  - Mostly inverter connected
  - No rotational Inertia
- Lower System Inertia => higher Rate of Change of Frequency (RoCoF)
- Challenge emerged first in island systems, e.g. Irish Grid system [Ref1]
  - RoCoF higher than conventional 0.5Hz/s Irish standard can occur during high wind generation & loss of single largest credible contingency
  - Simultaneous Non Synchronous Penetration (SNSP) limited to 50%
  - For RoCoF ≤1Hz/s (average over 500ms) SNSP can be increased to 60%
  - Impact on conventional generators unknown => requirement for technical study for compliance with higher RoCoF
- Similar developments expected eventually in other grid systems

[Ref1] Commission for Energy Regulation in Ireland: www.cer.ie

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Study Approach

- Electrical stability simulated for four 1Hz/s RoCoF events defined by Transmission System Operator (TSO) EirGrid:
  - Frequency rise
  - Frequency rise with subsequent fast drop
  - Frequency drop with subsequent recovery
  - Frequency drop
- To be studied at following operating conditions at least:
  - Maximum load, full lead power factor
  - Maximum load, full lag power factor
  - Minimum load, full lead power factor
  - Minimum load, full lag power factor
- This gives 16 Study Cases in total
- Minimum grid Short-Circuit Level assumed for worst case

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16 Study Cases (minimum required by TSO)

Cases	Load	Power Factor	Short-Circuit Level	RoCoF event
1a	Maximum	Full Lead	Minimum	Frequency Rise
1b	,,	,,	,,	Frequency Rise and Fast Drop
1c	,,	,,	,,	Frequency Drop and Fast Rise
1d	,,	,,	,,	Frequency Drop
2a	,,	Full Lag	,,	Frequency Rise
2b	,,	,,	,,	Frequency Rise and Fast Drop
2c	,,	,,	,,	Frequency Drop and Fast Rise
2d	,,	,,	,,	Frequency Drop
3a	Minimum	Full Lead	,,	Frequency Rise
3b	,,	,,	,,	Frequency Rise and Fast Drop
3c	,,	,,	,,	Frequency Drop and Fast Rise
3d	,,	,,	,,	Frequency Drop
4a	,,	Full Lag	,,	Frequency Rise
4b	,,	,,	,,	Frequency Rise and Fast Drop
4c	,,	,,	,,	Frequency Drop and Fast Rise
4d	,,	,,	,,	Frequency Drop

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Model and Input Assumptions (1)

- Grid Model
  - Voltage source behind equivalent Thevenin Impedance (more detailed grid model required for full transmission grid stability studies)
  - RoCoF event simulated by frequency variation according to defined traces
- Generator Model
  - Combined Cycle Gas Turbine (CCGT)
  - Separate generators for Gas Turbine (GT) and Steam Turbine (ST)
  - Model representation:
    - Rstr, Xd, Xq, Xd’, Xq’,Xd’’, Xq’’, Tdo’,Tqo’,Tdo’’,Tqo’’
    - Saturation Characteristics
    - Inertia: multi-mass model to derive torsional shaft torques

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Model and Input Assumptions (2)

- Excitation System Model
  - Automatic Voltage Regulator
  - Power System Stabiliser
  - Under-Excitation Limiter; important for RoCoF events during full lead power factor operation to prevent tripping on Loss Of Field protection
  - Dynamic model checked against site measurements of voltage step test
- Turbine-Governor Model
  - Frequency Control – 4% droop
  - Limit Frequency Control
  - Load Control
  - Thermal time constants of Turbine tuned to match measurement of frequency injection step test

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Model and Input Assumptions (3)

- Mechanical model: lumped multi-mass
  - Inertias of turbine sections and generator with shaft stiffness in between
  - Model based on 3 rotating masses and 2 shafts sufficiently detailed:

Torsional frequency in Hz		
Mode	GT	ST
1st	11.3	16.1
2nd	169.4	120.1

- More detailed model not needed because torsional interaction principally in sub-synchronous frequency range
- Auxiliary System
  - Unit transformer and distribution transformers
  - MV motors (individual representation)
  - LV motors (aggregate representation)
- Protection functions based on admittance and impedance loci simulated

Study Results

- All 16 RoCoF study cases simulated
- Case 1c (max load, full lead pf, freq. drop and fast rise) most severe for deviation in voltage, electrical torque and shaft torque.
- Frequency traces defined up to 8s, however results presented up to 18s with frequency held at the end value at 8s
- Variables of interest: active power, reactive power, generator rotor speed, stator and grid voltages, electrical torque and stator current, auxiliary system voltages and currents, and motor speeds.
- Some significant deviations in variables but within capabilities of generations and transformers
- Simulation results allow assessment of:
  - Risk of Tripping
  - Impact of shaft torque variations

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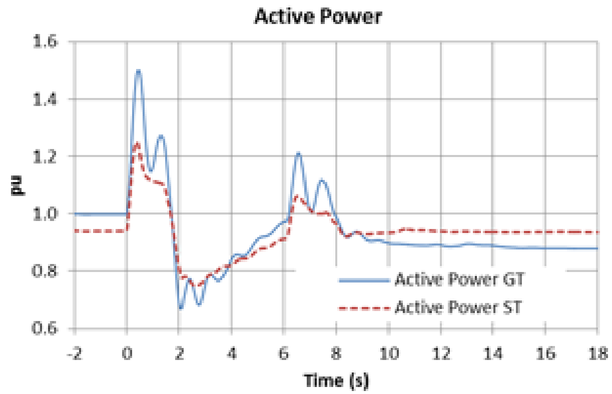
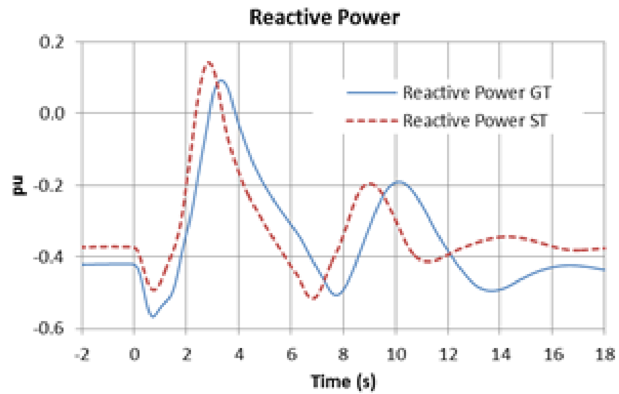
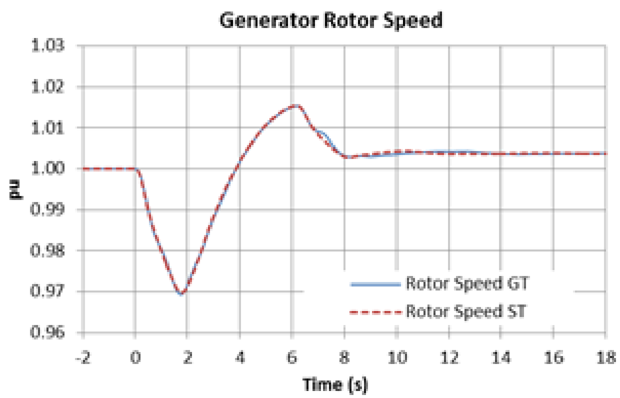
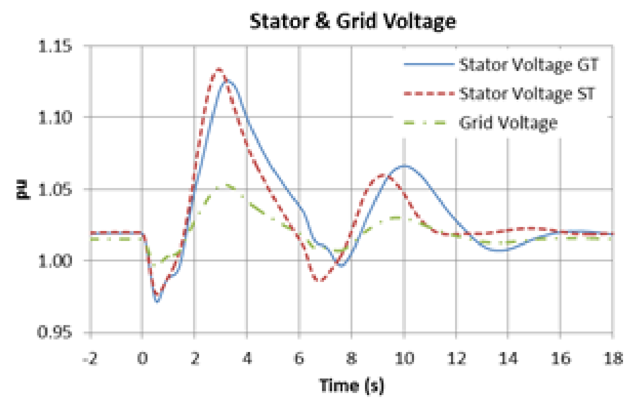
Case 1c Max Load, Full Lead, Frequency Drop + Rise

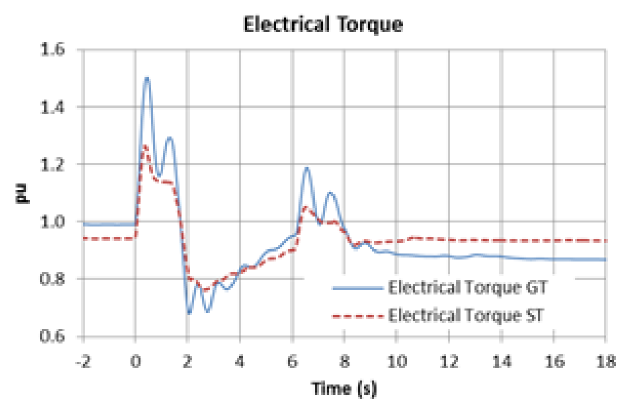
Generator Variables

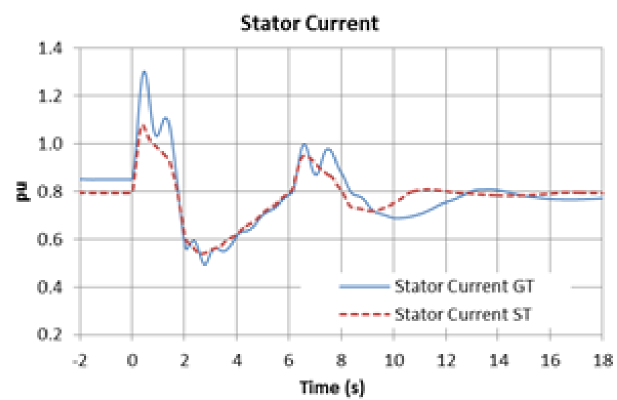












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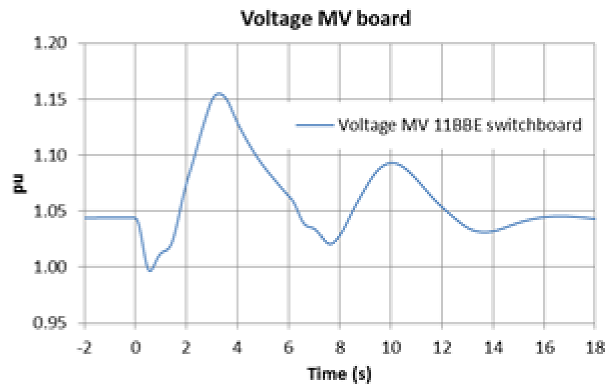
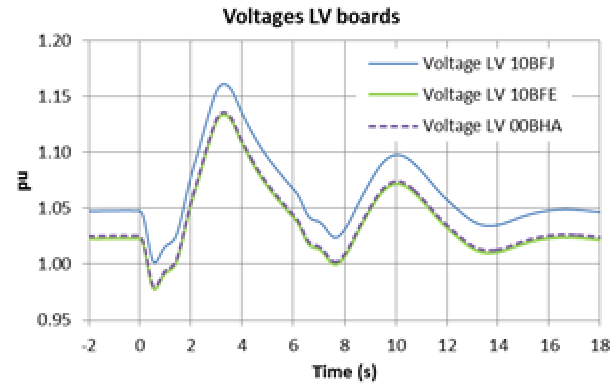
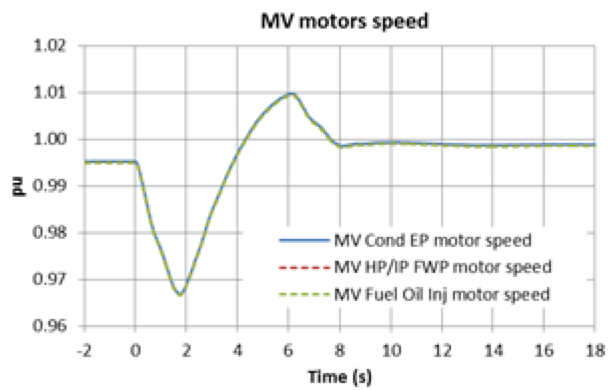
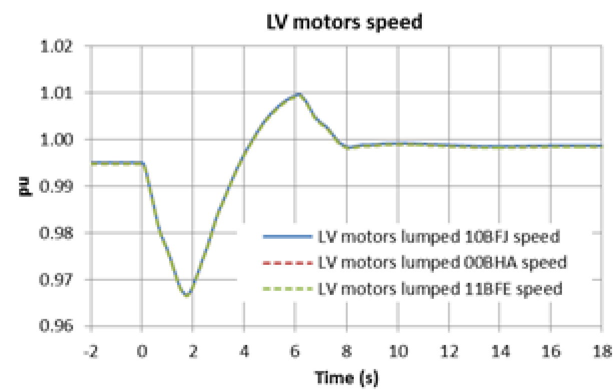
Case 1c Max Load, Full Lead, Frequency Drop + Rise

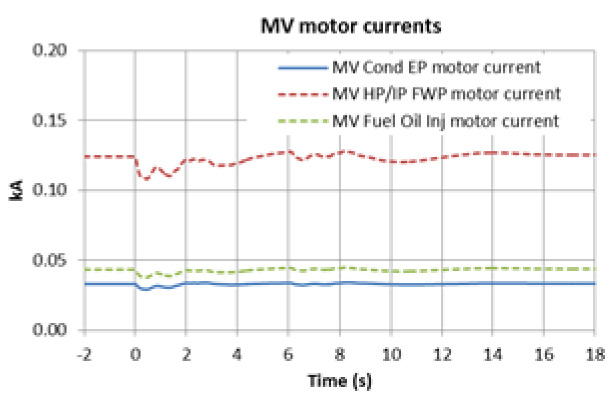
Auxiliary System Variables

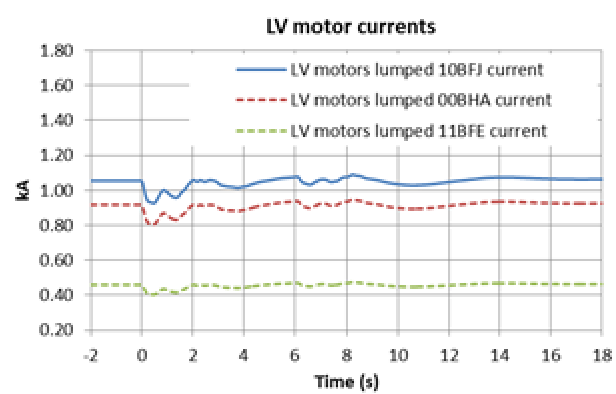










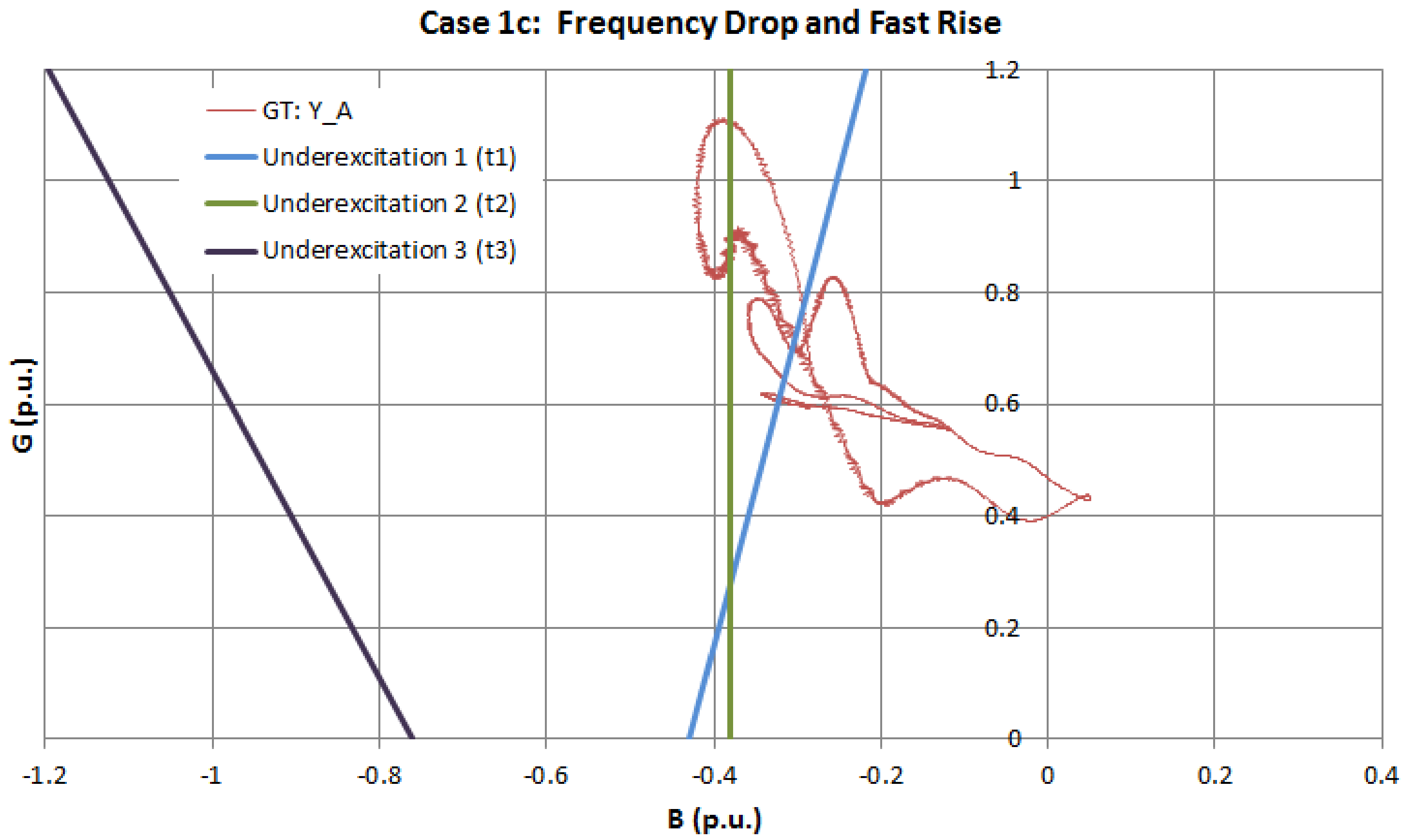


Risk of Tripping of Protection Functions

- RoCoF disturbances of this study relatively small compared to for example short-circuit faults
- Not internal, but originate from the grid
- No trip risk of: differential, earth fault, overload, neutral voltage displacement, unbalanced load, stator earth fault, rotor earth fault and unit transformer overcurrent and earth fault protection
- Current and voltages in MV and LV auxiliary systems do not reach ‘pick up’ levels of overcurrent, under- and over-voltage protection
    - Further margin due to time delay settings

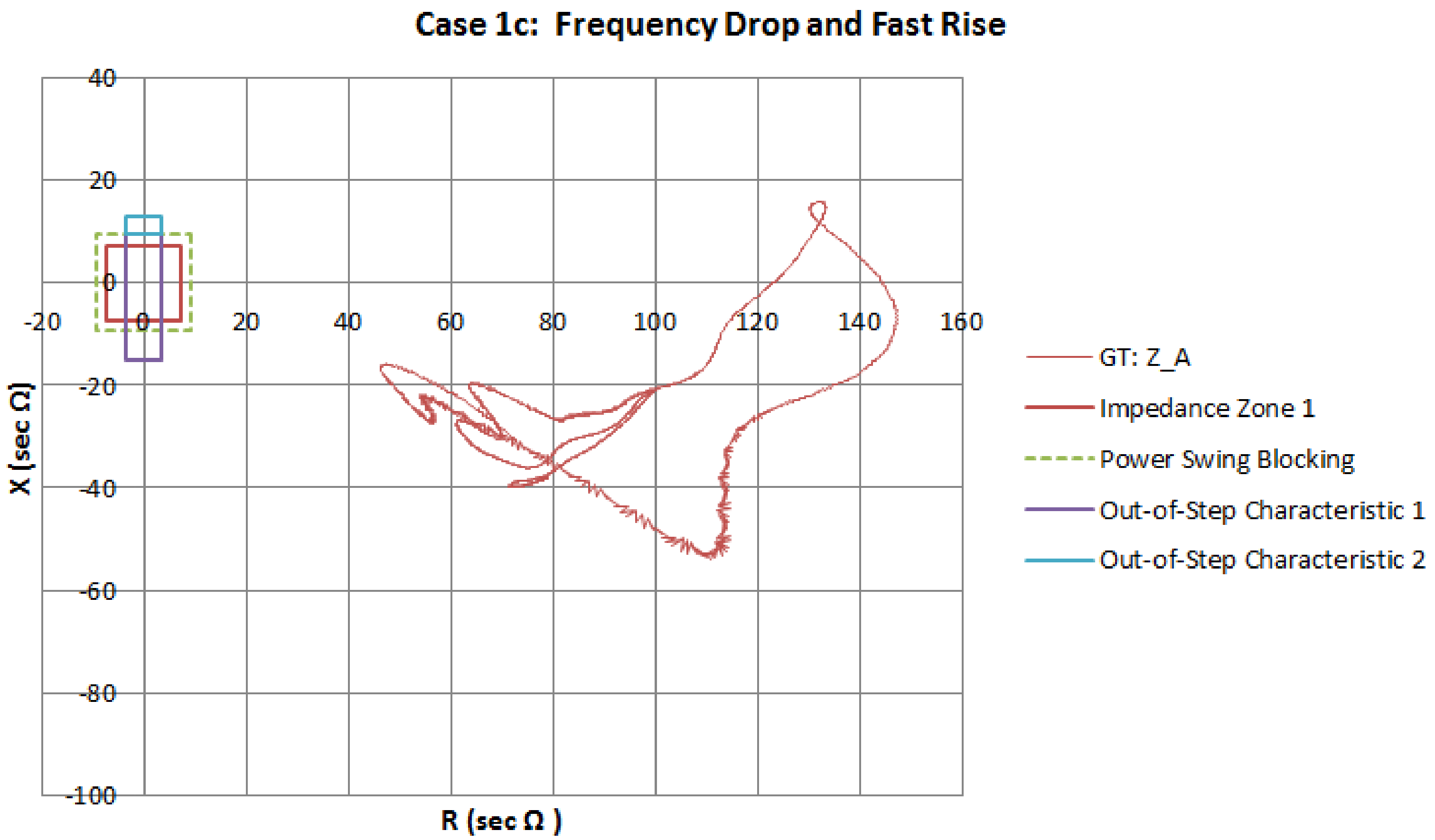
Loss of Field (Under-excitation) Protection

- In most cases with full lead pf, admittance loci shortly cross the underexcitation trip zone, but duration much less than corresponding trip delay time.
- For example case 1c below: max load, full lead pf



Impedance and Out-of-Step Protection

- For all cases impedance loci do not reach trip zones
- For example case 1c below: max load, full lead pf



Other Relevant Protection Functions (1)

- Generator Overvoltage
  - Worst case 1c with GT and ST stator voltages peaking at 1.13pu
  - No trip in any cases because
    - No pick up, or
    - Pick up level exceeded for much shorter than time delay setting
- Underfrequency and Overfrequency
  - RoCoF frequency profile traces within 48.5Hz to 51Hz
  - Note existing Grid Code requirement: 47.5Hz to 52Hz for 60 minutes
- Generator and Main Transformer overcurrent
  - Highest overcurrent in max load, full lag cases 2c (freq. drop and rise) & 2d (freq. drop): relay picks up but for too short a time to cause a trip

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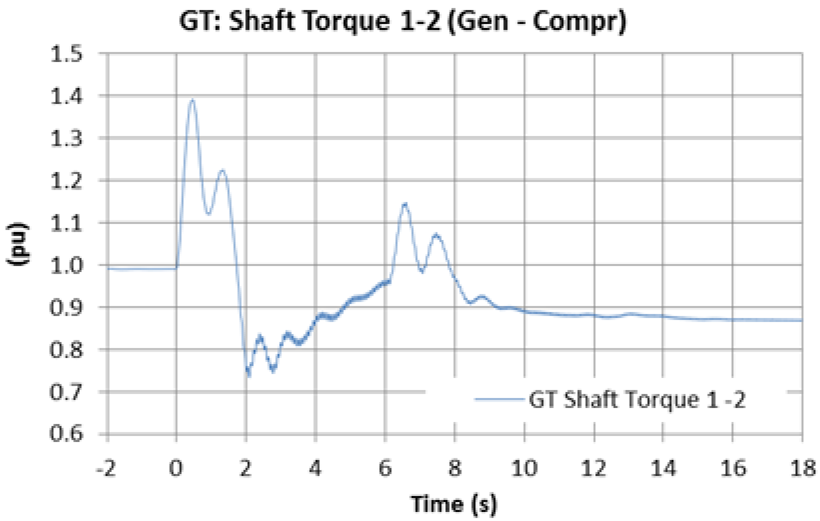
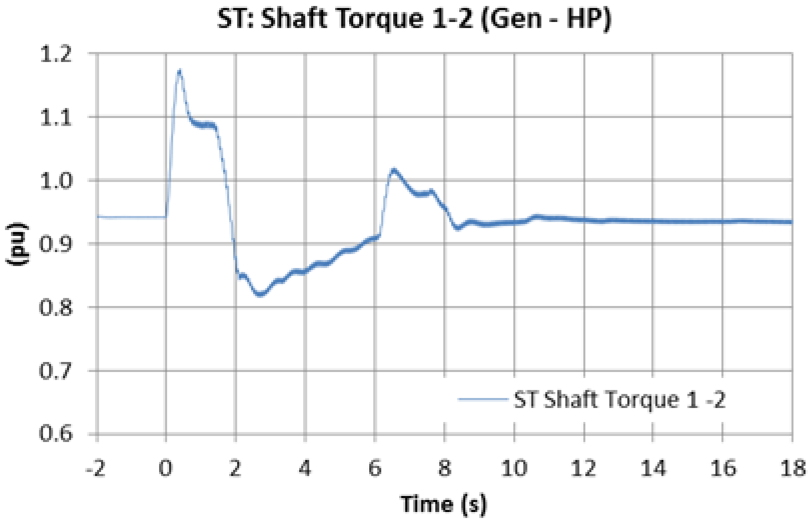
Other Relevant Protection Functions (2)

- Reverse power
  - Min load, full lag pf cases 4a (freq. rise) & 4b (freq. rise and drop) are worst
  - No pick up by a small margin, but delay setting provides great margin
- Reactive power, lead pf
  - Max load, full lead pf cases 1c (freq. drop and rise) & 1d (freq. drop) are worst
  - Picks up but for much shorter than delay setting => no trip
- Overfluxing
  - Max load, full lead pf cases 1c & 1d are worst
  - U/f value exceeded but for much shorter than delay setting => no trip

RoCoF Mechanical Impact Assessment – Shaft Torques

Most severe: Case 1c Max load Full lead pf Freq. drop and rise

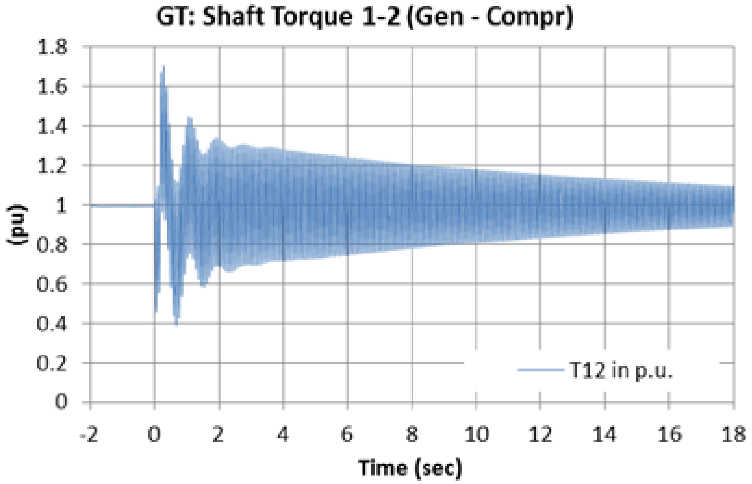


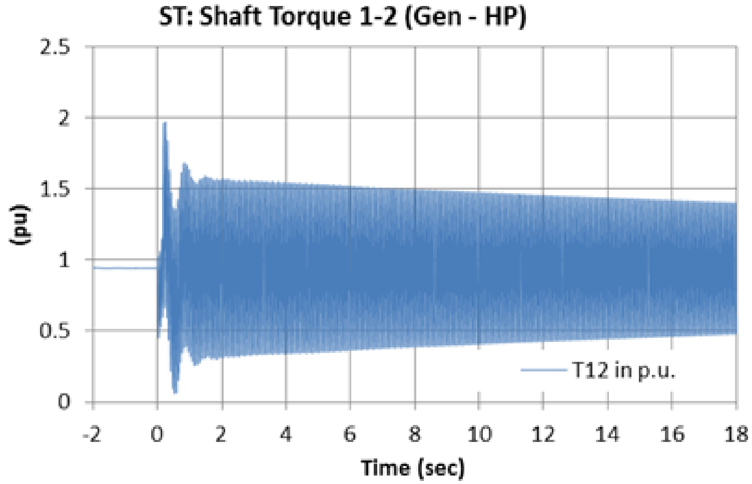


- Torsional stress analysis reveals no catastrophic failure to shaft line
- Fatigue impact similar to increased start-stop cycles: can be managed during scheduled maintenance
- No issues that result in non-compliance
- Shaft torque deviations from grid faults much more severe, see next slides

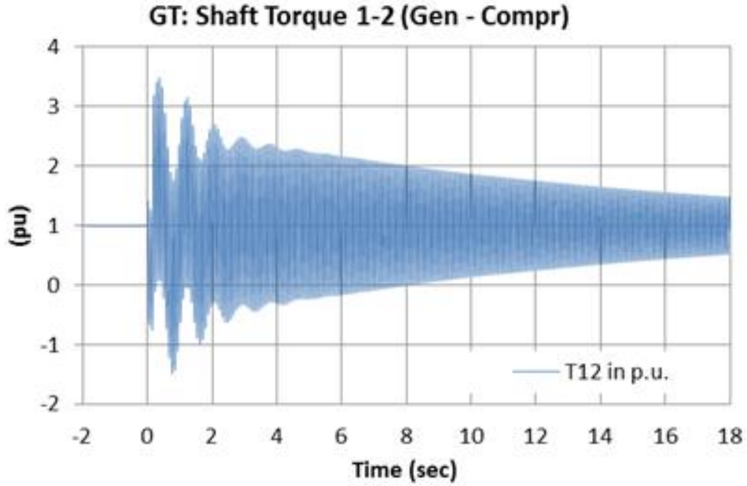
Compare with Shaft Torques for solid grid faults

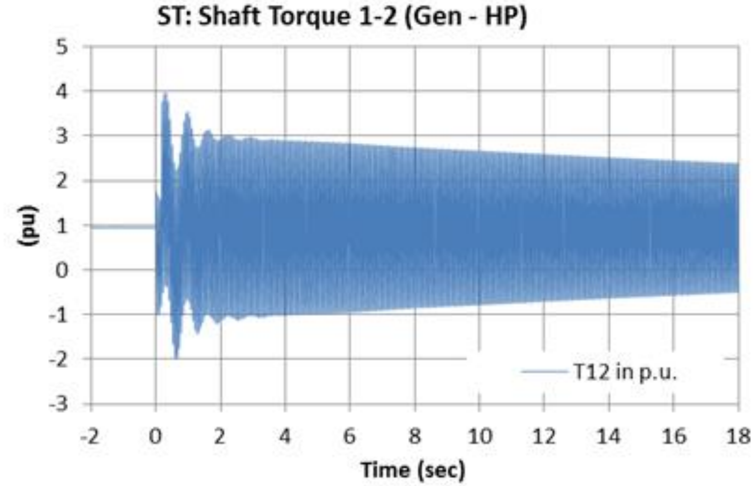
Solid 1 phase to ground fault for 150ms at grid connection point





Solid 3 phase to ground fault for 150ms at grid connection point





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Combustion Impact Assessment

- Gas Turbine combustion system evaluated qualitatively
  - Critical areas of the shaft line identified and assessed against the transient torques
- In this particular GT there is Pre-positioning of the Inlet Guide Vanes in response to any fuel flow
  - Risk of loss of flame or levels of humming considered very low

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Conclusions

- More Renewable Generation => Lower System Inertia => less stable frequency / higher RoCoF
- Modification to Irish Grid Code proposed which requires a generator to ride through a 1Hz/s RoCoF event
  - Impact is uncertain => technical studies are required
- Results of a ‘RoCoF’ compliance study for a CCGT in Ireland
  - System remains stable during and following defined RoCoF events
  - Significant deviations in voltages and torques for given grid frequency variations, but no risk of tripping identified
  - No issues in the mechanical or combustion system leading to non-compliance
- Conclusion not universal, and bespoke studies required for each power plant

Thank you!

If you need any further information, please contact us:

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