Type 5 Wind Turbine Technology:

how to eliminate inverters and the uncertainties about interoperability under IEEE 2800:2022

Geoff Henderson
SyncWind Power Ltd

Vahan Gevorgian
NREL

Contents

Background: recap of WIW Papers 2017 and 2021

- History dating back to torque limiting gearbox (TLG) invention in 1987, prototype in 1990
- Primary purpose to protect the gearbox, reduce cost
- Synchronous generation enabled by differential stage in TLG
- 32-year track record, >1000 turbine-yrs, full synchronous benefits
- TLG limitation (narrow-band VS) overcome by LVS system
- LVS demonstrated at 0.5 MW scale and designed for multi-MW
- recent focus on system strength vindicates synchronous wind power
- fundamental barriers to inverter based resources (IBRs) providing system strength

IEEE 2800:2022: tries to provide guidance about system stability with IBRs

- Title: “Interconnection and Interoperability of IBRs Interconnecting with Associated Transmission Electric Power Systems”
- Attempts to codify the relationship between IBRs and the Transmission System Operator (TSO)
- Defines ‘system strength’ for its purposes as “*source impedance strength, whereby a ‘weak’ system has a high source impedance relative to the generation connected at that point*”
- But explains that quantification of system strength is problematic
  - E.g. short-circuit ratio is “*the most basic and easily applied metric to determine the relative strength of a power system*”
  - But this (along with other metrics) “*essentially provides no guidance*” as to an IBR’s impact on system stability.

IEEE 2800:2022: IBRs alone cannot guarantee grid stability

- Lacking simple guidance on use of IBRs, IEEE 2800:2022 advises "*more rigorous studies such as electromagnetic transient (EMT) study tools … as a more reliable means to help ensure that the IBR operates as intended*"
- But even then it goes on to state:
  - "*General requirements for IBR to prevent any control interactions with the network are impossible to guarantee by manufacture or developer, since it is originated not in the control, but in the combination of control and rest of the grid*."
- This conclusion about inherent risks of grid instability is in line with the findings of Gevorgian et al in IEEE's March magazine article, which explained in some depth the limitations of IBRs.

IEEE 2800:2022: a driver for Type 5 wind power

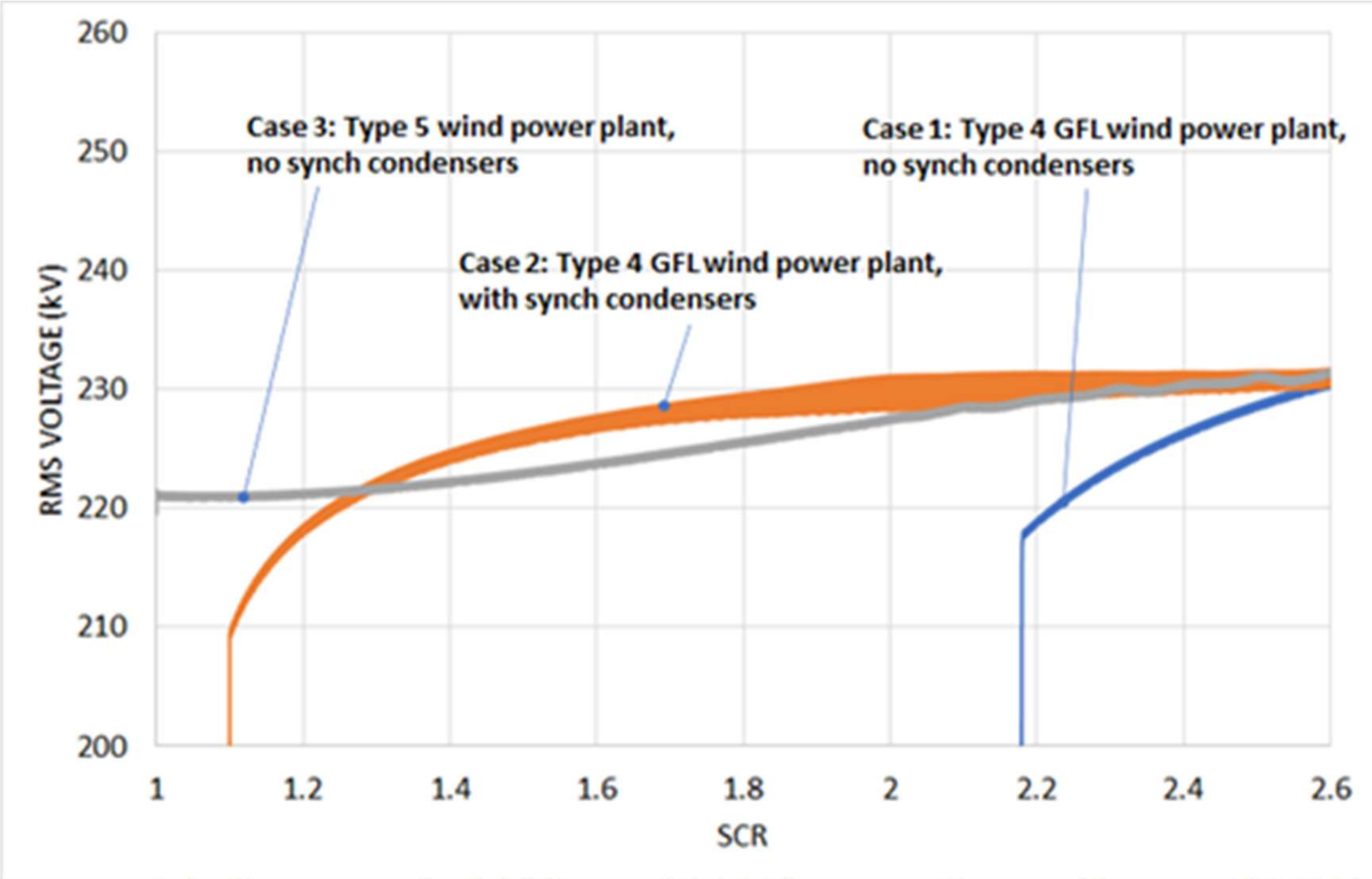
- Lacking guarantees of stability, IEEE 2800:2022 sets out mitigation options for IBRs which range from adding synchronous condensers to being curtailed
- Such mitigation options have been required by the TSO in Australia, causing significant financial pain and planning uncertainty to wind farm developers there
- Thus it is apparent from IEEE 2800:2022 that there remain fundamental problems with quantifying, before an IBR is connected, whether system strength will present a problem for ensuring system stability after that IBR is connected
- Low-cost, Type 5 wind power will provide new solutions to such problems.

NREL review of IBRs

- An NREL-led team authored an article* in the March 2022 IEEE Electrification Magazine explaining limitations of IBRs:
  - Limited overcurrent ability – costly to oversize or add synchronous condensers
  - Complex to determine optimal grid-forming control strategy to avoid instability
  - E.g. “Inertia-like response” is not the same as inertia, relies on controller
- NREL has continued to research Type 3, 4 and 5 turbines, including the GFM and GFL Type 3 and 4 turbines.

* Gevorgian, V., Shah, S., Yan, W. & Henderson, G. –
“Grid-Forming Wind: Getting Ready for Prime Time with or without Inverters”

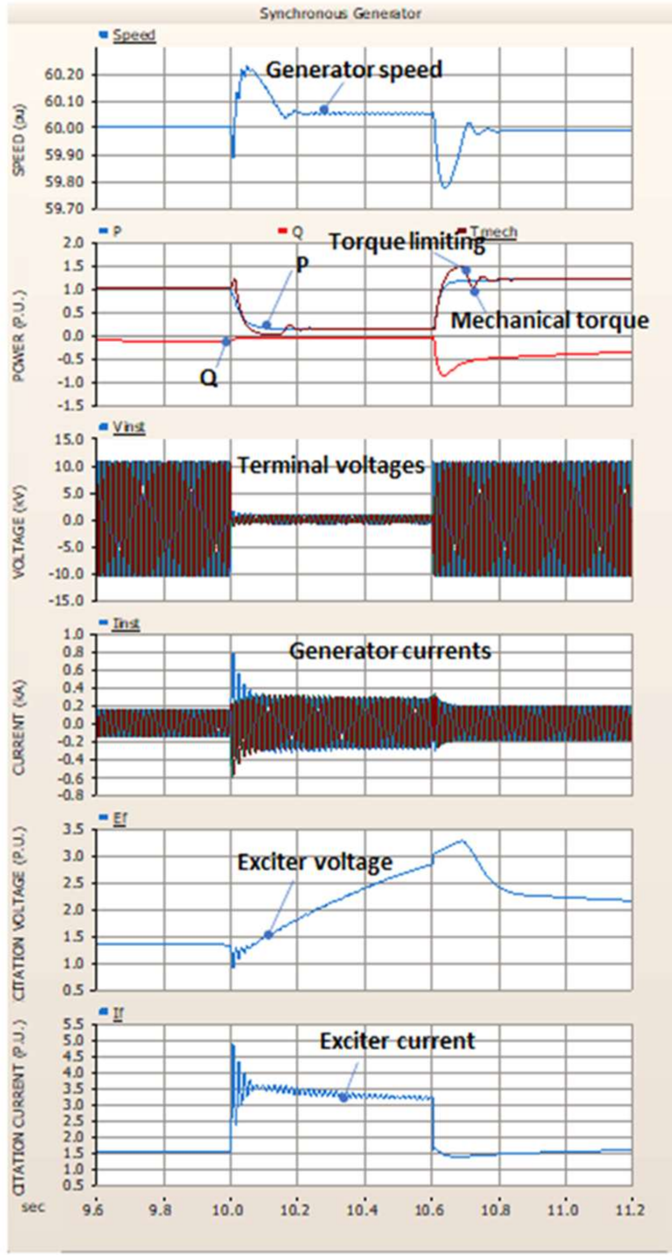
Comparison of Type 4 and 5 systems



Voltage stability at POI as a function of SCR

NREL Type 5 (synchronous) project

- NREL study: examining impacts on grid reliability of Type 5 wind turbines, which offer unique characteristics unmatched by any IBRs
- both simulation and testing tasks
- graph at right shows preliminary LVRT modelling:
  - Type 5 wind turbine with variable torque limitation
  - 3-phase near zero-voltage 600 ms fault
  - generator speed increases initially, arrested by rapid reduction of hydraulic torque reaction
  - Similarly, the torque increase during recovery is contained by the torque limiting system at 1.5 p.u.
  - Significant, helpful levels of short circuit current during the beginning of the fault.



What is Syncwind's synchronous power-train?

Mechanical VS System:

- Enables synchronous generator directly on-line
- **Low cost** because:
  - hydraulic sub-system only handles 5% of turbine power
  - no inverters
  - mass-produced, efficient generator (zero slip)
  - better torque-limitation reduces gearbox factors
  - reduced wind farm electrical connection requirements
- New development ("LVS") provides broad-band VS (hydraulics are still 5% of turbine rating)
- It uses hydrostatic torque reaction (efficient, low-cost)
- Not hydraulic transmission (inefficient, costly)
- Preliminary design for 2.3 MW Type 3 retrofit
- Scalable to 10-20 MW turbines

Prototype LVS turbine near Edinburgh, Scotland

How Type 5 power-train costs < Type 3

POWER-TRAIN COMPONENT	Type 3	Type 5	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.

46 MW Synchronous Wind Farm

- Proven design at high wind New Zealand site
- 15 years operation and still going
- >1000 turbine-years track record
- Type certification
  - IEC 61400-1:2008 (Edition 3)
  - Class 1A

TRH List
06/01/2022 19:37:54
Net Power: 25.33 MW
Net Energy: 1394.38 GWh
Number Available: 89
Number Generating: 88
MeanWindspeed: 12.0 m/s
Wind Dir: SE (143.8 degrees)
High Windspeed (TRH_T072): 18.3 m/s
PSDs: Yes (5). (with RunFlag: 0)
Controller: Pete Darke

Txxx	Run	Status	PSD	Power
T001	ON	AutoGen	PSD:No	515 kW
T002	ON	AutoGen	PSD:No	498 kW
T003	ON	AutoGen	PSD:No	502 kW
T004	ON	AutoGen	PSD:No	511 kW
T005	ON	AutoGen	PSD:No	435 kW
T006	ON	AutoGen	PSD:No	452 kW
T007	ON	AutoGen	PSD:No	378 kW
T008	ON	AutoGen	PSD:No	272 kW

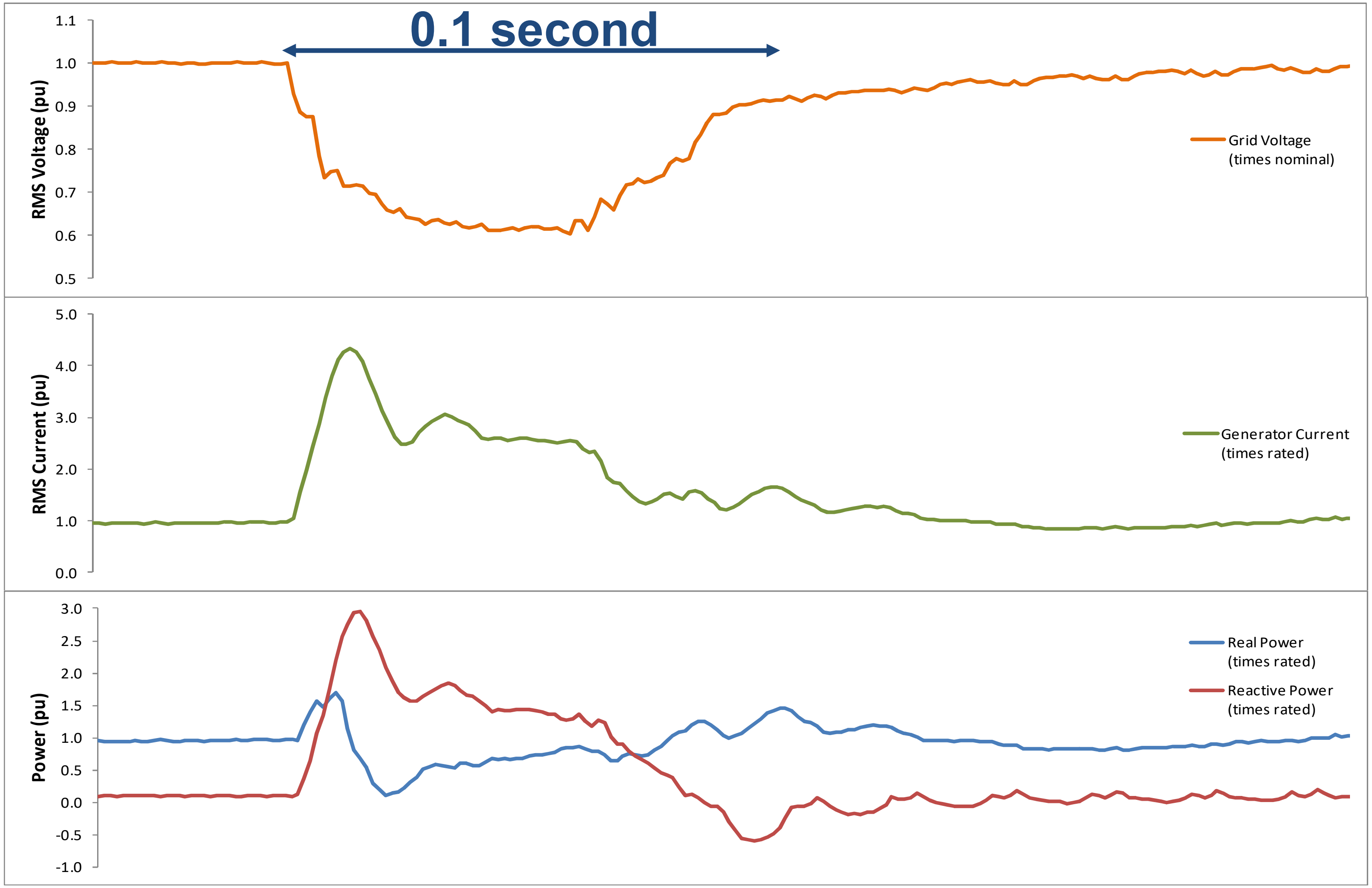
Contributing System Strength during 0.1 s LVRT event in New Zealand, 8 September 2012

GRID VOLTAGE (0.5 to 1.1 pu)

GENERATOR CURRENT (0 to 5 pu),

KW (-1 to 3 pu),

KVAR (-1 to 3 pu)



Conclusions

- Degradation of system strength because of IBRs is a major concern. IEEE 2800:2022 leans towards increasing need for IBRs to add synchronous condensers or be curtailed
- Syncwind's synchronous power-train has been running in a 46 MW wind farm in New Zealand since 2006
- embodies a synchronous condenser in each turbine's generator and eliminates the inverters
- scalable to multi-MW and will cost less than a Type 3 power-train
- NREL is studying Type 5 turbines so as to give new answers to question: "How to transition reliably and economically from the present largely synchronous grid to the future 100% renewable grid?"