The Latest Development in Synchronous Wind Turbine Technology:

how the LVS System can deliver low cost, broad-band variable turbine speed and Type 5 grid connection

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Contents

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Background: recap of WIW 17 Paper

- History dating back to torque limiting gearbox (TLG) invention in 1987, prototype in 1990
- Primary purpose to protect the gearbox, reduce cost
- Synchronous generation was secondary
  - Enabled by differential stage in TLG
  - Not valued then – prevailing wisdom was “wind power will always be small, Britain has a massively stiff electricity grid”
- 30-year track record outlined with illustrative experiences:
  - Reactive power export for revenue generation (even in calm winds)
  - Reactive power import to compensate for weak 11 kV network
  - TLG shown to protect gearbox and generator from costly damage during islanding/voltage instability/poleslip event on Orkney
  - Frequency control ability demonstrated
  - System strength contribution apparent in LVRT behaviour in New Zealand

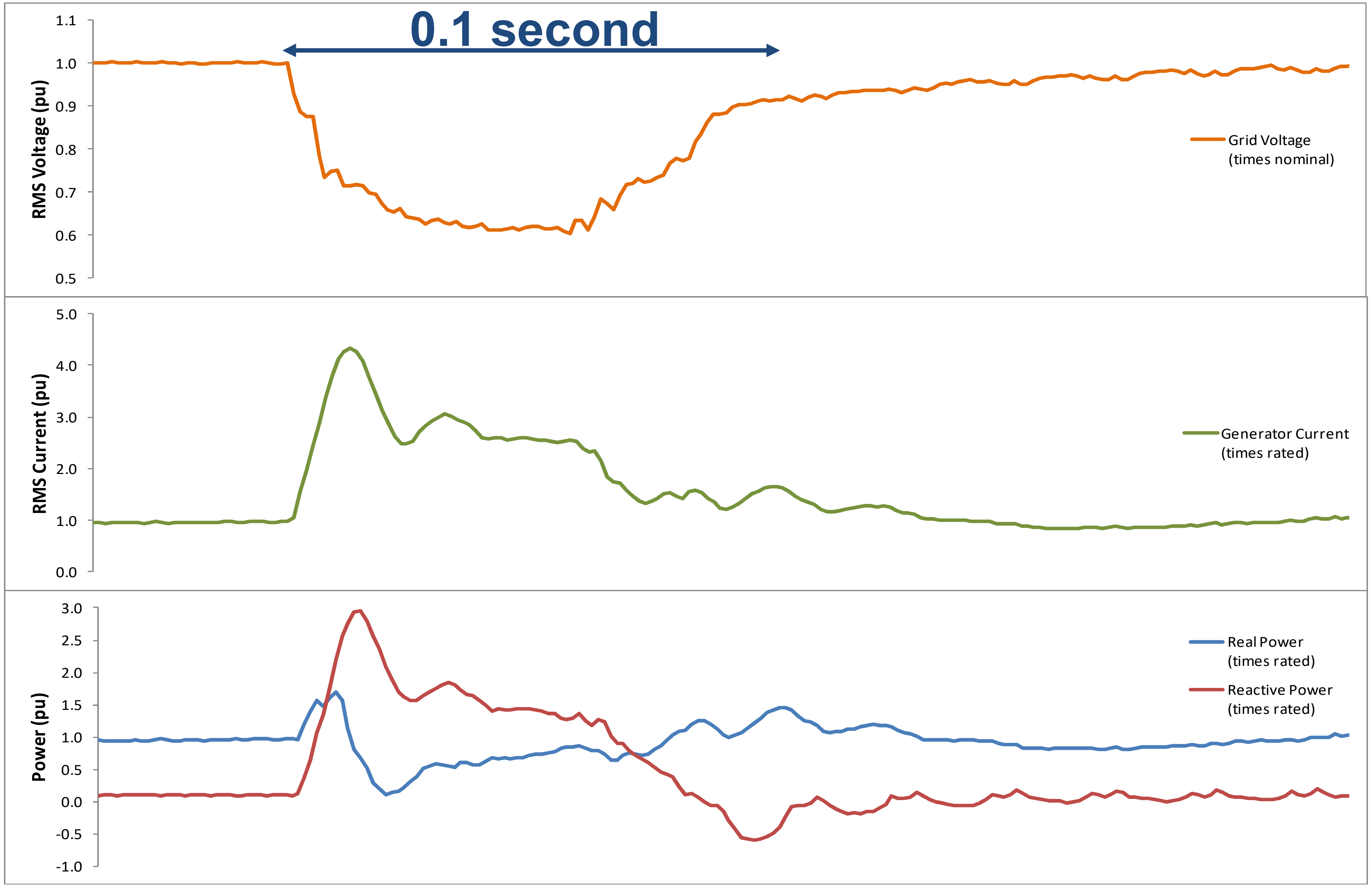
Contributing System Strength during 0.1 s LVRT event in New Zealand, 8 September 2012

GRID VOLTAGE (0.5 to 1.1 pu)

GENERATOR CURRENT (0 to 5 pu),

KW (-1 to 3 pu),

KVAR (-1 to 3 pu)



Developments since 2017

Low Variable Speed (LVS) Prototype Track Record:

- 0.5 MW turbine near Edinburgh, installed late 2016
- Commissioned early 2017
- Refinements added in 2018:
  - New, low-slip control loops and cut-in parameters
  - Fan-cooler for low wind operation
- Ongoing commercial operation

Australian Market Focus on System Strength:

- Electranet spending A$166 million to install 516 MW synchronous condensers in South Australia
- Some new renewable projects also need sync-cons
- Ongoing regulatory uncertainty, court actions etc

LVS turbine installed near Edinburgh

East England Blackout 2019

9 August 2019:

- A lightning strike was followed by loss of 737 MW from Hornsea offshore wind farm and 244 MW from Little Barford thermal power station, leading to a significant blackout
- power was restored in 15 to 45 minutes, but many train passengers stranded for several hours
- While most blame was on rare combinations of events and software flaws on some trains, the operators of Hornsea and Little Barford each paid £4.5 million to OFGEM's voluntary redress fund for not remaining connected.

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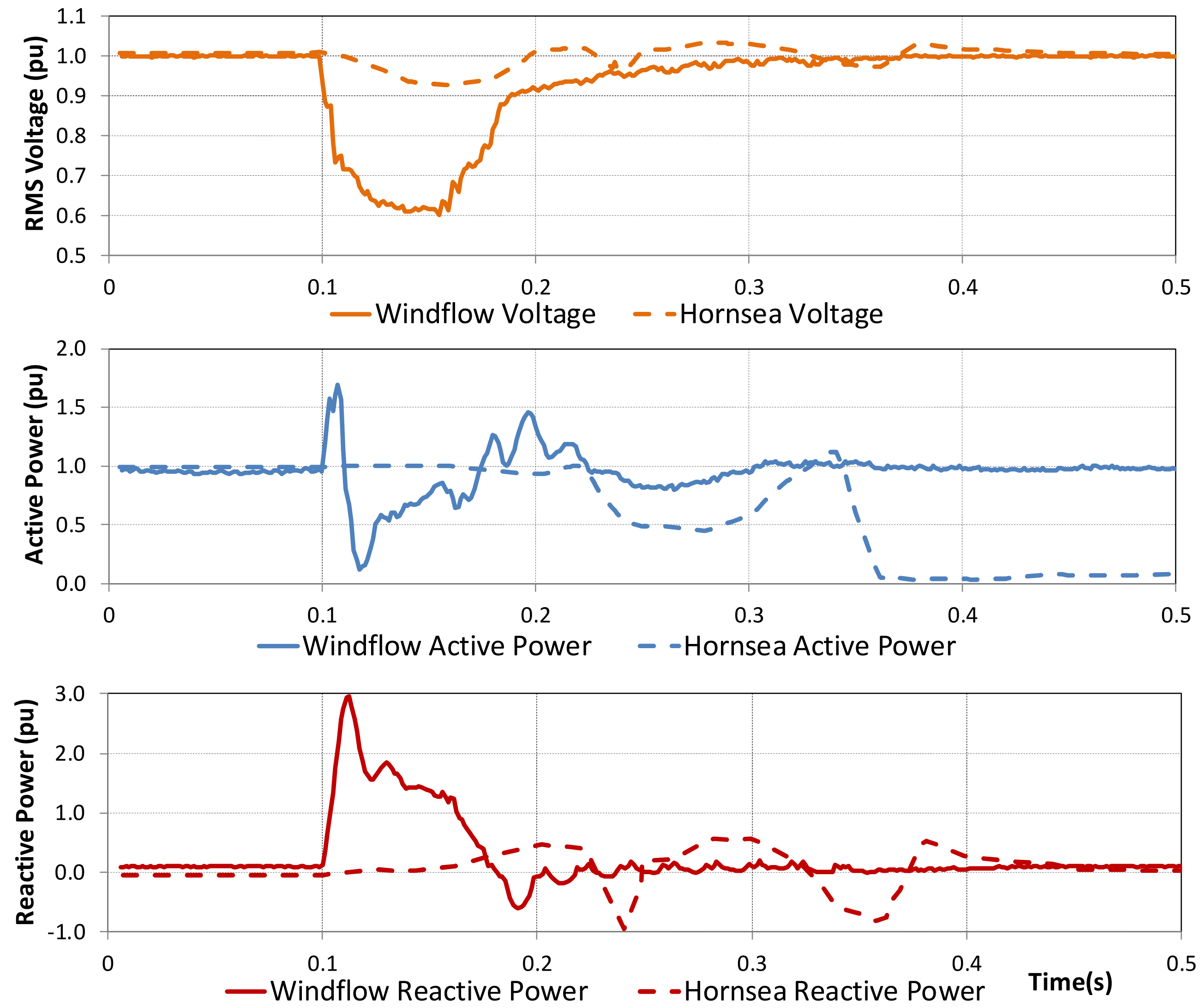
East England Blackout 2019

Synchronous (Windflow) and Asynchronous (Hornsea) Responses Contrasted:

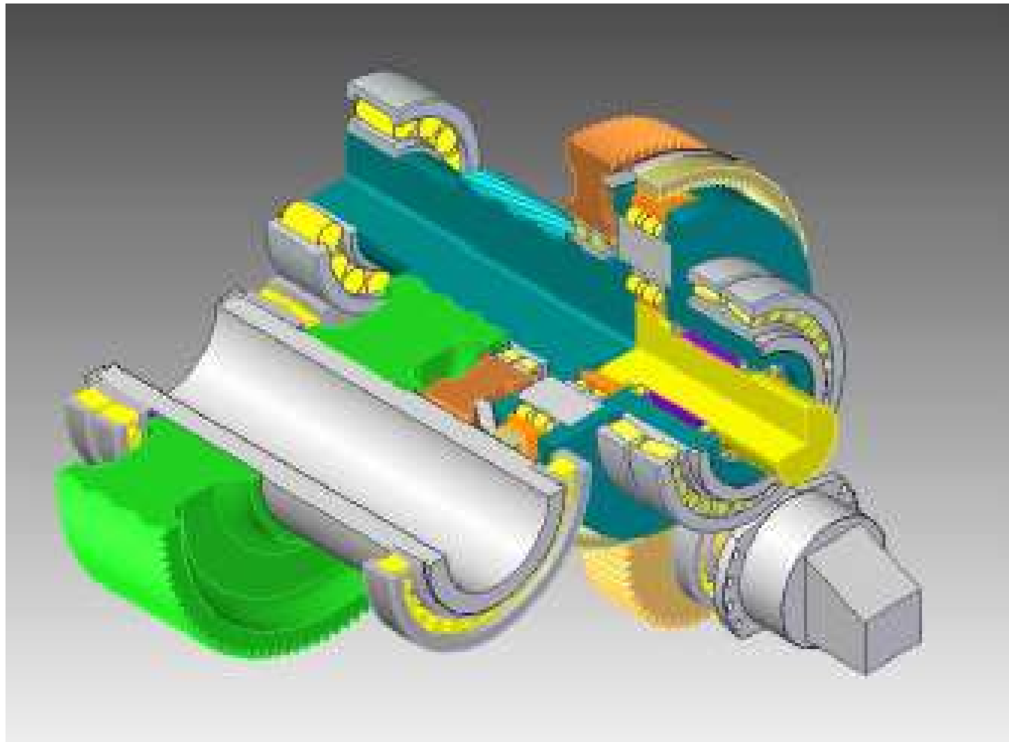
- Immediate, large reactive power vs delayed, small reactive power
- Active power stabilised vs tripped off to near-zero
- “unexpected large swings” … “should not have occurred” (National Grid Report)



Comparison of fault response of Windflow 500 synchronous turbine at 48 MW wind farm (8/9/2012), and Hornsea 737 MW wind farm (9/8/2019)

2.3 MW LVS Gearbox Design Work

- common turbine gearbox design:
  - 3-stage (one planetary plus two parallel)
  - for a 4-pole DFIG
- main planetary stage internals, front housing and its mounting to the nacelle are all unchanged
- rear housing redesigned with similar split housing to existing design
- gearing inside rear housing is changed to have one parallel stage and one planetary epicyclic stage, with annulus reacted by a radial piston pump
- output shaft is kept in the same alignment with the generator shaft



The Need for System Strength

Definition of System Strength

- Australian Energy Market Operator (2020) defines system strength: *"the ability of the power system to maintain and control the voltage waveform at any given location in the power system, both during steady state operation and following a disturbance. …Synchronous machines are a source of system strength"*.

- Inertia and high "fault current" are involved:
    - Inertia keeps rotors more or less together during short-circuit fault
    - High fault current "muscles" the rotors back into sync immediately afterwards

Analogy with a Formula One Start

- Cars remain more or less together for the first second or so:
  - because their power to weight ratios are similar, like “H” ratio of inertial energy to rated power

- But after that, nasty collisions are possible:
  - avoidance needs powerful, synchronised reaction torques, like those provided by instantaneous high fault currents from sync-gens

Can PECs provide System Strength?

"Virtual inertia"?

- maybe
  (though yet to be done absent any grid reference)

High fault currents?

- **Not** economically

That being the case, asynchronous renewables will increasingly be asked to pay for their "free-ride" on the system strength provided by synchronous generators.

Synchronous Powertrain Benefits

TLG/LVS system enables synchronous generation and broad-band variable speed (VS)

Eliminates PECs

Three main elements are low-cost:

- Small addition to gearbox - low-torque, high-speed stage becomes differential
- Small additional hydraulic system (5% turbine rating)
- Replace generator and PECs with standard synchronous generator/AVR

What is the TLG/LVS?

Mechanical VS System:

- TLG was first invented in 1980s to protect gearbox against torque overloads
  - Eliminates referred generator inertial torque and electrical transients
  - Provides narrow-band VS
  - Enables synchronous generator directly on-line (no PECs)
- LVS was invented in 2010s to provide broad-band VS
  - Prototype running near Edinburgh since 2016
  - Low cut-in wind speed suits class 2-4 sites

What it is <u>not</u>:

- It is not like an automatic transmission in a car
- It does not handle all the power (only 5%)

More specifically:

- It uses hydrostatic torque reaction (efficient and low-cost)
- <u>Not</u> hydrodynamic torque transmission (inefficient, costly)

How Powertrain Costs Reduce

POWERTRAIN COMPONENT	Conventional	TLG/LVS	Notes
Gearbox	60	60	Lighter vs more complex
Generator	20	15	Mass-produced for diesel gen’rs
Hydraulics	10	20	Low cost because only 5% of power
PE Converter, SVC	10	0	Big saving because 100% of power
OVERALL	**100**	**95**	**Lower overall cost**

*** Numbers are estimates of relative cost within turbine build. All other components (tower, rotor etc) unchanged.**

SyncWind's Proposal to the large Wind Turbine Industry

Design synchronous power-train for a multi-MW turbine, ex-factory or wind farm retrofit :

1. Keep first, main stage(s) of existing gearbox
2. Only change the last, high-speed (smallest) stage
3. Add hydraulics for TLG/LVS system
4. Provide software for system control
5. Install standard synchronous generator and AVR
6. Remove the power electronics

Summary of Advantages

1. TLG/LVS enables synchronous generation with broad-band VS and superior protection of gearbox
2. Low cost **based on turbine alone** because hydraulic sub-system is low power (5% of turbine rating)
3. Synchronous generator:
   - avoids major, growing ancillary costs of grid connection
   - is mass-produced for diesel-genset market
   - removes looming obstacle to wind power's continued growth as leader of the renewable transition

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Conclusions

- Synchronous wind power is possible, proven and cost-effective
- It removes a serious obstacle to growth of wind power
- Cost-effective power-train option for OEMs
- Proven reliability – >1000 turbine-years track record, 10% of NZ wind power, most history of any synchronous wind turbine option
- If you're a large turbine OEM, why not be the first mover?