TYPE 5 SYNCHRONOUS WIND TURBINES: GRID-FORMING SYSTEM STRENGTH AND THE DIFFERENTIAL THAT MAKES THE DIFFERENCE

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Abstract

System stability for power systems with inverter-based renewables (IBRs) is a topic of much discussion. Experience of recent blackouts has highlighted two key characteristics, in addition to inertia, which are needed to ensure system stability:

- Ability to regulate voltage automatically,
- Ability to provide and tolerate high short-circuit currents during and after a fault.

Experience from the 2025 Spanish blackout has indicated that wind and solar power should contribute more than they historically have to the first characteristic. Type 5 wind turbines driving synchronous generators under automatic voltage regulator (AVR) control and grid-forming IBRs can provide steady-state reactive power for voltage regulation. The reactive power capability depends on the active power being generated, which gives rise to a synergy between wind farms and solar PV, whose active power output is often inversely correlated. The second characteristic is more challenging for IBRs. The paper discusses a mechanical difference between wind turbines and solar PV systems which presents a fundamental barrier to cost-effective implementation of grid-forming IBR wind turbines. By contrast, the proven SyncWind Type 5 wind turbine power-train overcomes that barrier, providing a robust pathway to renewable grid stability.

1 Introduction

Grid strength has diminished due to substitution of synchronous generators with IBRs. The reduced strength has led, or at least contributed, to blackouts. Type 5 wind power, alongside hydro-power, solar thermal, biofueled and geothermal stations, provide system strength through synchronous generators.

The South Australian blackout of 2016 and the Spanish blackout of 2025 are two examples which had very different mixes of IBRs and synchronous generators on-line, and very different root causes. However, in both cases the majority of load was being met by IBRs, and the grid was presented with a sequence of stability challenges which included:

- Voltage fluctuations initially
- Local disconnections followed by some successful and unsuccessful attempts at reclosure
- A final stage of widespread, rapid voltage and frequency collapse.

This sequence of events follows from a hierarchy of characteristics that the system needs to remain stable. In other words:

- Ability to regulate voltage automatically to minimise voltage fluctuations,
- Ability to ride through a voltage fault, providing and tolerating high short-circuit currents during the fault and returning to stable operation after the fault is cleared,
- Provision of physical inertia to slow the rate of change of frequency during a frequency fault, along with primary frequency response (PFR) to help correct the grid frequency.

For the South Australia blackout, some IBR wind farms failed to ride through a series of voltage fluctuations robustly. In Spain, the synchronous generators on the system, and other non-IBR elements, collectively failed to regulate the voltage adequately, highlighting the potential benefits of a greater contribution to voltage regulation by wind farms in particular.

This paper examines the Spanish blackout, using data from the March 2026 Final Report by the ENTSO-E ICS Incident Investigation Expert Panel, to answer how Type 5 wind turbines could potentially have contributed, if they had been present on the grid. The examination is prompted by the observation that, at the time of the blackout, active power from wind farms was much lower than solar PV generation in Spain. A synergy would arise because the reactive power capability of Type 5 wind turbines increases when their real power output falls. Thus, for the conditions of the Spanish blackout, Type 5 wind turbines would have had close to their maximum reactive power capability available for voltage regulation, although it

is well noted that the usefulness of that capability is subject to their location on the grid, and their proximity to the (initial) affected areas.

The paper goes on to discuss and analyse further, related synergies between SyncWind Type 5, wind farms and solar PV power. One issue relates to the ability of solar PV based on grid-forming (GFM) inverters to manage robustly phase jumps (for example, line disconnection followed by attempted reclosure), whereas wind turbines with GFM inverters are less tolerant.

However, SyncWind Type 5 wind turbines are uniquely tolerant of phase jumps due to their built-in differential gearing, and the very low inertia of their torque limiting hardware. The basis for this design was established in the 1980s with the invention by Henderson et al. [1] of the torque-limiting gearbox (TLG) system as a way to control turbine-side torque transients. It was also recognised that this approach would enable the use of a synchronous generator, which would otherwise cause destructive torsional oscillations for a conventional fixed-ratio wind turbine drive-train. Turbine-side or generator-side torque transients will be destructive with such a power-train due to the synchronous generator's zero-slip characteristic, which follows from the same electro-mechanical properties that give it high system strength with short-circuit current capabilities up to 10+ times the rated current.

The TLG system enables the high short-circuit current capability from a synchronous generator to provide system strength during network faults, including significant phase mismatches up to and including pole slip events, without causing proportional torque reactions in the drive-train. The generator structural supports may experience high torque reactions from the electromagnetic effect of these transient currents causing rapid acceleration of the generator rotor. Hold-down bolts and the bedplate structure will typically provide adequate overcapacity for this duty at zero or negligible incremental cost. However, the gearbox will not, and does not need to do so, in the SyncWind power-train, as it cannot transmit the acceleration to the wind turbine. Instead, the low-inertia torque limiting system accelerates transiently with the generator rotor while limiting the torque reaction to the rated setpoint.

As an illustration of the above turbine behaviour, a SyncWind power-train experienced a very severe phase jump event on the Orkney Islands in 2017, which was presented by Henderson [2]. Further recent analysis of that event is presented to illustrate the fundamental robustness that the SyncWind torque-limiting (TL) system provides, as well as the counterfactual problem faced by an IBR wind turbine with a fixed-ratio drive-train.
The latter problem has come to the fore in recent years as GFM inverters have been developed for wind turbines in an attempt to create, for example, virtual synchronous generator (VSG) characteristics. With a fixed-ratio drive-train, the VSG is recreating the fundamental problem that spurred the invention of the TLG system in the 1980s. As Ferry et al [3] have shown, there is a trade-off in GFM IBR wind turbines between grid-support and protection of the wind turbine.

One way to minimise the above trade-off, in order that VSG wind turbines could better support the grid would be to strengthen the drive-train, in particular the gearbox and generator hold-down bolts, in order to accommodate torque transients of (say) 5-10 times rated. However, such modifications to the uptower hardware in a wind turbine would be very heavy and costly.

We submit that the SyncWind system provides a lighter, more cost-effective way for wind turbines to provide the traditional system strength attributes of conventional wound-field synchronous generators and their automatic voltage regulators (AVRs).

2 SyncWind's Torque Limiting Gearbox-Low Variable Speed (TLG-LVS) Type 5 System

The authors have previously presented work on Type 5 wind turbines to this workshop [2] [4] [5] [6] [7]. The 2022 paper by Henderson and Gevorgian [5] included PSCAD simulations comparing the stability of 1 GW of Type 5 turbines to Type 4 grid-following (GFL) IBR turbines with and without synchronous condensers for a range of values of short-circuit ratio (SCR) down to 1.0. The result (summarised in Figure 1 below) was that Type 5 wind power plant demonstrates significantly more stable operation for very low SCRs (without synchronous compensators) than even the case of Type 4 turbines **with** synchronous compensators.

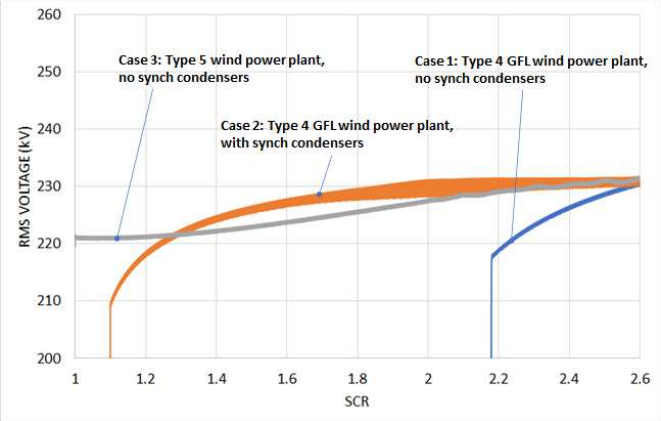


Figure 1 – Comparison of the voltage stability (as a function of SCR) at the point of interconnection for three PSCAD studies of 1 GW wind power plant riding through a 200 ms line-to-ground fault.

This is an important result for the wind industry and the content of this paper, because it highlights the need for wind turbines to have synchronous grid-forming capabilities, not mere GFL. But can VSG meet that requirement cost-effectively?

The 2024 paper the authors presented [6] compared three variants of Type 5 hydraulic variable speed system:

- SyncWind's TLG-LVS system
- Voith's Windrive, and
- Full-hydrostatic drive systems.

They explained that the SyncWind Type 5 power-train is the most cost-effective of these three, because its hydraulics are only rated at 5% of turbine power, giving it a total turbine cost less than that of a Type 3 turbine.

SyncWind's Type 5 system has been running successfully on a 46 MW wind farm in a high wind site in New Zealand for 20 years, accumulating more than 1500 turbine-years track record. Note that the three shafts of its differential stage (turbine input plus outputs to the generator and TL pump) provide a second degree of rotational freedom. This ensures that destructive torque transients cannot occur, just as a car differential protects the drive-train from harmful transients when wheel loading is asymmetric.

Furthermore it must be stressed that, when torque limiting, torque is kept constant on all three gearbox shafts by the principle of equal and opposite reactions (Newton's 3rd Law). So the power to the constant-speed generator remains constant, while power varies on the turbine and TL pump shafts as their speeds vary. The torque throughout the gearbox stays remarkably constant for two reasons:

- the radial piston pump (patented by Poclain in the 1980s) dispenses with traditional conrods and crankshaft, and achieves 48-cylinder smoothness from its 8-lobed cam and 6 roller-piston arrangement;
- the pump has very low inertia, of the order of 1/1000th that of the generator, 1/10,000th that of the turbine. Together with the spool of the relief valve weighing only grams, this enables negligible inertial resistance to changes in turbine or generator speed. Hence, the gearbox does not have to transmit the generator inertial term during turbine-side transients, nor the turbine inertial term during generator-side transients.

This last point minimises the gearbox's application factor and thus weight and cost. It also means that the system's synchronous inertia is limited to that associated with the generator rotor, so it is small but (unlike IBRs) non-zero. However, the turbine's considerable inertia can generally be accessed as a form of fast frequency response (FFR). By adding a controllable relief valve to the circuit, the TLG system can rigorously provide short-term FFR for both over-frequency and under-frequency events. In the case of under-frequency events an additional short-term boost of torque/power of (say) 20% or more above rated could also be provided, subject to meeting gearbox life design criteria. See also Henderson [7] for considerable further details about the SyncWind TLG and LVS sub-systems, including schematics, empirical data and control system descriptions.

In summary, the TLG system has been running on over 100 synchronous Windflow 500 turbines, accumulating more than 1500 turbine-years of track record that is ongoing at high wind sites in New Zealand (a 46 MW wind farm) since 2006 and Scotland since 2013 (several individual turbines). The patented LVS system, which has been demonstrated on a prototype in Scotland, adds the important feature of broad-band variable speed (VS) while keeping the hydraulic system rated at 5% of turbine rated power.

3 Slow Voltage Stabilisation: Steady-State Reactive Power (SSRP)

Some illustrative experiences of the SyncWind system's ability to regulate voltage at distribution level (11 kV) were set out by Henderson [2]:

- 550 kVAr steady-state export from the prototype Windflow 500 kW turbine for 11 kV voltage support (Christchurch, NZ). This was enabled even under calm wind conditions, with the turbine stationary and the generator online as a synchronous compensator;
- 1500 kVar steady-state import for voltage control when the first five Windflow 500s at Te Rere Hau wind farm (Manawatu Saddle, NZ) were required to be derated to 200 kW each (1000 kW total) for two years, because the initial 11 kV connection was weaker than expected;

Blackouts, such as the one in Iberia on 28 April, 2025, highlight the need for steady-state (and dynamic) reactive power capability. The final ENTSO-E report confirmed the initial assessments that voltage stability was a key issue [8]. The initial response of the system operator was "procuring greater volumes of gas-fired generation and reducing anticipated real-time output from wind and solar resources" according to Davi-Arderius and Graf [9].

Figure 2 is taken from Figure 2-86 of the final ENTSO-E report [8] and shows the reactive power provided by conventional generation units larger than 100 MW in the east/north-east area of Spain in the 3 hours leading up to the blackout, as compared to the reactive power requested from them. In general, the requested reactive power was not provided, with deficits of up to 400 MVAr in cases of both positive and negative VAr being requested.

The report also contains similar graphs for the centre/south-west and north/north-west areas of Spain. The latter shows requested VAr being generally met, albeit for lower levels (< 400 MVAr) being requested. The centre/south-west picture is similar to Figure 2, although with lower levels being requested. When positive VAr was requested for the centre/south-west, they were less than 400 MVAr and the volume supplied corresponded well to that requested. However, when negative VAr (again <400 MVAr) was requested (to reduce the voltage), the amounts drawn were in deficit, typically by ≈200 MVAr. Elsewhere in the report the evolution of the voltage during the morning is shown, with the comment that the "first significant variations of the voltage" began at 10:30 am, two hours before the blackout.

In summary, the voltage was varying up and down during the morning, with the requested VAr not being supplied/drawn, and with deficits often in the range 400-600 MVAr from the north-east to the south-west of Spain. As a result of the asymmetric response of the reactive power providers in the centre/south-west, the voltage also tended upwards during the morning so that from 10:30 am onwards, the voltage was frequently exceeding the normal operating maximum of 420 kV.

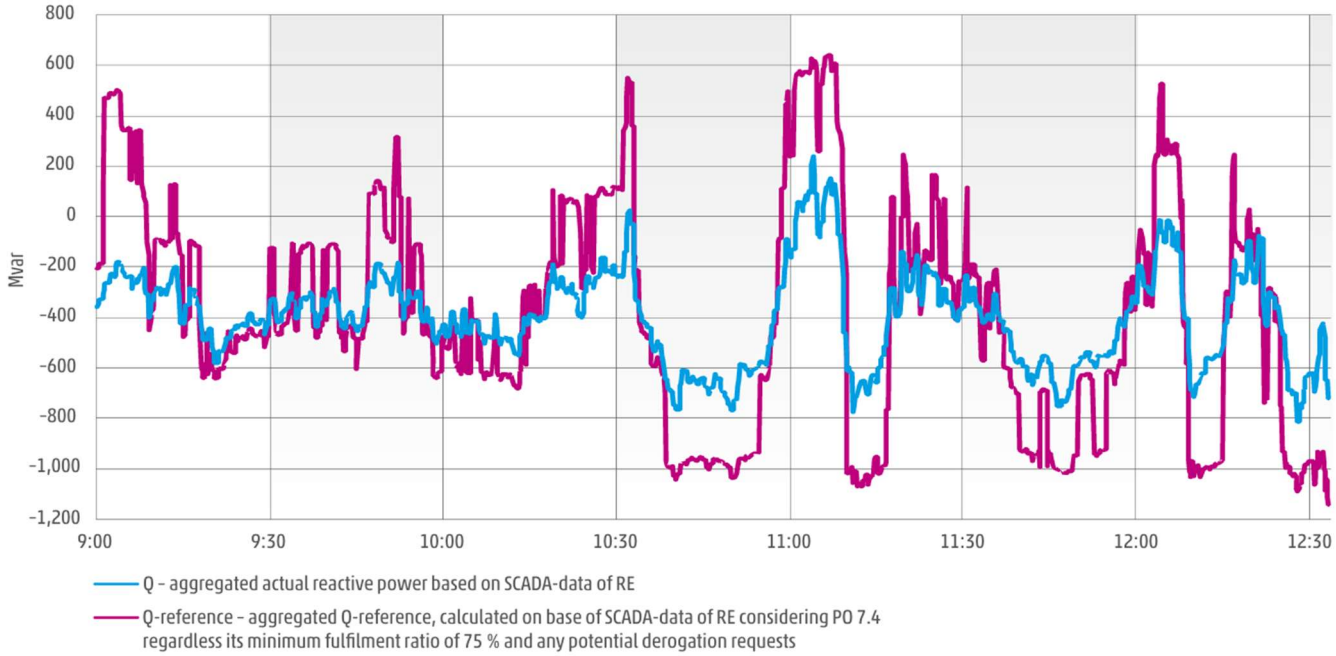


Figure 2 (taken from Figure 2-86 of the final ENTSO-E report [8]) - Reactive power provided by conventional generation units larger than 100 MW in the east/north-east area of Spain in the hours leading up to the blackout, 28 April 2025 (blue line), compared to the reactive power requested from them (purple line).

This left little margin, relative to the absolute maximum 435 kV level, which was breached around 12:30 pm, triggering generators to isolate, leading to the blackout.

From the root cause tree analysis, Figure 1-15 of the final ENTSO-E report, it is notable that two of the initiating causes numbered '1' and thus assigned primary importance are:

> "The reactive power framework for conventional generators did not provide for explicit criteria concerning dynamic behaviour and there were no economic consequence if the requirements regarding voltage control were not met"; and
>
> "RES power plants follow fixed power factor" (0.98 leading to 0.98 lagging).

So what could Type 5 wind turbines, or indeed any wind turbines with controllable reactive power, have contributed to avert that situation?

The installed capacity of wind power in Spain was ≈32 GW in April 2025, compared to solar PV at about 40 GW. On 28 April, 2025, the output from wind farms was quite low at ≈3 GW compared to 17 GW from solar installations of >1 MW. With weather conditions apparently sunny with light breezes, there would have been ample reactive capability from wind turbines with controllable reactive power, assuming that the wind farms were located in areas suffering voltage problems. Some simple calculations illustrate the potential:

- Assuming export VAr capacity up to 100% of rating, 3 GW of real power from a fleet of 32 GVA implies more than 31.8 GVAr of export capacity when the system was in deficit by typically 0.4 GVAr.
- Assuming import VAr capacity of 40% of rating (based on experience with the SyncWind system) implies 12.8 GVAr of import capacity when the system was in deficit by typically 0.6 GVAr.

Thus, it would have been quite achievable for wind turbines with controllable reactive power to provide the services being requested on that day, while also recognising that the location of those turbines is extremely relevant here. These comments are based on experience with the SyncWind system and its remotely controllable AVR, capable of operating in voltage, VAr or power factor control modes.

Conversely there could be occasions (such as a windy night) when wind farms are outputting maximum real power, but solar PV is off, and so should be able to provide reactive power control, if suitably incentivised or required to do so.

If Type 4 IBR wind turbines and solar PV are capable of reactive power control, it is notable that they have not been used in this role. In fact, Figure 2-88 of the final ENTSO-E report [8] indicates that another 400 MVAr could have been drawn to reduce voltage levels if the wind farms had been operating at 0.98 power factor (importing VAr) instead of close to 0.99. However, section 9 of that final report makes no recommendation about specifically integrating them for that purpose.

It should be noted that the modern AVRs of SyncWind's system provide a capable remote interface to facilitate such a role from Type 5 wind turbines.

4 Fast Voltage Stabilisation: Dynamic Reactive Response (DRR) with high fault current

The short-circuit current (or "fault current") capacity of synchronous machines is a powerful voltage stabiliser because the stator windings of synchronous generators (or compensators) in an AC grid are electro-magnetically coupled to each other across large geographic distances. This enables them to respond to system voltage and frequency changes, and holds the inertial energy of their rotors together, at sub-millisecond timescales. Figure 3 shows an example of SyncWind's system at Te Rere Hau wind farm in New Zealand providing instantaneous fault current to counter a voltage fault.

It is this immediate fault current capacity of synchronous machines which is irreplaceable for system stability, more so than the inertia. For example, IEEE 2800:2022 [10] states that adding synchronous compensators is "presently the primary solution for adding system strength because of multifaceted benefits including large capability to supply fault current, inertia and voltage support capability". ABB [11] reports that "After decades out of favour, utilities and industrial operators around the world have started to place major orders for synchronous condensers to address grid stability issues associated with the increased penetration of renewables".

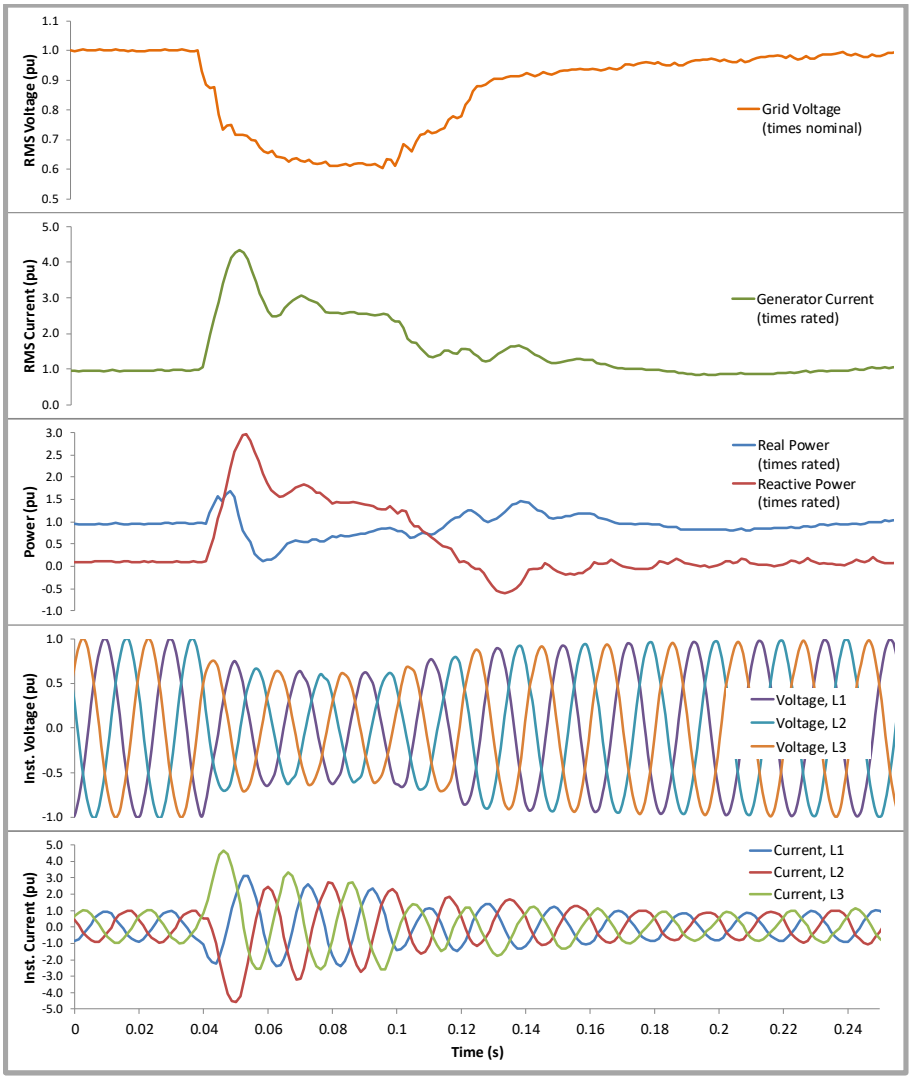


Figure 3 - Fault response of Windflow 500 synchronous wind turbine during voltage sag event, 8 September 2012, at the 48 MW Te Rere Hau wind farm, New Zealand. This shows an example of short-circuit current contribution and ride-through of a Windflow synchronous turbine during a system voltage disturbance that lasted ≈100 ms. Note in particular:

- the red trace in the third pane, which shows reactive power immediately being exported to oppose the dip in voltage. This is initially ≈0 kVAr but shoots up to 3 times rated before settling as the voltage recovers;
- the turbine remains online and the output power (blue trace in the third pane) returns to pre-fault levels shortly afterward;
- the peak current on one phase (green trace in the fifth pane) is nearly five times the rated current (it was at rated before the disturbance) and that this peak precedes the maximum voltage dip.

5 Bypassing the Phase Jump Barrier

5.1 What is the Phase Jump Barrier?

With a fixed-ratio drive-train, as Ferry et al. [3] have shown, there is a trade-off for GFM IBR wind turbines between grid-support and protection of the wind turbine. As stated in their analysis of 10° phase jumps (one of several types of generator-side torque transient), "total suppression of the active power jump [is] only feasible by breaking with the GFM-principle" through current-limiting software. Otherwise "severe impact on [the] WTG-system may be expected".

The problem arises because the phase angle mismatch between the generator- and network-sides of GFM inverters causes a torsional impulse on the generator, similar to what would occur with a synchronous generator. With a fixed-ratio drive-train, this also reaches the turbine through the gearbox, causing significant torsional overloads due to the significant inertia of the turbine.

To avoid this behaviour, the GFM controls impose current limits, which compromise the grid-support. In order to minimise the above trade-off, so that VSG wind turbines can better support the grid, the drive-train needs to be strengthened, in particular the gearbox and generator hold-down bolts, in order to accommodate torque transients of (say) 5-10 times rated. Such modifications to the uptower hardware in a wind turbine would be very heavy and costly.

5.2 How SyncWind system bypasses the Phase Jump Barrier

While the SyncWind system's synchronous generator rotor experiences torsional impulses during phase jumps and other generator-side transients, the torque reactions (and hence currents) are substantially reduced because the generator rotor is the only significant inertia involved. The differential stage and the very light TL pump of the SyncWind system perform the same function as the differential in a car, providing a second degree of rotational freedom to protect the main drive-train from overloading its larger torsional resistance.

By way of illustration, it should be noted that every time the SyncWind system synchronises with the grid, there can be a phase jump of up to 10°, which is the tolerance for phase mismatch on the auto-sync unit. In the 1500 turbine-year track record of the SyncWind system, millions of auto-sync closures have occurred. Every time, there has been no measurable current inrush, as the TL pump can easily be jolted a little to eliminate the torsional mismatch.

5.3 Experience of a Severe Phase Jump/Pole-slip Event

Only once in the track record of the SyncWind system has there been a notable "phase jump" event. This was more akin to a pole-slip on a Windflow 500 installed on the Orkney Islands in Scotland after an islanding event in 2017 on a 33 kV network, which lasted 300-500 ms, as reported by Henderson [2]. Phase jumps occurred at ≈11.1 s (loss of grid) and 11.4 s (reclosure) in the following graphs. The actual phase angle mismatch is indeterminate, but it is thought to have been considerable. The Windflow synchronous generators were accelerated by 10 MW of islanded GFL Type 4 turbines, then decelerated by the collapsing frequency on the 33 kV system. This provided experience of the benefit of the TLG in protecting the drive-train (generator and gearbox) from torsional shocks for such electrical fault events, while sustaining only low-cost damage to the TL pump itself.

Henderson [2] presented several field experiences, with the 2017 Orkney event being the most recent. Figure 4 from that paper presented the only frequency data available at the time, which was reported by the SEL relays of one of the affected turbines. That reported frequency showed steps every 100 ms, which were not possible to interpret in detail, other than to indicate that large frequency swings had occurred. The most likely explanation for this is that the GFL inverters of the larger Type 4 turbines (which were islanded along with two Windflow 0.5 MW turbines in this event) created a major swing upward, followed by a large correction downward after reclosure.

Since then, the event has been re-analysed using voltage data from the SEL relay, which logged the event at 800 Hz (1.25 ms time step). Using a zero crossing algorithm, it has been possible to create a realistic graph of what was happening to the frequency and hence the rotor speed of the Windflow generators (Figures 4 and 5).

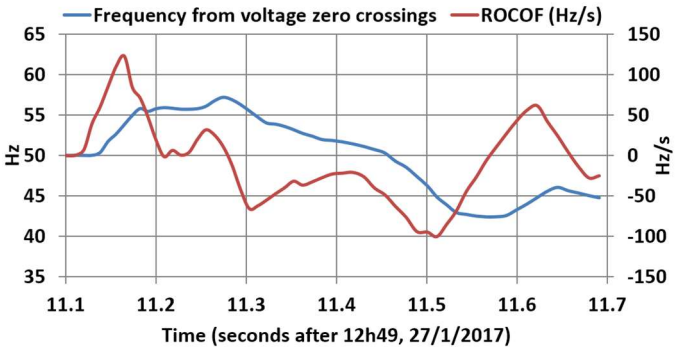


Figure 4 – Islanding event: calculated frequency and ROCOF

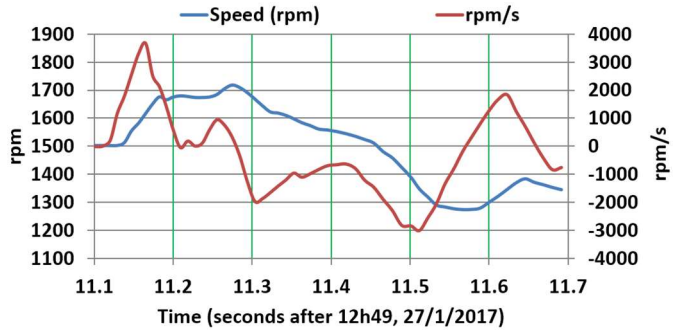


Figure 5 – Islanding event: generator speed and acceleration

From this, knowing the inertia of the generator rotor, it was possible to calculate the inertial torque that was experienced by the generator, and, therefore, by its hold-down bolts. Figure 6 presents this as a percentage of rated, as well as absolute values. The impulsive torques were non-trivial, but only of the same order as the generator rated torque, and, therefore, not damaging to the turbines.

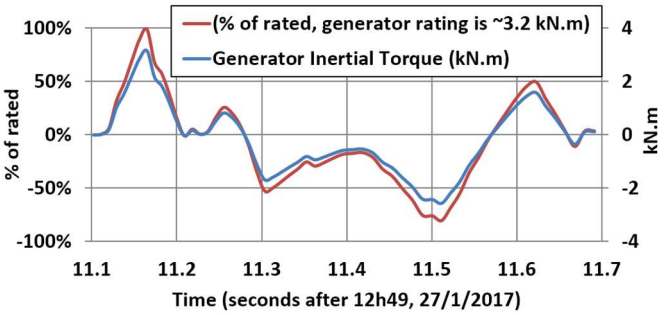


Figure 6 – Islanding event: generator inertial torque

Figure 7 shows that the speeds and accelerations of the TL pump were significant, while the turbine speed remained steady, due to its inertia and the short timescales. Given that the TL pump's rated speed is less than 400 rpm, it is not surprising that one of the TL pumps suffered damage as a result of this event.

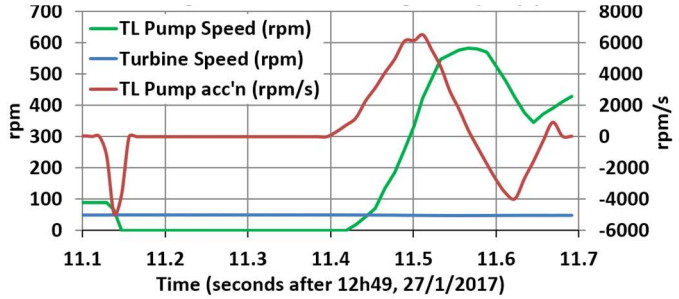


Figure 7 – Islanding event: TL pump speed and acceleration (one-way clutch on generator shaft prevents generator accelerating the turbine or reversing the TL pump)

On the other hand, Figure 8 shows that 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.

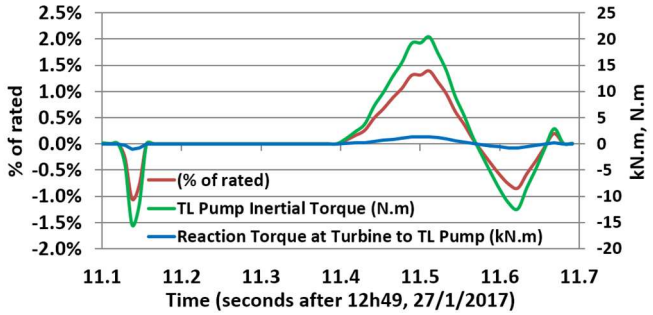


Figure 8 – Islanding event: TL pump inertial torque on turbine (gear ratio 70:1)

Hence, despite the large and rapid accelerations experienced by the generator, there was no damage to the generator hold-down bolts, nor to the main gearbox as a result of this event. Of the two Windflow turbines on this particular 33 kV circuit in the Orkneys, one was able to resume operation as soon as power was restored (there being a 15 minute outage when power was cut within seconds of this event). The other Windflow turbine experienced damage to the TL pump, which clearly acted as a sacrificial element in this unusual and unprecedented event. As the TL pump is a regular maintenance item, able to be readily replaced uptower, and with a scheduled refurbishment period of 3-5 years (i.e. not a 20-year component), this event has vindicated the value of the minimalist TL system design as a cost-effective protection for the main drive-train components.

In contrast, Figure 9 estimates 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. In the case of the gearbox torque transient, this is 800 times higher than that experienced by the SyncWind system that day.

Such overloads would be seriously damaging to the gearbox, and, hence, there is the need for current limitation of GFM inverters in wind turbines.

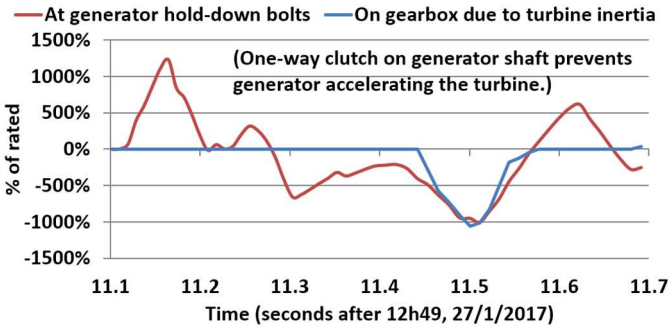


Figure 9 – Counterfactual to TL event: major inertial torques (without differential and TL system)

It is important to note that:

- the counterfactual presented in Figure 9 is not intended to represent any real-world event or scenario. In particular it is not intended to represent what happened to the 10 MW of GFL Type 4 turbines which were on the same islanded 33 kW network. The operators of that project did not share any information in this respect, but local reports indicated that those turbines were shut down for an extended period following this event,
- the purpose of the counterfactual is simply to illustrate why a fixed-ratio synchronous power-train, or its VSG equivalent, would not have survived without major damage the event that the SyncWind system was able to survive,
- the contrast provided by Figure 8 is important, showing how the differential and low-inertia TL system provide a second degree of freedom to protect the gearbox,
- the limitation on current (needed to protect a VSG system from failure) compromises the GFM principle, including both the ability to handle the real power spikes and provide reactive over-currents for system strength,
- analogous compromises do not occur with the SyncWind system. Real power/torque spikes occur, but they are minor because only the generator inertia is involved. Reactive currents many times rated are not limited, and provide conventional system strength, because they do not cause

real power/torque spikes, and there are no sensitive inverters to overload.

Thus, the new analysis of this event has illustrated how SyncWind's differential gearing and low-inertia torque limiting fundamentally eliminate all inertial torque reactions associated with turbine-side and generator-side transients, resulting in a lighter gearbox. Occasionally, the result of frequent or extreme generator-side transients can be that the TL pump/motor acts as a "sacrificial element". However, this is a deliberate strategy for cost optimisation as its failure-mode is benign. It is relatively inexpensive to replace uptower, and it can be refurbished for 5-year scheduled maintenance.

6 Conclusion

The large contribution of wind power in Spain would, if capable of voltage regulation, have reinforced the reduced number of synchronous generators on the system to achieve the voltage control which was lacking on 28 April, 2025. This comment applies to Type 5 wind turbines (which can be configured to act as synchronous compensators even while the turbines are parked) and equally to IBR wind farms, assuming their voltage control capabilities are approved by grid operators to work alongside synchronous generators with AVRs. The converse situation would apply on a windy night if solar PV inverters were able to export or import their rated reactive power.

The mechanical engineering implications of wind turbines as large rotating machines create a fundamental difference between them and solar PV systems, as regards the fault tolerance of GFM inverters. This presents a significant barrier to the cost-effective implementation of GFM IBR wind turbines. That barrier which does not exist for solar PV, nor for the SyncWind Type 5 wind turbine power-train, which bypasses that barrier due to its differential gearing and low-inertia TL system, giving an 800-fold reduction in gearbox torque in certain transient events. Consequently, SyncWind Type 5 wind turbines can operate synergistically with GFM IBR solar PV, and they can provide a robust, cost-effective pathway to synchronous compensation and grid stability.

This is a significant, fundamental advantage of the SyncWind system relative to GFM inverters. We submit that the pursuit of GFM inverters for wind turbines, in the hope that they will provide reliable system strength without massive strengthening of the drive-train, is like designing a car with one motor and no differential. It will only work if the car always drives in a straight line on perfectly smooth tarmac with no bumps!

We submit that the SyncWind system provides a lighter, more cost-effective way for wind turbines to provide the traditional system strength attributes of conventional wound-field synchronous generators and their AVRs.

7 References

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