



**National
Laboratory
of the Rockies**

Type 5 Wind Turbines: Grid-forming System Strength and the Differential that Makes the Difference

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Contents

1. **Summary: why Type 5 and why SyncWind Type 5?**
2. **What is the SyncWind TLG-LVS Type 5 system?**
3. **Slow Voltage Stabilisation**
4. **Fast Voltage Stabilisation**
5. **Bypassing the Phase Jump Barrier**
6. **Conclusion**

Why does the industry need Type 5?

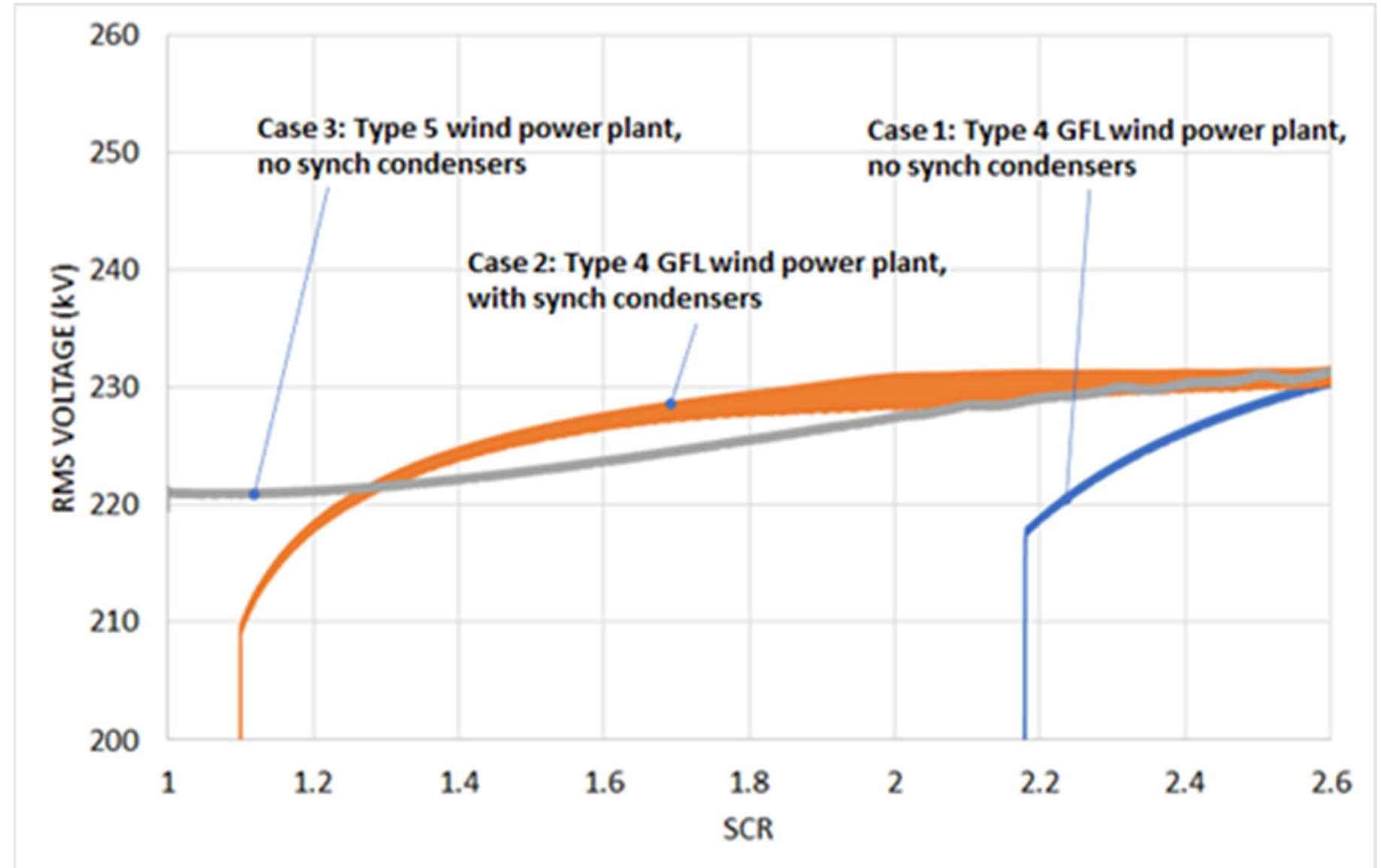
- Type 5 turbines have no inverters. They drive grid-connected synchronous generators, which are **grid-forming** just like conventional power plants
- The familiar history:
 - **System strength** from conventional power plants (>3 pu current capability, inertia etc) has ensured system stability
 - System strength has degraded because of wind and solar inverter-based resources (IBRs)
 - Type 3 and Type 4 wind turbines have inverters capable of typically only 0.4 pu and 1 pu current respectively, and no synchronous inertia
 - As renewables' penetration increases, synchronous compensators etc are increasingly being required in order to avoid curtailing IBR renewables
- Type 5 wind turbines avoid the need and cost of separate sync-comps etc
- SyncWind's Type 5 is the most cost-effective and avoids the phase-jump barrier to “grid-forming” VSG IBR wind turbines.

Summary of SyncWind Type 5 contributions to system strength

Attribute	SyncWind system	Best IBR System	SyncWind compares?
Turbine Cost	No inverters offsets hyd. cost	Type 3 GFL	Equal
SSRP	AVR -> V, pf or VAR control	Type 4	Similar?
LVRT/Stability	AVR -> DRR and FPFAPR	Type 4	Faster
Fault current	Up to 20 x rated	Type 4 GFM	Stronger
SIR	Non-zero synchronous I	Zero SI	Better
Virtual I/FFR	Turbine rotor's I is available, within torque limits		Same
Torque limiting	Differential protects drive-train from generator-side transients	Phase jumps etc rule out full VSG	Much better

Comparison of Type 4 and 5 systems: Voltage stability at POI as a function of SCR

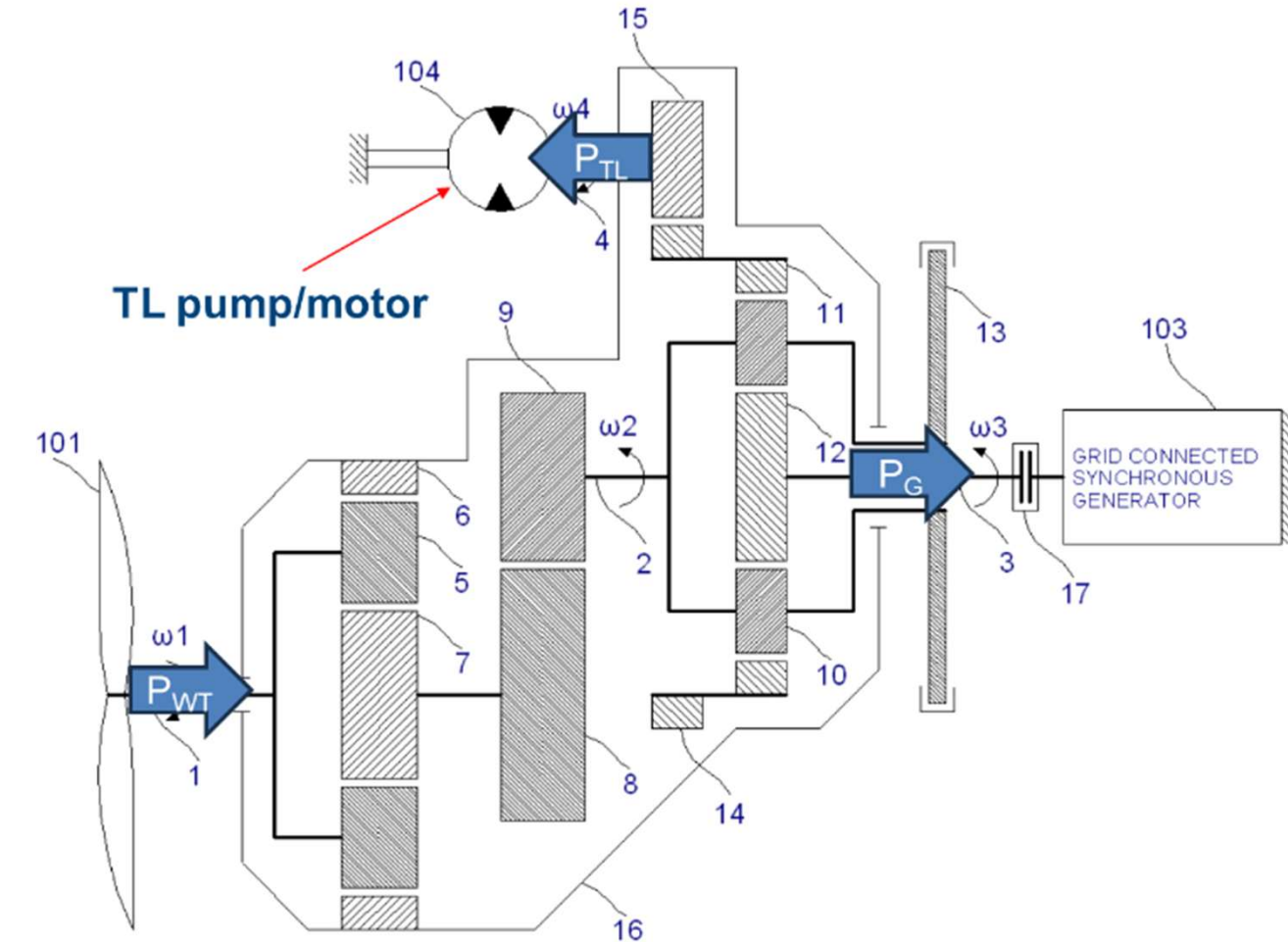
- PSCAD simulations of 1 GW of wind power comparing:
 - Type 4 (with and without sync-comps)
 - Type 5 (without)
- Type 5 significantly more stable for very low SCRs (**without sync-comps**) than Type 4 turbines (**with sync-comps**)



Contents

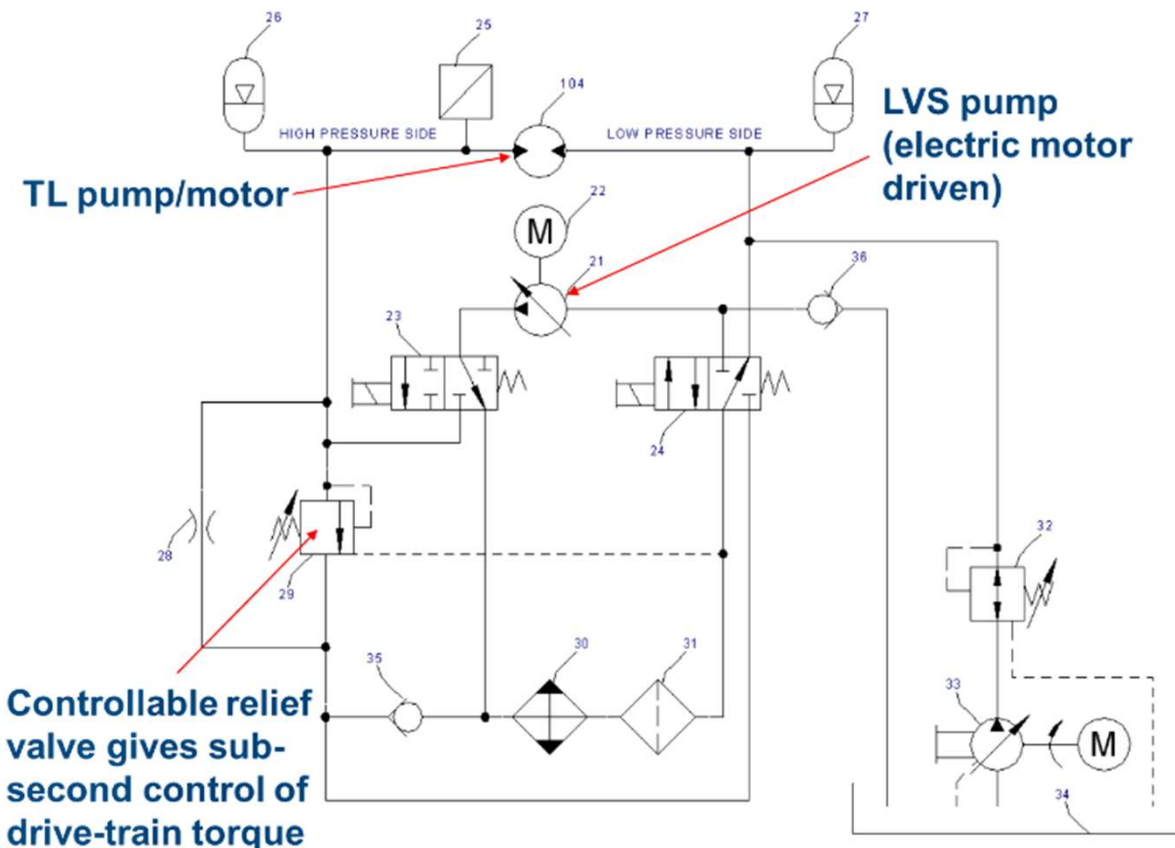
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SyncWind's TLG-LVS System



- Hydrostatic torque reaction at final differential epicyclic stage of gearbox
- Torque limiting (TL) pump/motor is fixed displacement radial piston
- Small TL pump can be sacrificial item, protecting main gearbox from electrical faults, pole-slip etc
- Torque limiting is provided by a relief valve with controllable setpoint
- LVS pump is variable flow axial piston, electric motor driven
- Both rated 5% wind turbine power
- Accumulators to smooth power output and turbine loads

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46 MW Synchronous Wind Farm

- Proven design at high wind New Zealand site
- 20 years operation and still going
- >1500 turbine-years track record
- Type certification
 - IEC 61400-1:2008 (Edition 3)
 - Class 1A



TRH List

14/02/2023 08:25:24

Net Power: 36.76 MW

Net Energy: 1505.10 GWh

Number Available: 86

Number Generating: 81

Mean Windspeed: 18.5 m/s

Wind Dir: SSE (154.6 degrees)

High Windspeed (TRH_T007): 28.5 m/s

PSDs: Yes (6). (with RunFlag: 0)

Controller: Pete Darke

Txxx Run Status PSD Power

T001 ON AutoGen PSD:No 500 kW

T002 ON AutoGen PSD:No 487 kW

T003 ON AutoGen PSD:No 425 kW

T004 ON AutoGen PSD:No 530 kW

T005 ON AutoGen PSD:No 511 kW

T006 ON AutoGen PSD:No 349 kW

T007 ON AutoGen PSD:No 526 kW

T008 ON AutoGen PSD:No 526 kW

T009 ON AutoGen PSD:No 517 kW

T010 ON AutoGen PSD:No 541 kW

T011 ON AutoGen PSD:No 428 kW

T012 ON AutoGen PSD:No 432 kW

T013 ON AutoGen PSD:No 517 kW

T014 ON AutoGen PSD:No 546 kW

T015 ON AutoGen PSD:No 407 kW

T016 ON AutoGen PSD:No 493 kW

T017 ON AutoGen PSD:No 462 kW

T023 OFF Standby PSD:No 0 kW

T024 ON AutoGen PSD:No 432 kW

T025 ON AutoGen PSD:No 548 kW

T026 ON AutoGen PSD:No 348 kW

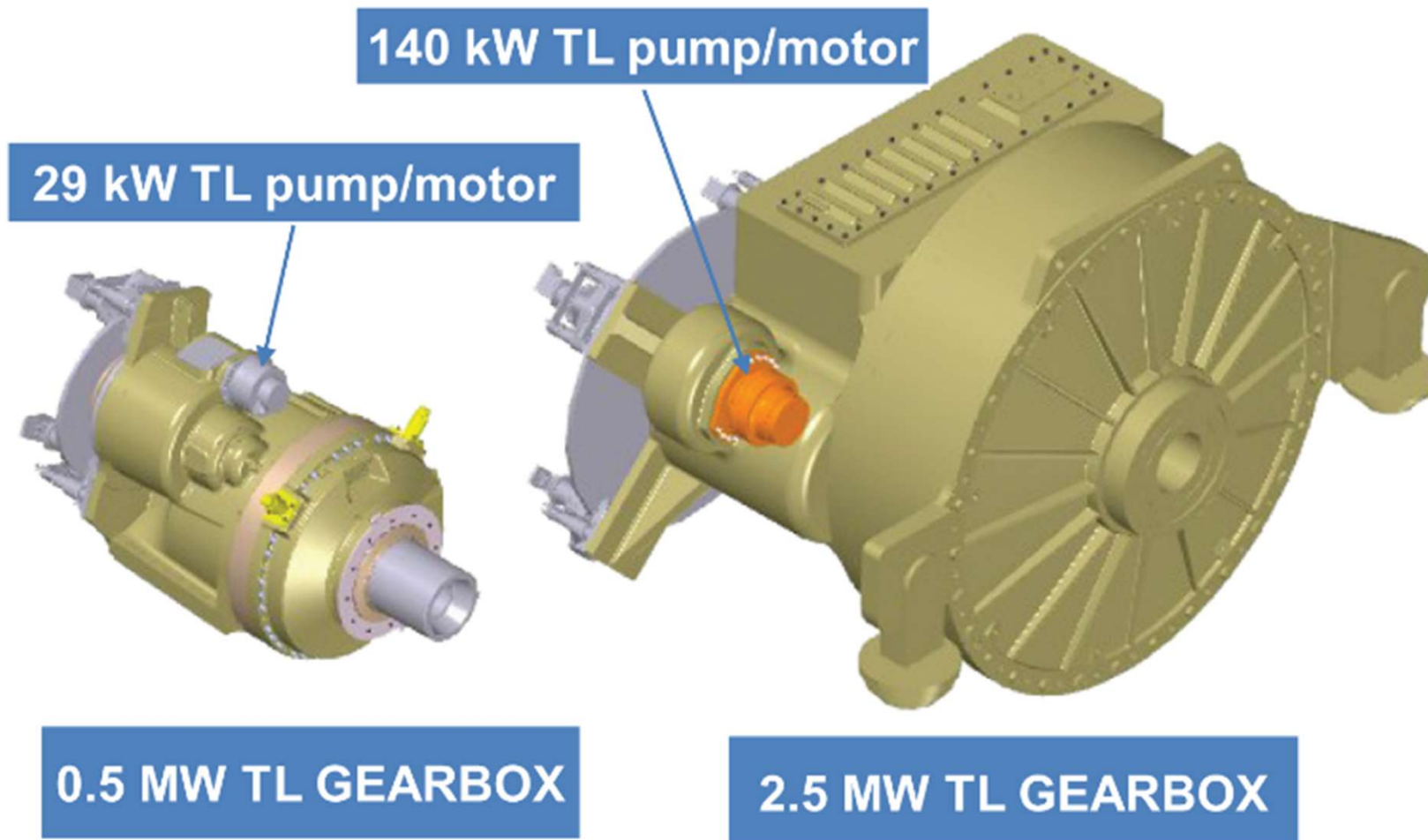
T027 ON Standby PSD:No 0 kW

T028 ON AutoGen PSD:No 500 kW

TLG-LVS System

Cost-Competitive with Type 3

Small hydraulic machines are key (low losses, low capital cost, scalable because they scale with power, not gearbox torque)

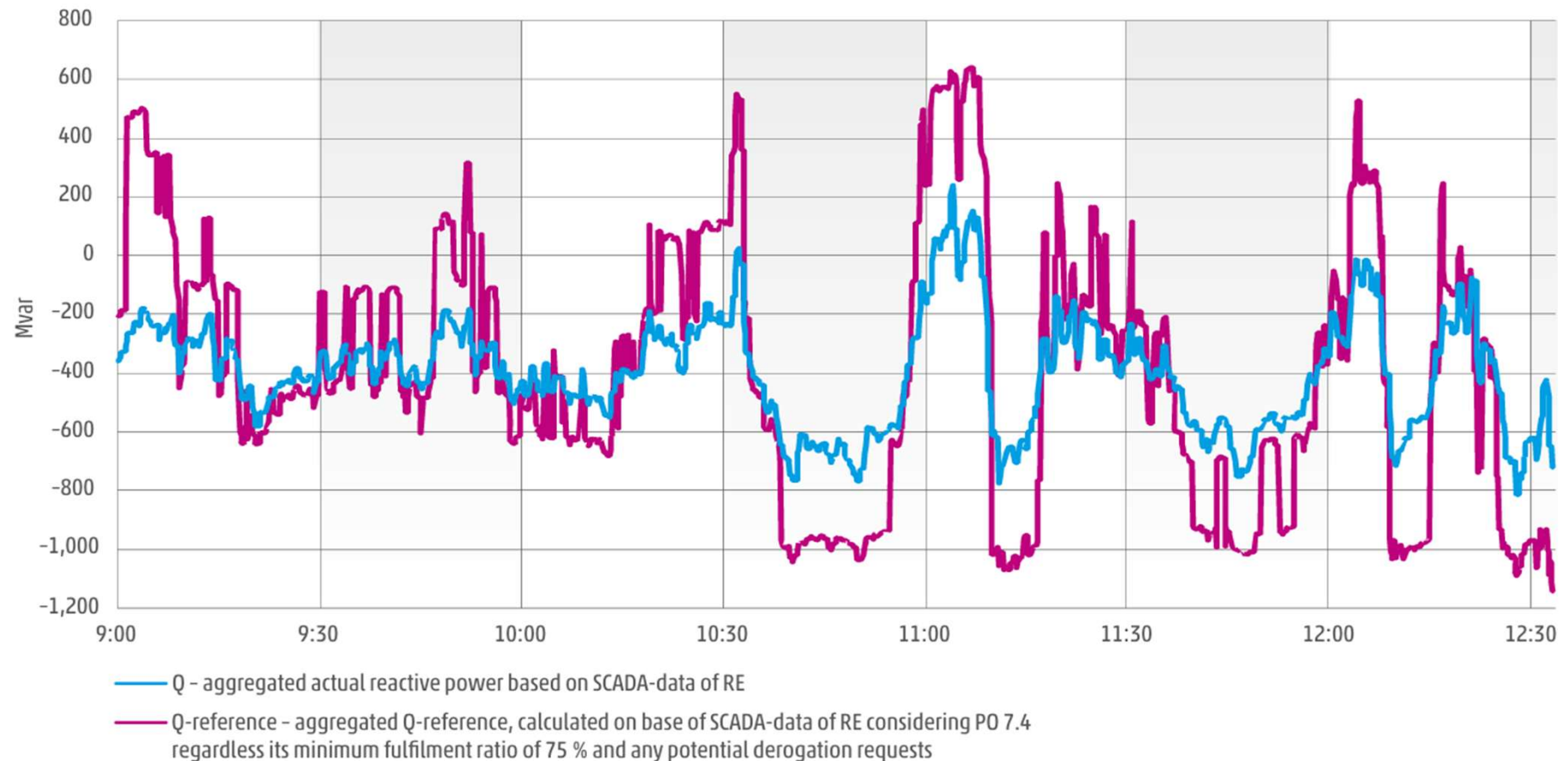


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Slow Voltage Stabilisation: Steady-State Reactive Power (SSRP) Needed for example in Spain on 28 April, 2025

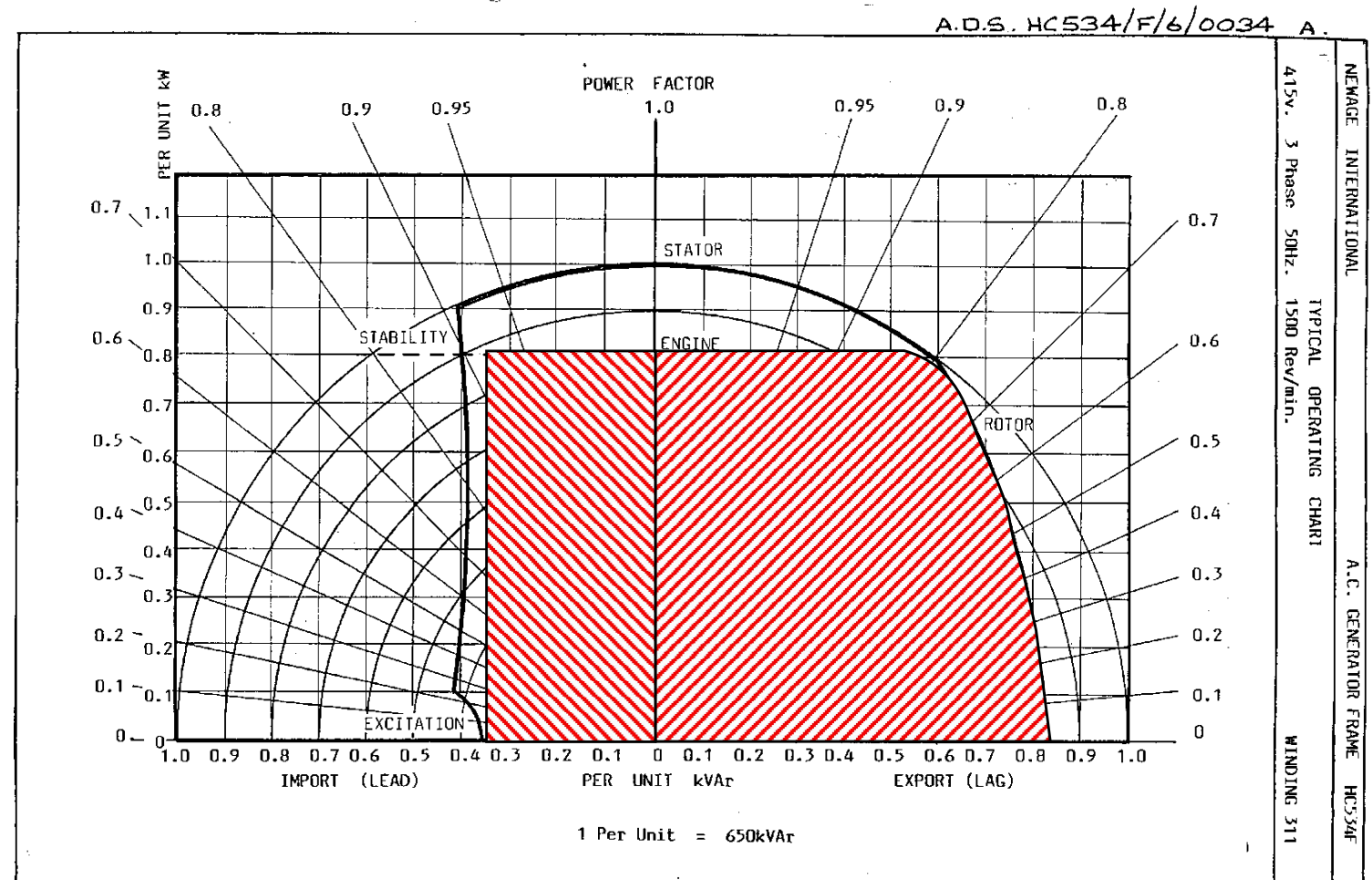
- Figure from final ENTSO-E report: blue line shows reactive power provided by conventional generation in ENE Spain for the hours leading up to the blackout. Purple line shows the reactive power requested.
- Asymmetric deficits in range 400 – 600 MVar caused voltage to rise. Blackout followed.



Reactive Power Export/Import:

Characteristic Curve of the W500's Sync Generator

- 2017 paper set out examples of Windflow 500s providing SSRP to:
 - Boost line voltage (VAr export)
 - Lower line voltage (VAr import)



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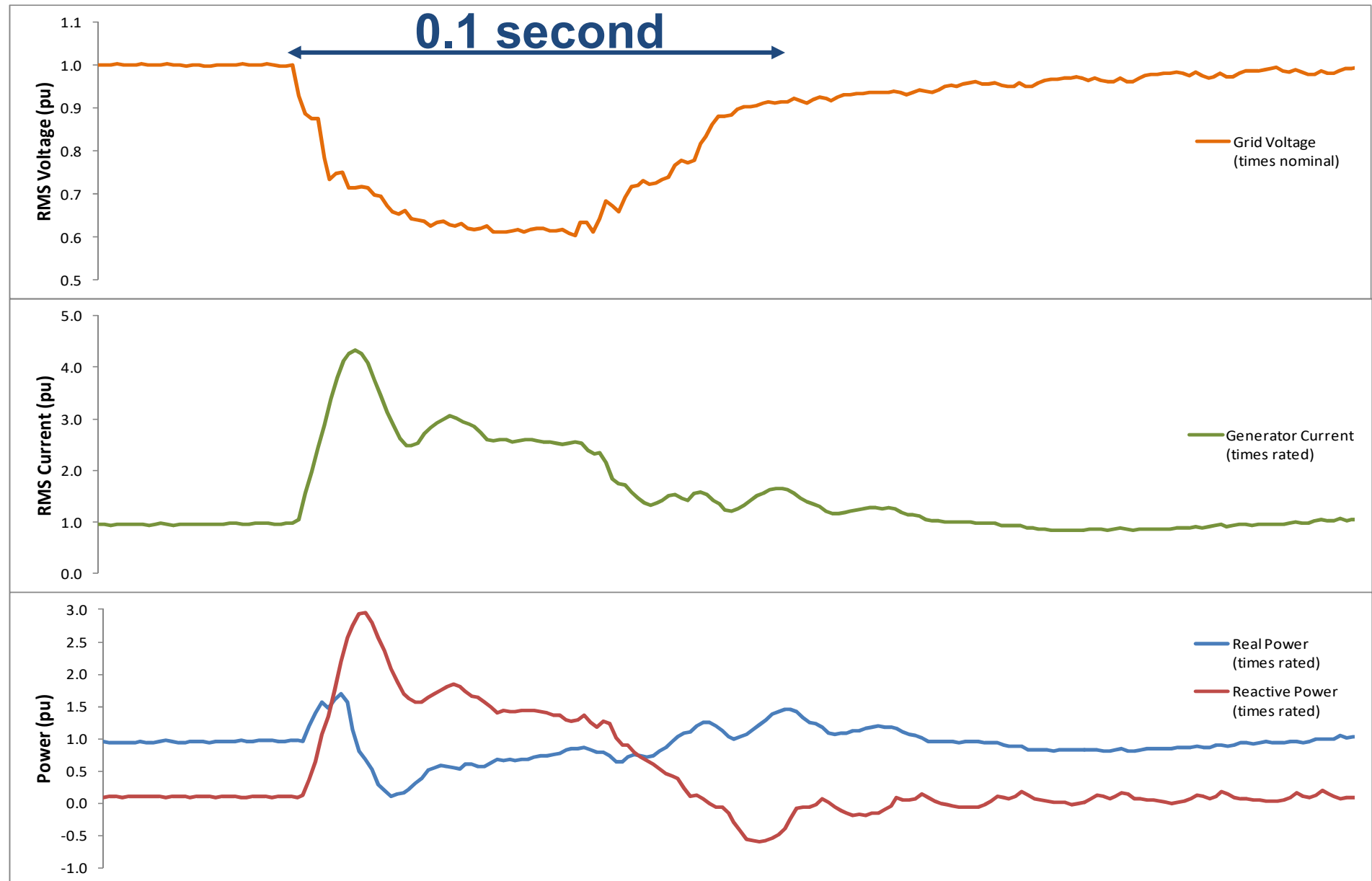
Contributing System Strength during 0.1 s LVRT event in New Zealand, 8 September 2012

GRID
VOLTAGE
 (0.5 to 1.1 pu)

GENERATOR
CURRENT
 (0 to 5 pu),

KW
 (-1 to 3 pu),

KVAR
 (-1 to 3 pu)



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What is the Phase Jump Barrier?

- 2025 WIW Berlin - “your system will have the same problem with damaging mechanical torques that grid-forming IBRs do”
- Initial reaction:- WTF??
- Ferry et al explained the problem for phase jumps as low as 5-10 degrees
- Phase jump -> active power spike -> torque spike -> generator rotor fights the wind turbine rotor’s inertia

Wind and Solar Integration Workshop 2025 | Impact of Phase Angle Jumps on GFM/GFL Type 4 WTG | e'n dynamic | 09.10.2025 | Seite 11

3. Results

- **Grid-following** inverter easily suppresses power variation during voltage phase angle jump conditions
- Voltage angle jumps have a severe impact on the **active power** output of the **grid-forming** inverter
- **Delay/filter times** within the control strategy have an influence on the P-provision

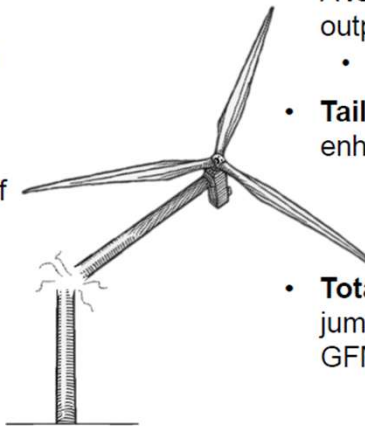


Fig. 12: Voltage phase angle jumped too much

Conclusion

- A **feed-forward term** may diminish the output energy following the jump
 - output power peak persists
- **Tailored inertia** is promising, but needs enhanced implementation
- **Total Suppression** of the active power jump only feasible by breaking with the GFM-principle

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- Above slide is from Ferry, J., Becker, H. & Gui, Q. – “Impact of phase angle jumps in the grid voltage on GFM/GFL wind turbine generators”, Proc. Wind Integration Workshop, Berlin, 2025
- Indicates grid-forming stability and turbine protection fundamentally need to be compromised (for only 10 degree phase jumps!)

How does SyncWind bypass phase jump barrier?

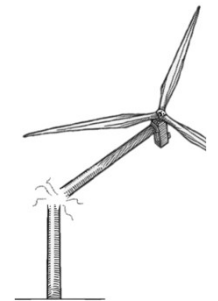
- This problem of generator rotors ‘fighting’ the wind turbines’ goes back to 1980s
- It is why Type 1 turbines were asynchronous, yet gearbox service factors were 2
- It is why I then invented the TLG
- The TLG’s epicyclic final stage is the ‘differential that makes the difference’:
 - **It provides a second degree of freedom**
 - The torque reaction is limited by the TL pump not only on its shaft, but through the differential gearing, it is **also limited on the turbine and generator shafts**
- The system has three inertias with very different magnitudes:
 - Let the synchronous generator rotor’s inertia = 1 unit (say G_S kg.m²)
 - The wind turbine rotor’s inertia $\sim 10 \times G_S$ kg.m² (referred to the generator shaft)
 - The TL pump/motor’s inertia $\sim 0.001 \times G_S$ kg.m² (referred to the generator shaft)
- The light-weight TL pump/motor has negligible inertia, but strong control of torque
- **Thus, the SyncWind Type 5 system definitely bypasses the phase jump barrier!**

What do car differentials do? Is it like that?

- All cars have differentials – and the reason goes beyond simply allowing cars to corner. The counterfactual (if cars did not have differentials) involves major stresses from any surface irregularity
- Like a car's differential, the SyncWind TLG prevents rotors (wheels) from fighting each other through the gearbox
- Unlike a car's differential:
 - the SyncWind system uses an epicyclic differential (more efficient than the bevel gears in a car differential)
 - the default power split is not 50:50 but 100:'3' (where '3' varies 0-5)
- IMO, the pursuit of GFM inverters for wind turbines is like designing a car with no differential. Having only 1 degree of freedom can work in theory ... if the car always drives in a straight line on perfectly smooth tarmac with no bumps!

2 empirical proofs that SyncWind's differential works

1. SyncWind turbines (the Windflow 500s) routinely experience phase jumps up to 10° each time they synchronise:
 - The generator rotor gets jerked around, which jerks the TL pump around (NOT the wind turbine).
 - A million such events have occurred in their >1500 turbine-year track record with no ill effects
2. One event with a much greater 'phase jump' has occurred in Windflow track record. The turbine gearbox and generator were undamaged. Data analysis from that event quantifies what the counterfactual would have been.

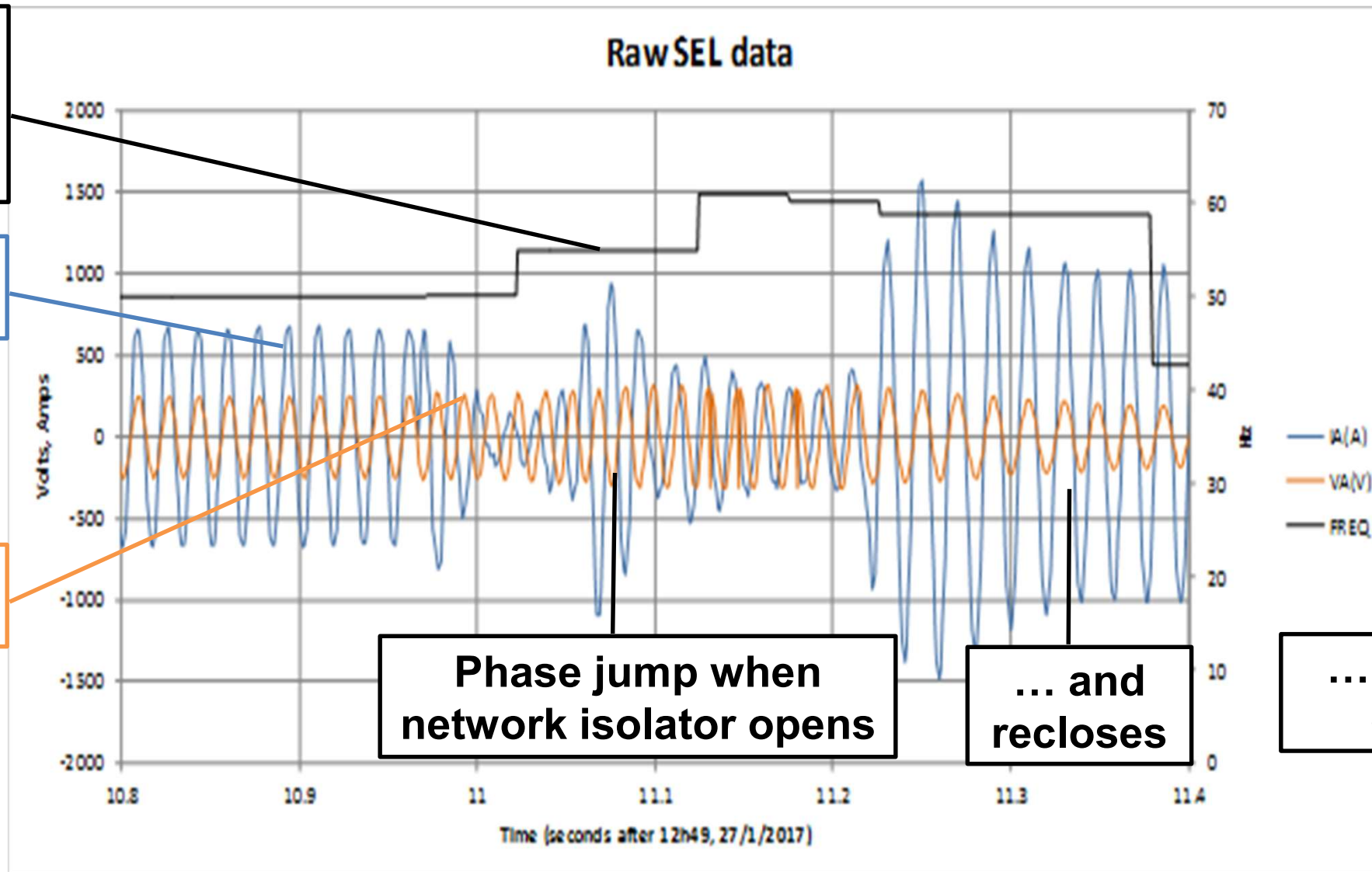


Islanded Operation with 10-15 MW of Inertia-less Neighbours: Current, Voltage and Frequency 27/1/2017

Frequency (Hz, RH scale)

Current (A)

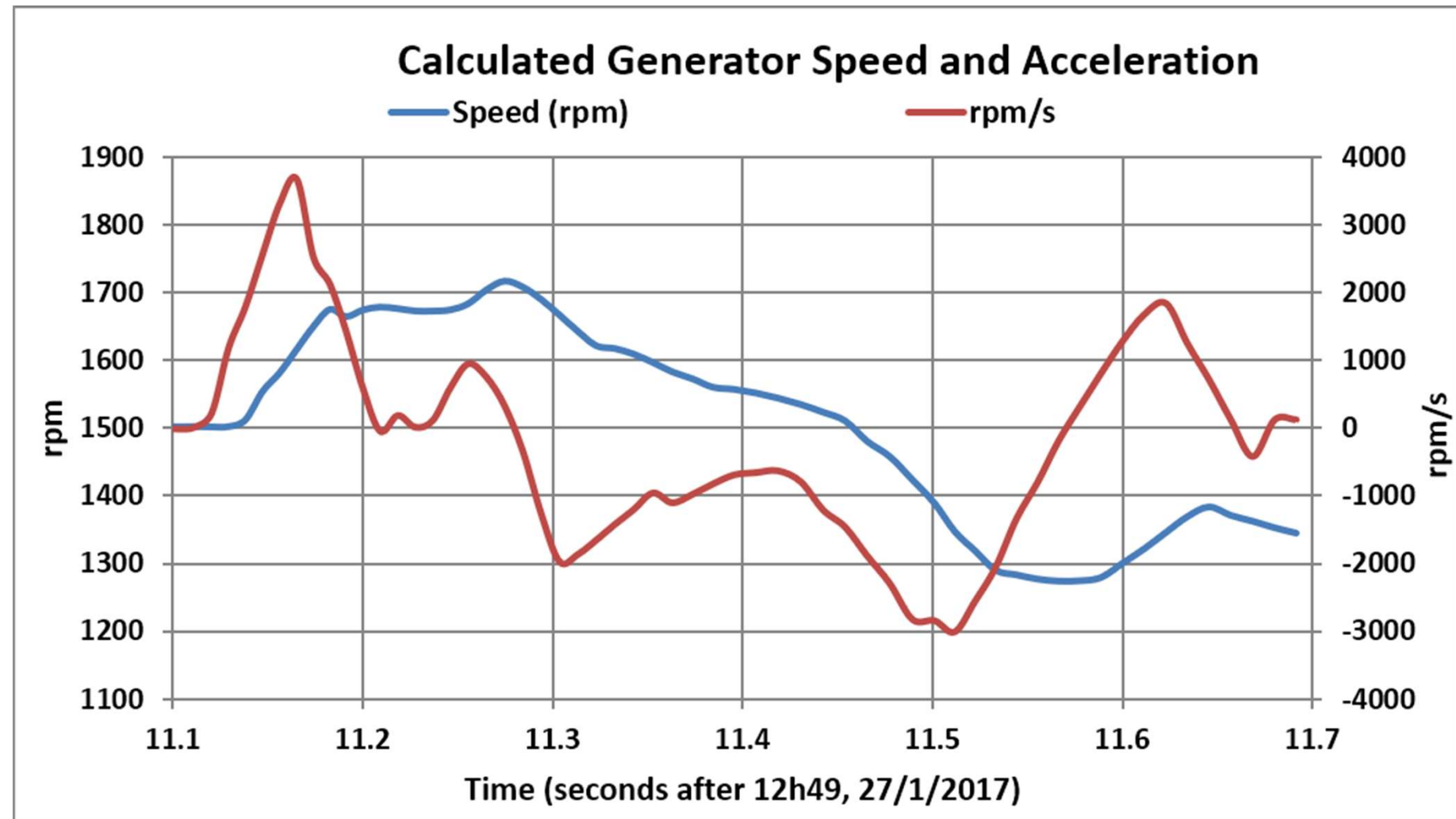
Voltage (V)



2017 Severe Phase Jump/Pole-slip Event: frequency from 800 Hz voltage data

- Voltage and current data was captured at high resolution (800 Hz = 1.25 ms time step) by the SEC relay during the “event”
- A zero crossing algorithm was used to create a realistic graph of frequency and hence ROCOF
- Sync generator speed (rpm) and acceleration directly follows from:

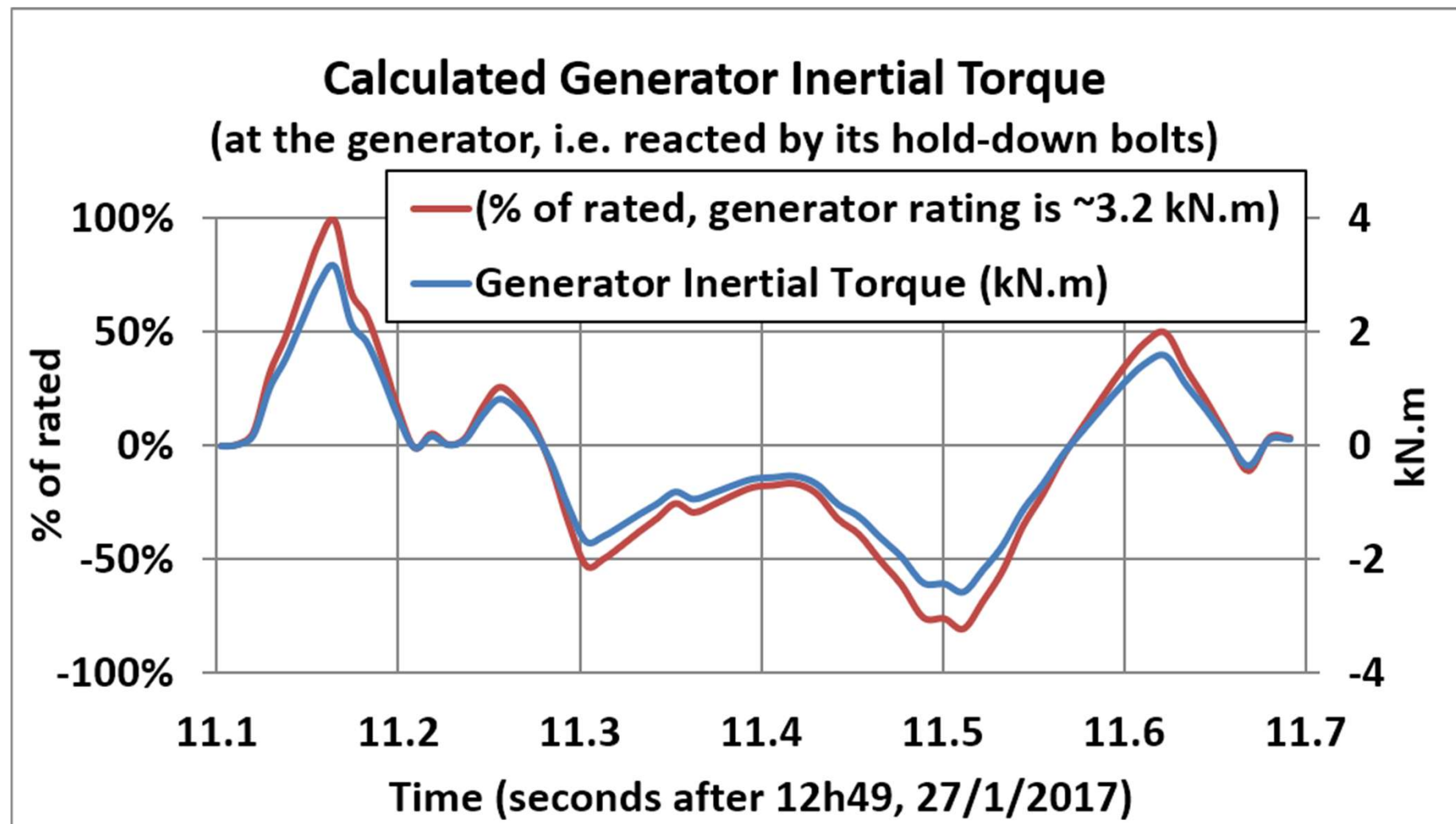
$$N = f \times 1500/50$$



2017 Severe Phase Jump/Pole-slip Event: generator inertial torque from its acceleration

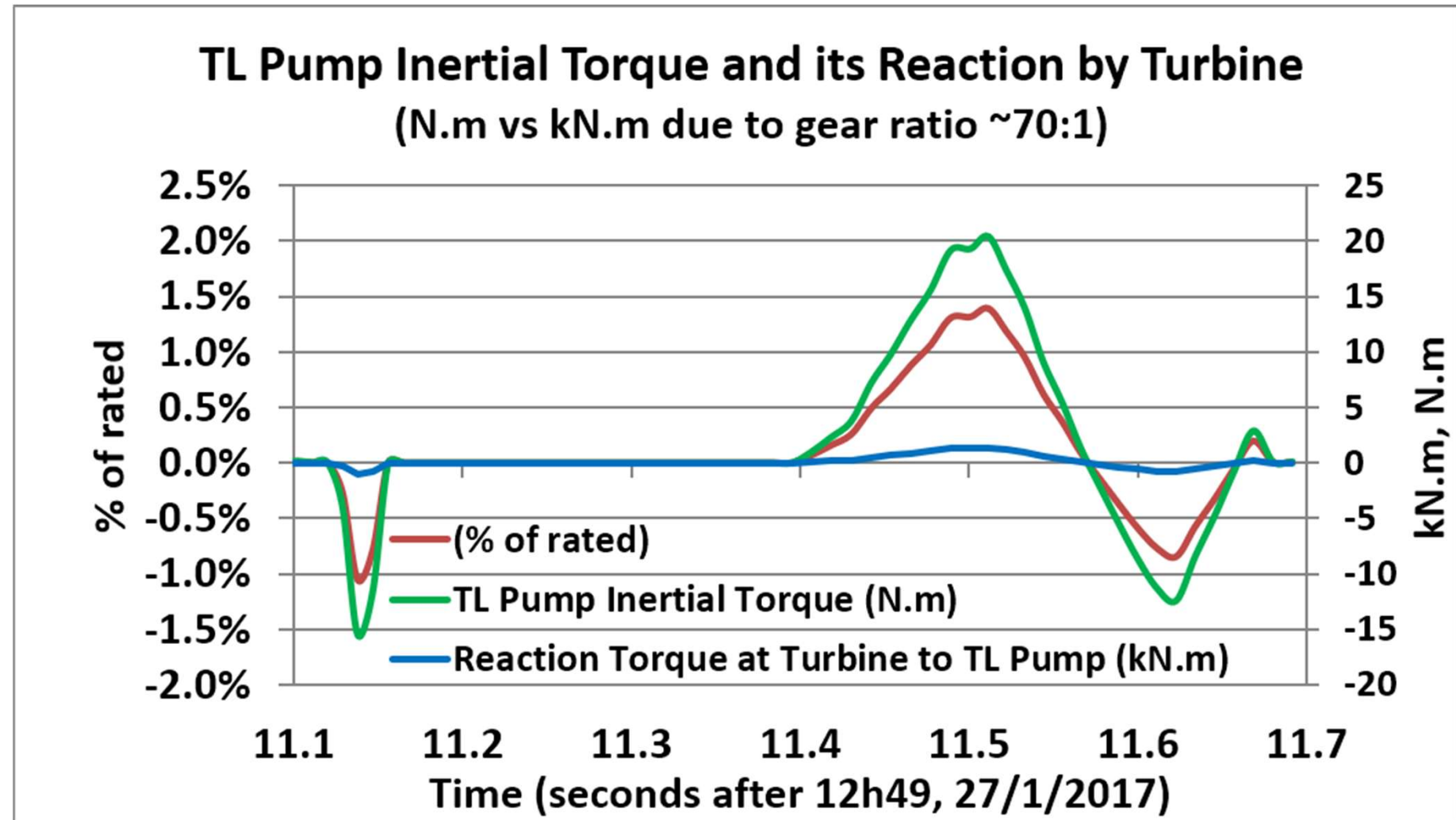
- Next, from the inertia of the generator rotor, the inertial torque on the generator hold-down bolts can be calculated:

$$T = I\alpha$$
- This is presented here as a percentage of rated, as well as absolute values
- The peak torques were non-trivial, but similar to rated torque, therefore, not damaging, even when added to the pre-existing shaft loading



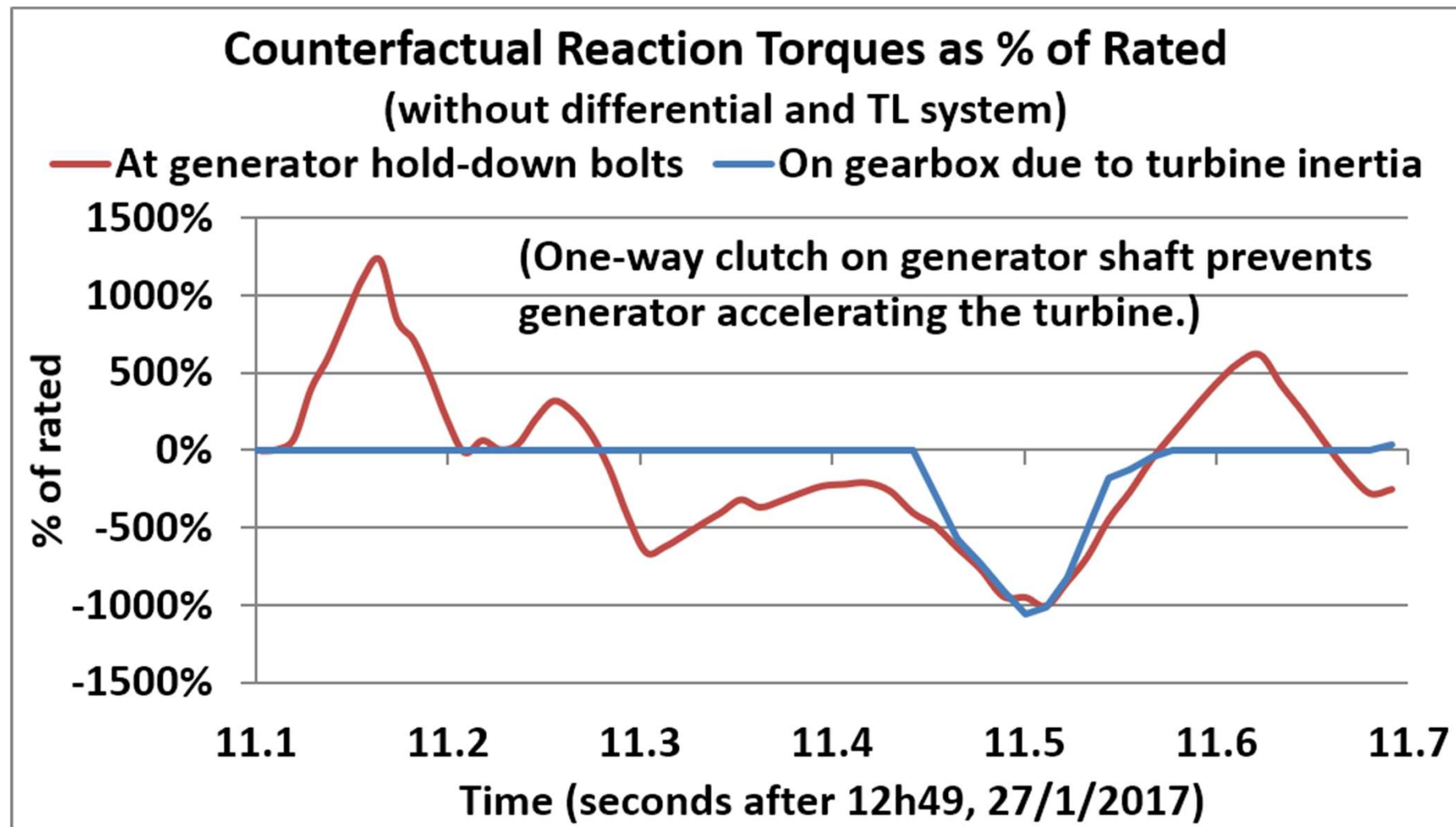
2017 Severe Phase Jump/Pole-slip Event: TL pump inertial torque from its acceleration

- The differential gear ratios enable the accelerations and torques on the TL pump and the wind turbine rotor to be calculated similarly from the generator speed
- the inertial torques involved (and reacted by the turbine through the gearbox) were trivial, peaking at around 1.3% of rated, due to the action of the differential and TL pump



2017 Severe Phase Jump/Pole-slip Event: reaction torques if no differential and TL pump

- In contrast, this graph shows the inertial torques which would have been imposed with a fixed-ratio gearbox
- The generator hold-down bolts would have experienced more than 12 times rated and the gearbox more than 10 times rated, seriously damaging the gearbox internally, if not ripping these major components out of the nacelle



Conclusions

- After the 2025 Spanish blackout, it is clear that slow voltage regulation (SSRP) can and should be provided by IBR solar and wind on a complementary basis. Type 5 wind can readily contribute also with proven AVR technology
- Fast voltage regulation - DRR and FPFAPR for system strength, not mere ride-through - is best provided by synchronous machines and SyncWind's Type 5 system has demonstrated this capability in a 46 MW wind farm in New Zealand
- The phase jump barrier and other generator-side transients affect the fault tolerance of GFM inverters, and also the strength of mechanical components like the gearbox which are already more highly loaded in gusts by generator inertial torques, a bit like designing a car with no differential
- The differential stage and low-inertia TL system enable SyncWind's Type 5 system to bypass these barriers. It does not have the same problem with damaging mechanical torques that grid-forming IBR wind turbines do. It can form the grid better and cheaper!