

PROVIDING GRID-FORMING FUNCTIONS WITH WIND TURBINE GENERATORS

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Vestas Wind Systems

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Annual general meeting and members' meeting for CIGREs Danish members September 23rd 2026

Outline

Providing grid-forming functions with wind turbine generators

01 **European Requirements and Key Grid Forming Functions**

02 **WPP GFM Control Concept Utilizing WTGs without Additional Storage**

03 **Simulation Results**

04 **Experimental Results**

05 **Conclusion**

Classification: Public

Requirements → Control concept → Verification → Conclusions

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European Requirements and Key Grid Forming Functions

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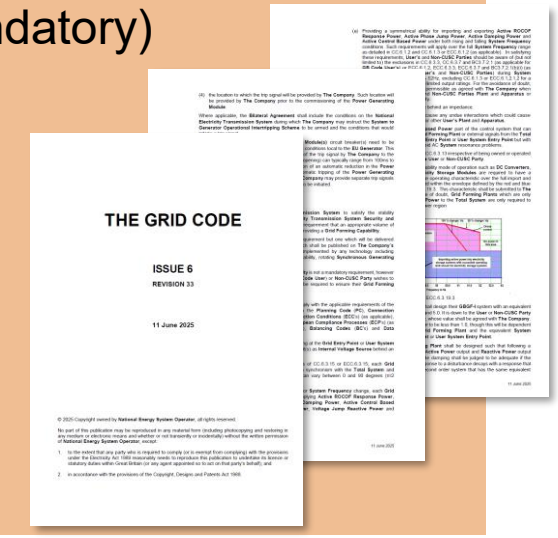
Selected European Requirements with Connection to GFM

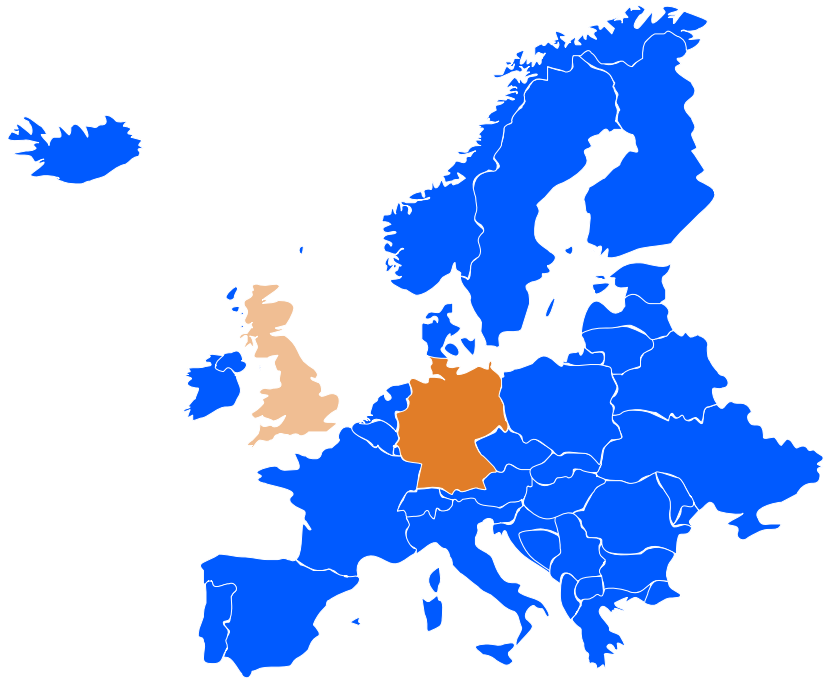
Part of an evolving requirements landscape

UK

GB Grid Code

GBGF-I: Power Park Module with GFM capability (non-mandatory)

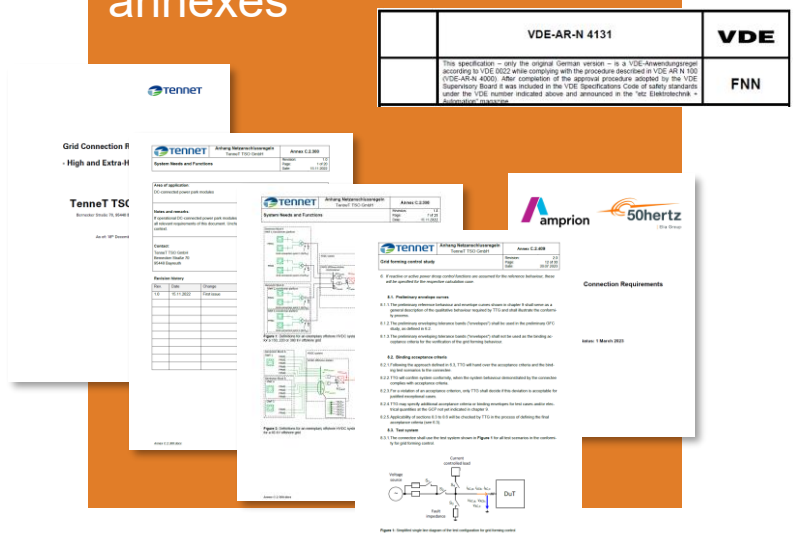




Germany, HVDC-connected plants

VDE AR-N 4131 HVDC network code*

TSO connection rules and annexes



*Some GFM-related requirements are “additional requirements”, requiring operator consent

Classification: Public

From technical guidance to harmonised grid-forming standards

European implementation and international standardisation are progressing in parallel

EUROPEAN IMPLEMENTATION PATH

Draft NC RfG 2.0

Non-exhaustive legal requirements

ENTSO-E Phase II report

Technical Group with CENELEC, EASE, EU DSO Entity, SolarPower Europe and WindEurope

ENTSO-E IGD

Implementation guidance after adoption of final NC RfG 2.0

CENELEC EN

Functional requirements proposed in CLC/TC 8X/WG 03

National implementation

Grid codes, conformity assessment and certification

INTERNATIONAL HARMONISATION PATH

Global inputs monitored

ENTSO-E RfG / IGD • CIGRE • NERC • AEMO • NESO • VDE

Alignment objective: common capability and performance framework

IEC + IEEE dual-logo project

IEC TC 8 / SC 8A / JWG 5 + IEEE 2800-series GFM task force

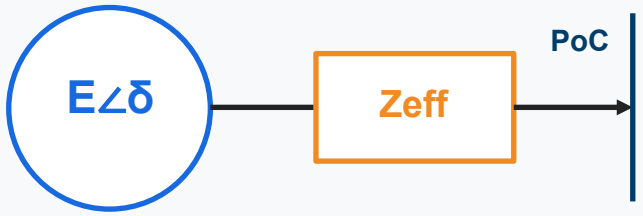
Framework for capability and performance of grid-forming functions provided by inverter-based resource equipment

Classification: Public

ENTSO-E Phase II: proposed grid-forming technical framework

The requirements are based on a simplified representation of the converter. The real application is more complex.
Wind Europe has delivered some concerns about the feasibility of this.

Core concept: voltage source behind impedance



Natural current response to ΔV, Δθ and Δf

The internal voltage characteristics remain effectively unchanged over the initial disturbance response, so current is determined by the voltage difference and effective impedance.

Performance is bounded by current, energy and equipment capability limits.

01 Voltage-source behaviour

Fast active and reactive current or power response to voltage-angle and voltage-magnitude changes; effective impedance limits shape the response.

02 Synthetic inertia

Active-power exchange linked to frequency dynamics, defined within available energy and power capability and assessed at the PoC.

03 Current capability limit

Stable, continuous operation at the current limit and stable recovery when the limitation is released; active and reactive response must be limited preserving the ratio between active and reactive current.

04 Damping and interactions

Adequate damping and stable interaction with the network and other controllers, including recovery after disturbances and capability-limit operation.

Compliance evidence proposed in the report

Voltage-angle steps • voltage-magnitude steps • RoCoF events • loss of last synchronous generator • current-limit and interaction tests

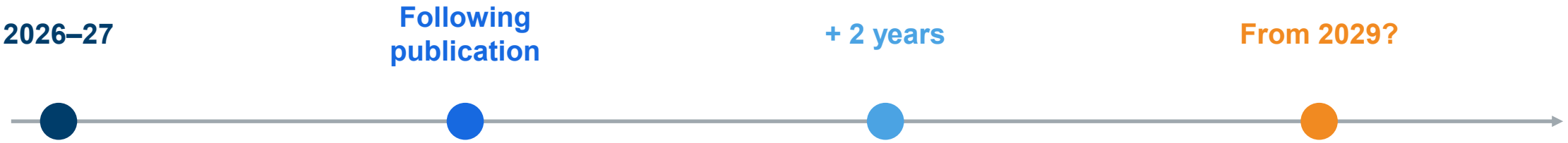
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European RfG 2.0: Grid-forming requirements may apply from 2029

Current proposal and indicative implementation pathway

The time-line of 2029 does not seem realistic given that none of the national implementations have been published yet.



EU adoption

NC RfG 2.0 publication expected window

Implementation

European and national implementation activities

Application

Current proposal links GFM application to publication of RfG

Possible trigger

New connections may require GFM-capable generating units

What this means for the sector

Connection date matters

The present proposal links applicability to grid connection rather than contract signature.

Unit-level capability

The current interpretation requires capability from the generating units, not only a plant-level add-on.

Standards must follow

Detailed national rules, conformity assessment and certification pathways still need alignment.

Classification: Public



WPP GFM Control Concept
Utilizing WTGs without Additional Storage

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Impressions from CIGRE 2026: Grid-forming wind

The wider converter industry is moving from concepts to applications. Grid forming wind is complex because of link to mechanical systems

GRID-FORMING AT CIGRE 2026

CONCEPTS → **APPLICATION & EXPERIENCE, VERIFICATION**

BESS • STATCOM • HVDC

Focus on implementations, operational experience, testing and system integration rather than debating the basic concept.

Why wind is different



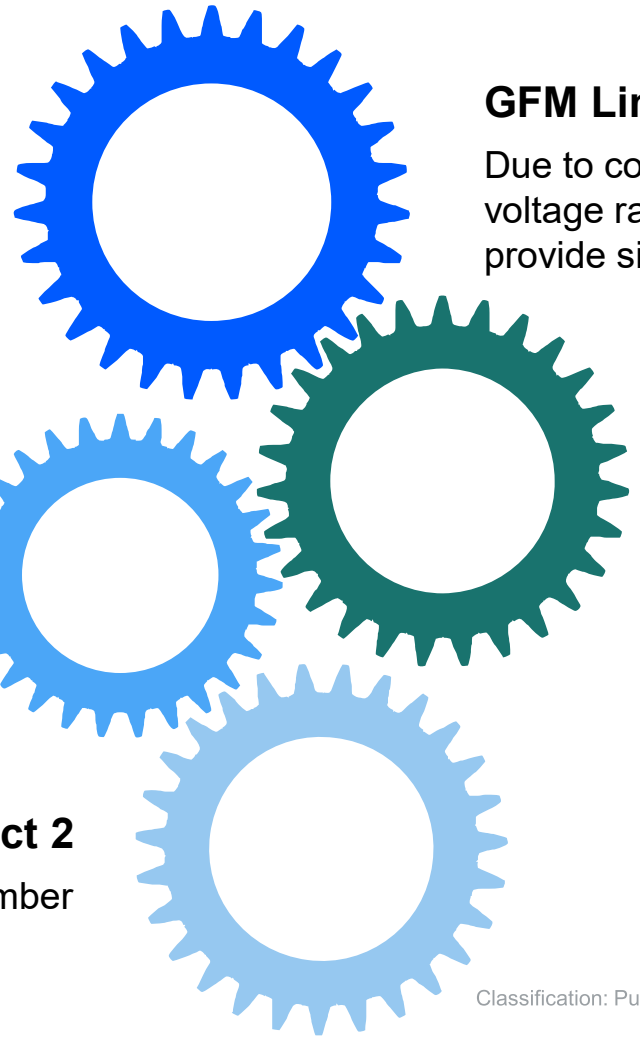
Like an HVDC pole regulating DC-link voltage, a wind turbine cannot create sustained active power independently. Grid-forming support is bounded by converter current, DC-link energy and mechanical-load constraints.

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Grid Forming (GFM) & Wind Turbine (WTG) Loads

Propagation through the WTG Components

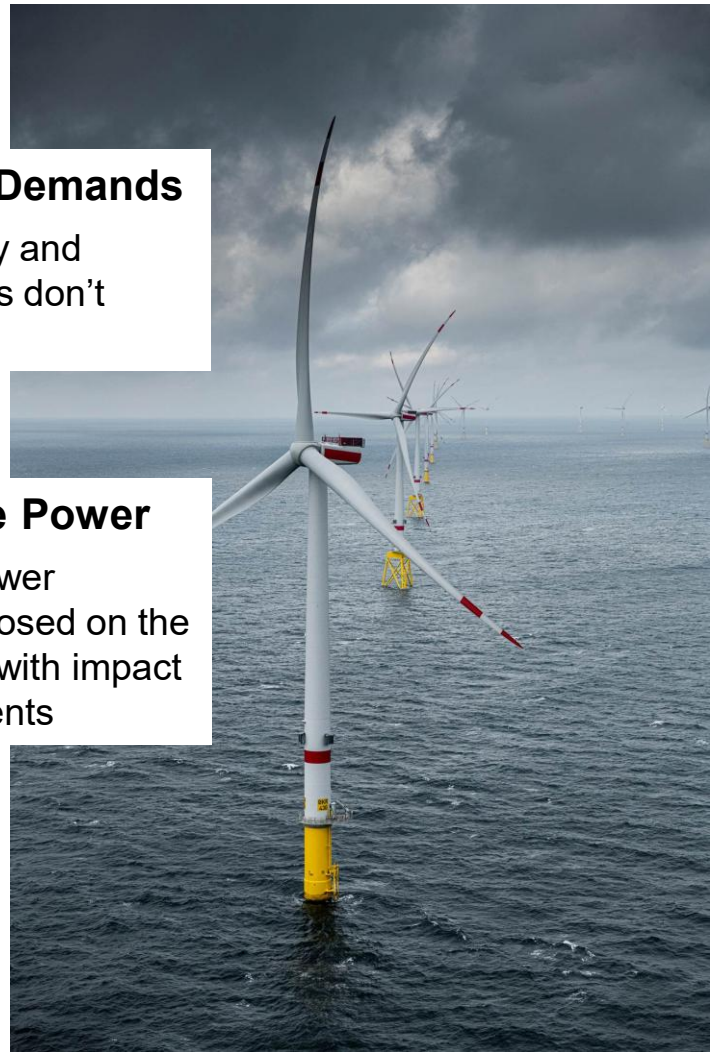


GFM Line-Side Active Power Demands

Due to constraints on DC link energy and voltage range, the DC-link capacitors don't provide significant inertia power.

Machine-side Active Power

Consequently, active power commands must be imposed on the machine side converter with impact on mechanical components



Potential Impact 1

Extreme mech. And elec. loading during high active power transients & oscillations drive component rating or derating

Potential Impact 2

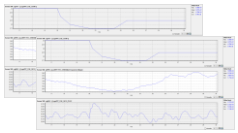
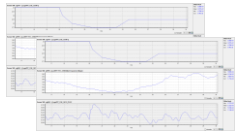
Fatigue loads from large number of events over WTG lifetime drive rating

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GFM Development

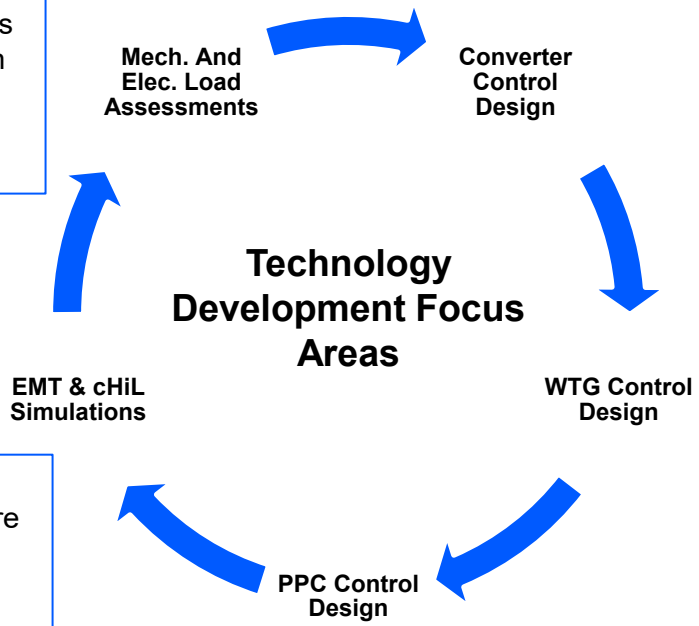
Concept, Technology, Product

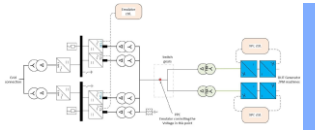
- ~11000 time series across all operating points and grid conditions
- Fatigue load assessment based on mission profile
- Extreme load assessment incl. for severe system contingencies

- 300 test cases in cHiL setup
- Verification on real control hardware
- > 400 test cases in PSCAD across all relevant grid dynamic events
- Plant-level control coordination






Full-scale Converter Test

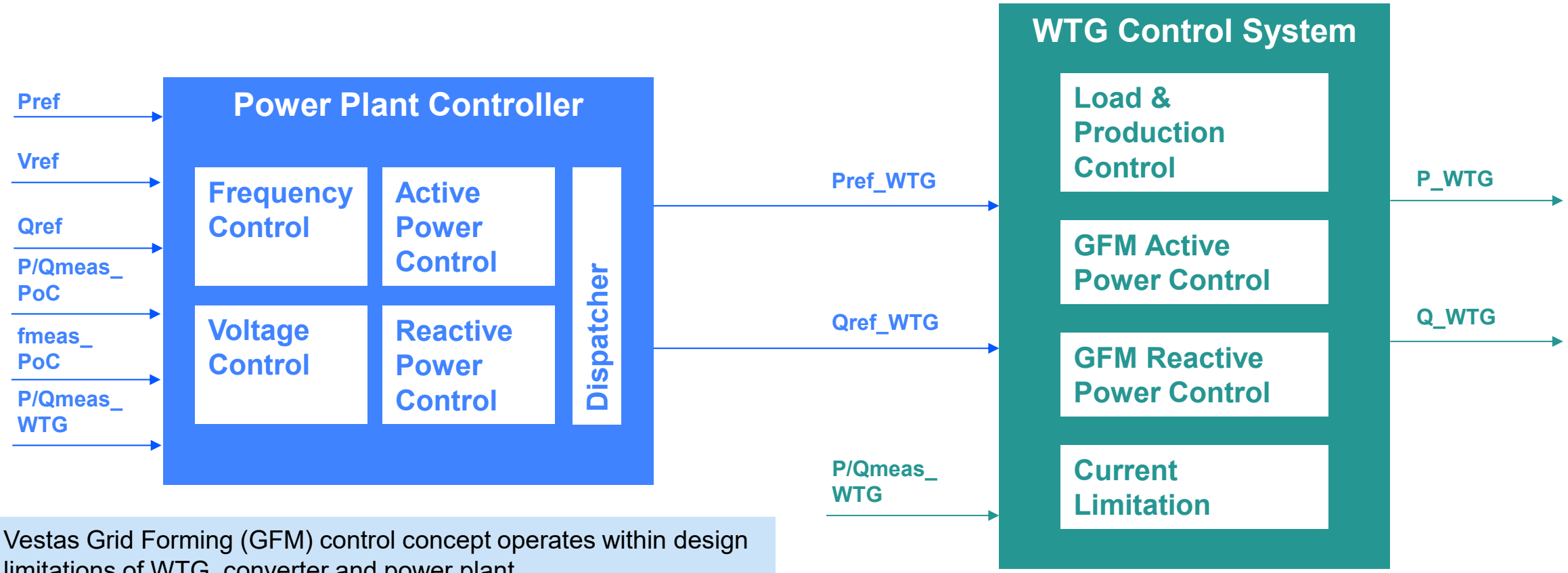
- Design verification on full-scale converter test rig (15 MW)
- Grid emulator capable of frequency and voltage dynamic event emulation
- Emulation of WTG mechanics with full control hardware in the loop
- ~500 test cases




Classification: Public

Vestas Grid Forming Control Concept

Functional Overview / Design Constraints



Vestas Grid Forming (GFM) control concept operates within design limitations of WTG, converter and power plant

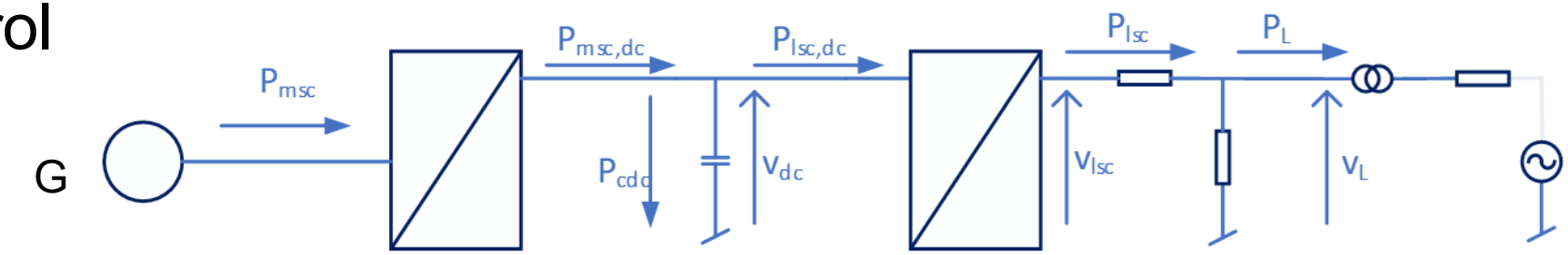
- No WTG storage
- No power plant storage
- Dynamic limitations -> constraints during dynamic events

assification: Public

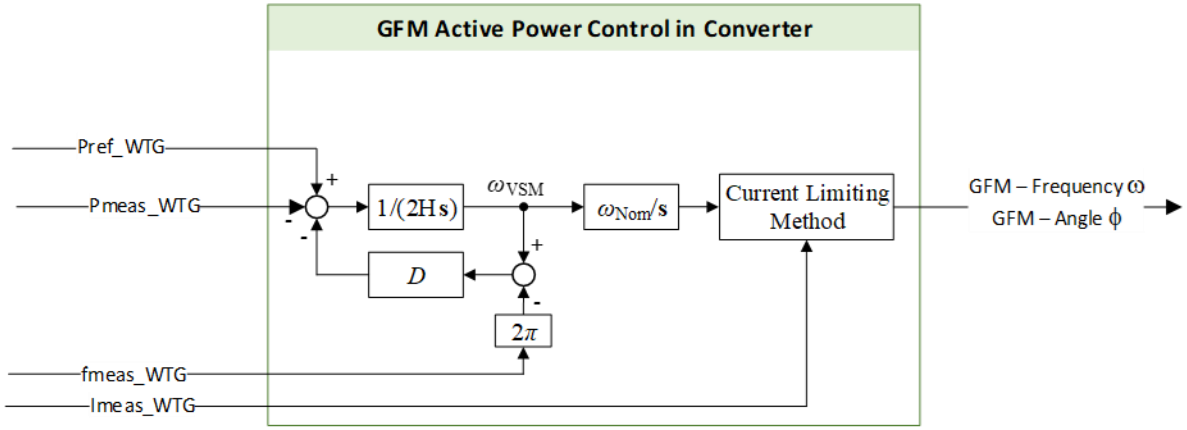
Vestas

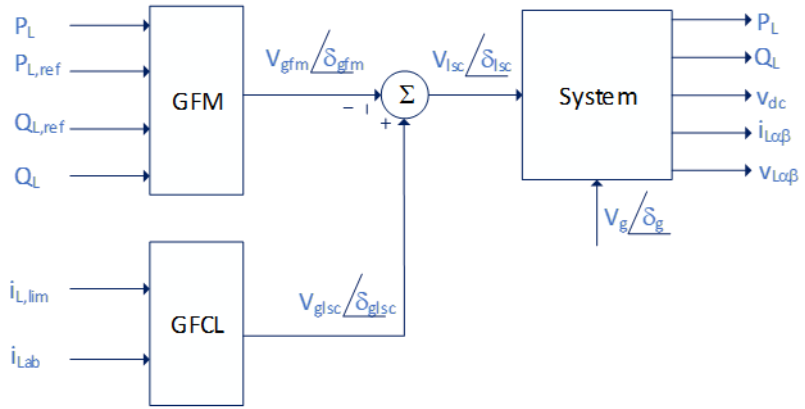
Vestas' Grid forming control

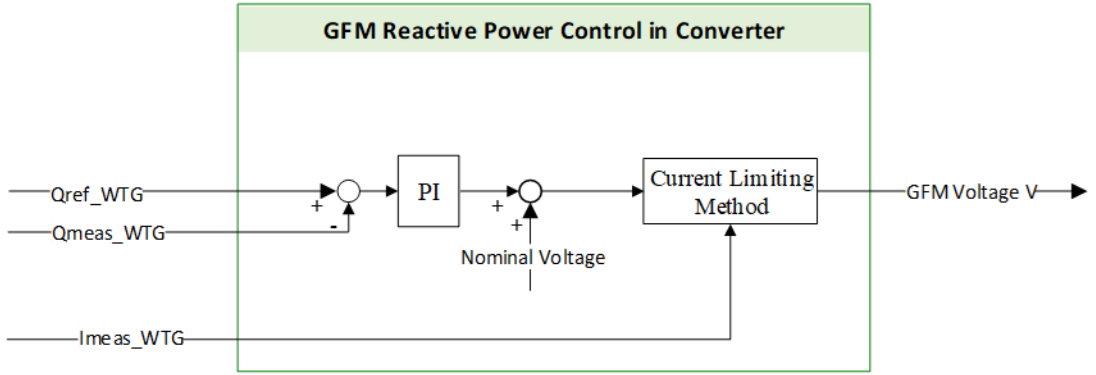
GFM converter control diagram



- Grid forming control concept
  - Swing equation H,D
  - Active Power : load angle
  - Reactive Power: Voltage magnitude
  - Current limiting by adjusting voltage output







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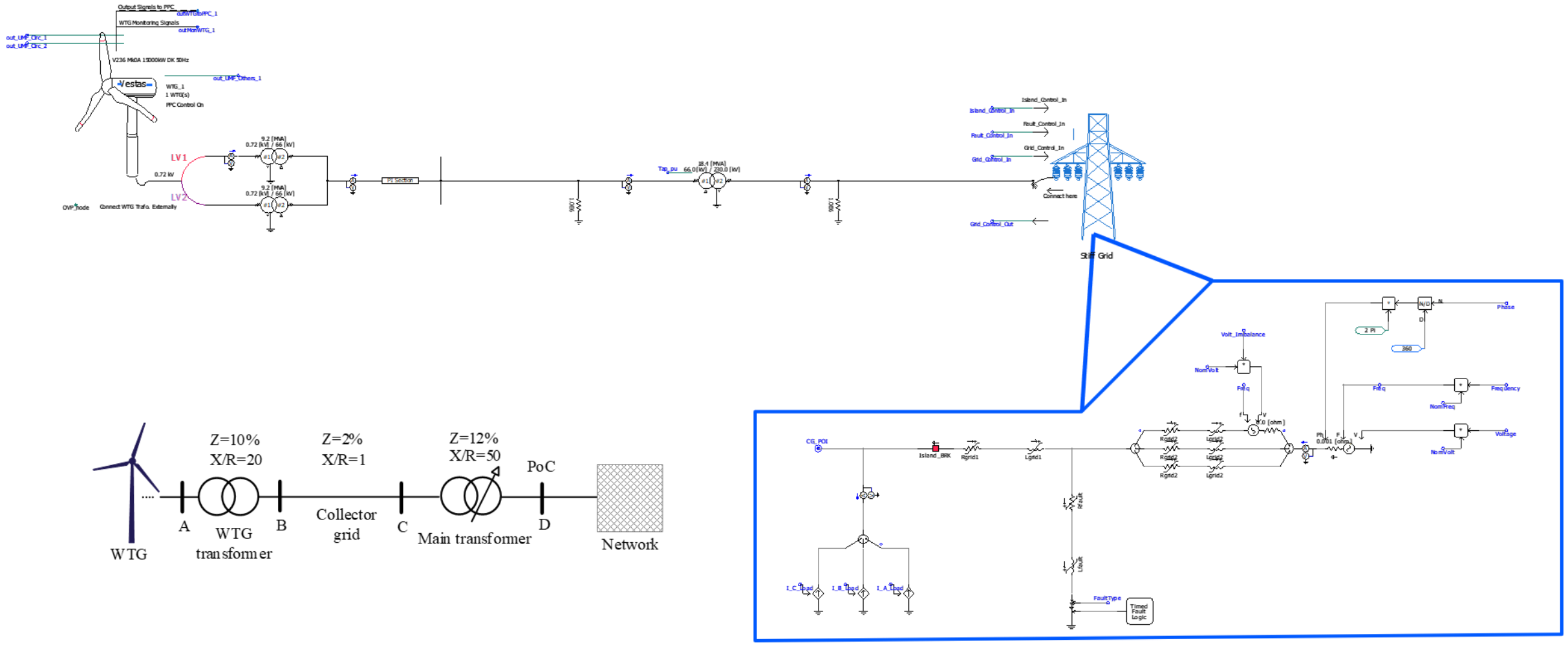


EMT Simulations - PSCAD

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PSCAD Simulation Setup



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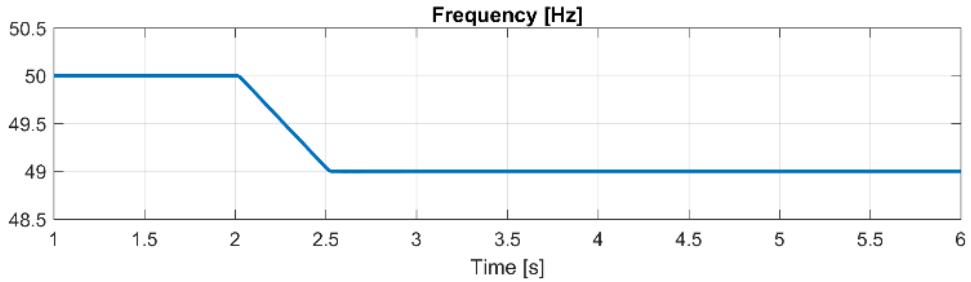
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Instantaneous Reserve Power / Inertia Power

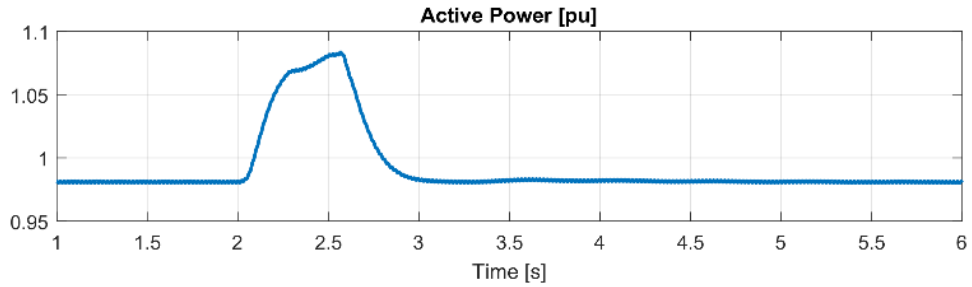
Active inertia power contribution over time

- ❑ Inertia power with fixed inertia constant
- ❑ Active/Reactive power control mode
- ❑ Operation at about nominal power
- ❑ Frequency 50 → 49 Hz in 0.5 s

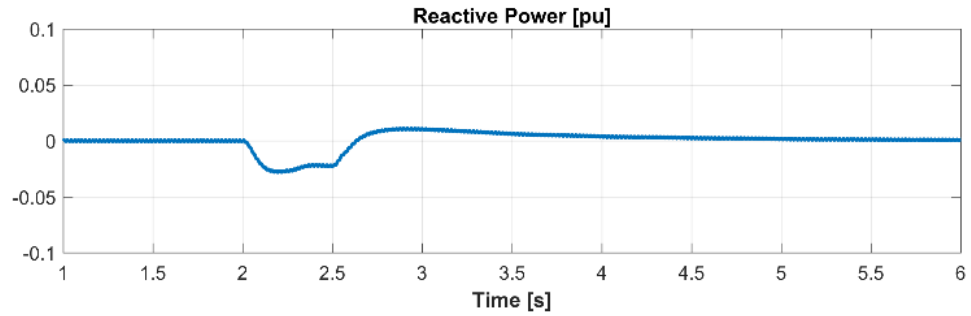
(a)



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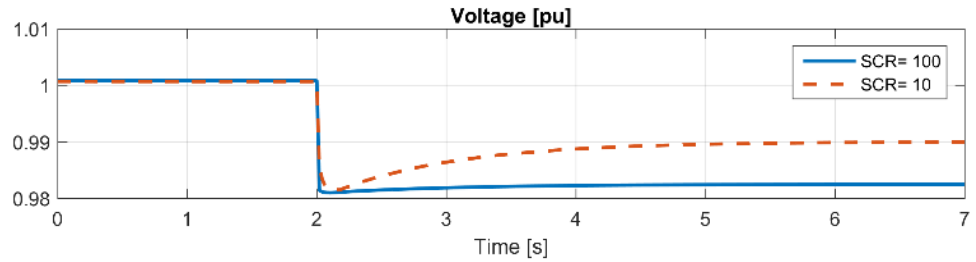
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Dynamic Voltage Control

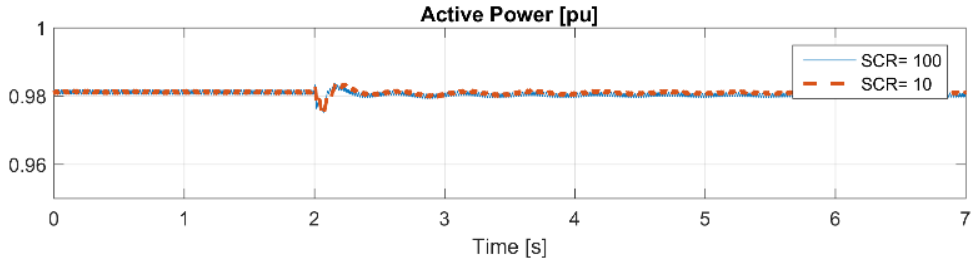
Continuous Response to Voltage Amplitude Change (Jump down by 2%)

- ❑ PPC in Active power/Voltage Control mode
- ❑ No voltage control deadband
- ❑ Operation at about nominal power
- ❑ Disturbance rejection according to set rise time

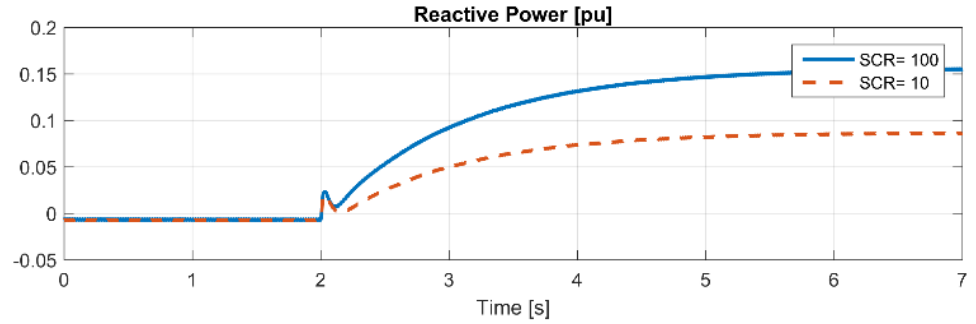
(a)



(b)



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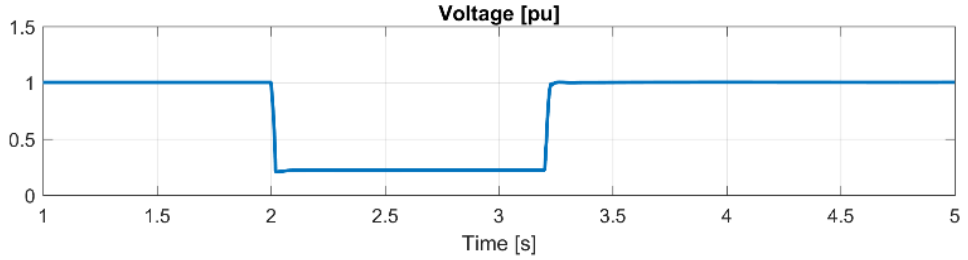
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Dynamic Voltage Control

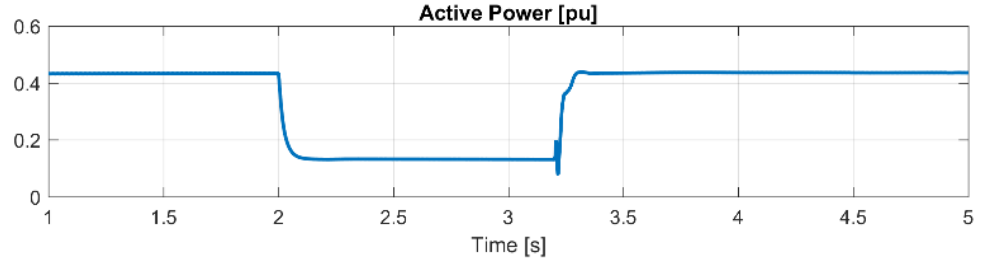
FRT/UVRT

- Partial power operation
- SCR = 10, fault voltage = 0.2 p.u.
- Reactive current/power injection.
- Reactive power is prioritized over the active power during fault

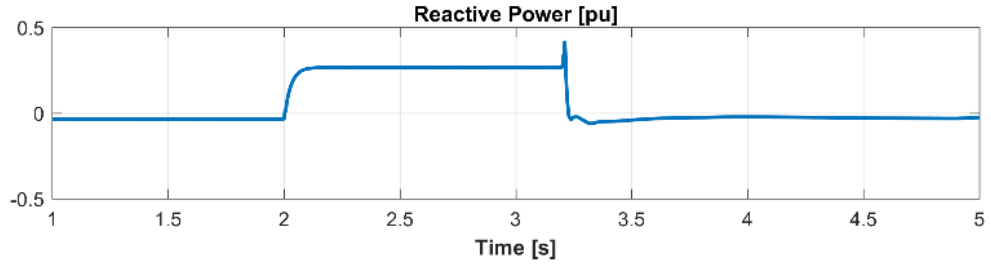
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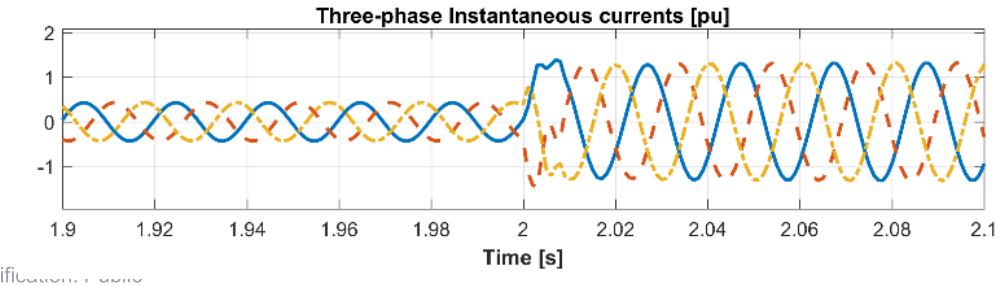
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(d)



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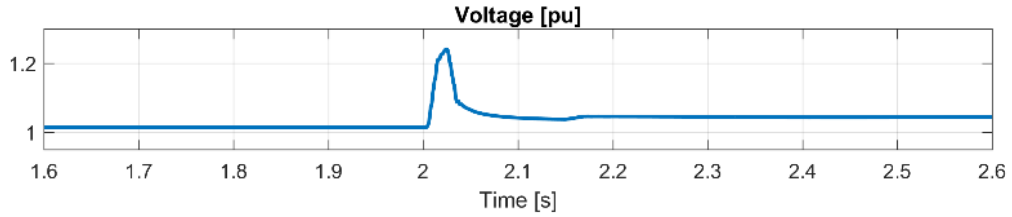
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Temporary Islanding

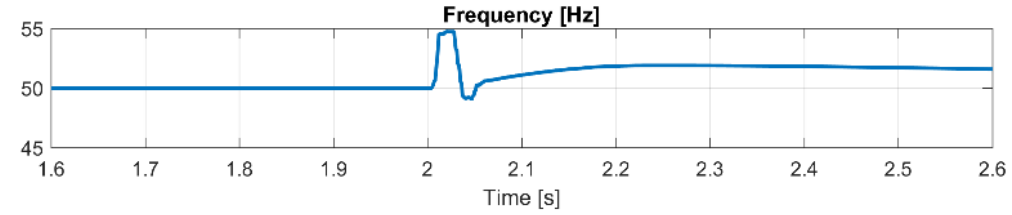
Response to Blocking of HVDC Converter – 100% Load

- ❑ Simulated according to TenneT C.2.409
- ❑ plant at full power production before the event
- ❑ Grid SCR of 10
- ❑ No remaining load in the island
- ❑ PPC is in frequency and reactive power control modes
- ❑ Brief voltage spike in first 1-2 cycles after islanding
- ❑ Frequency contained

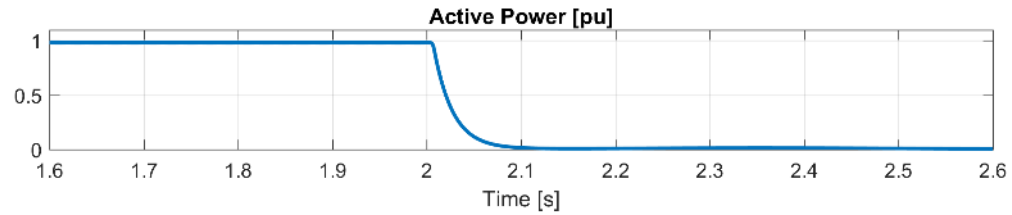
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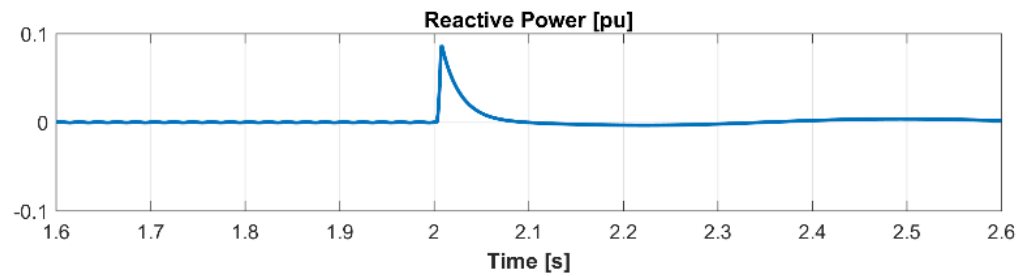
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Test Rig Results

22 September 2026

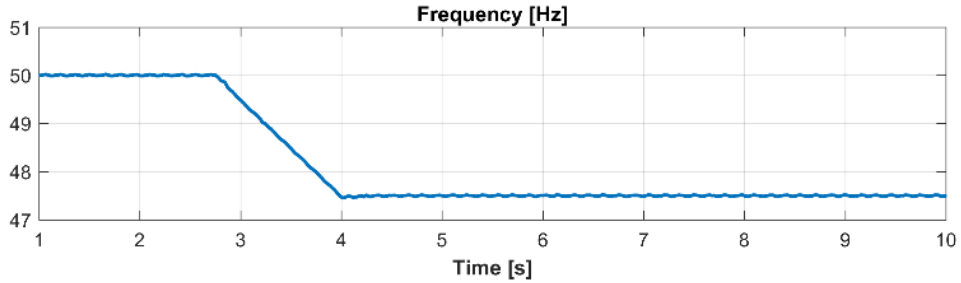
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Instantaneous Reserve Power / Inertia Power

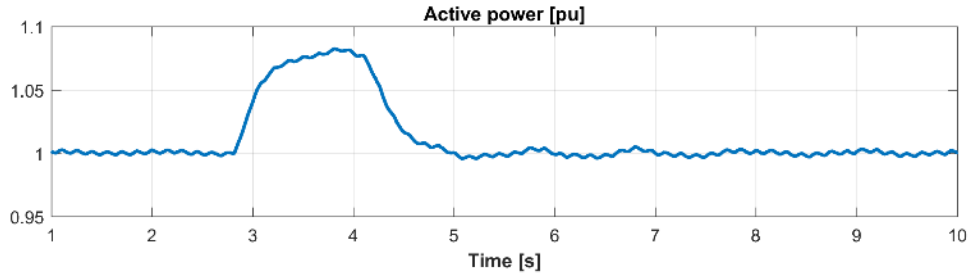
Active inertia power contribution

- ❑ Inertia power with H = 1.5 s
- ❑ Active/Reactive power control mode
- ❑ Operation at about nominal power
- ❑ RoCoF of 2Hz/s, Frequency 50 → 47.5 Hz

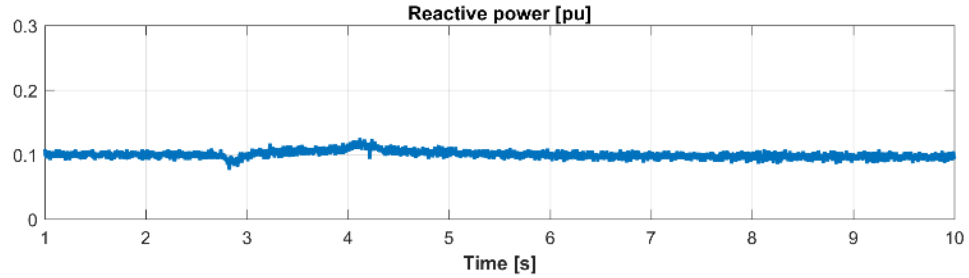
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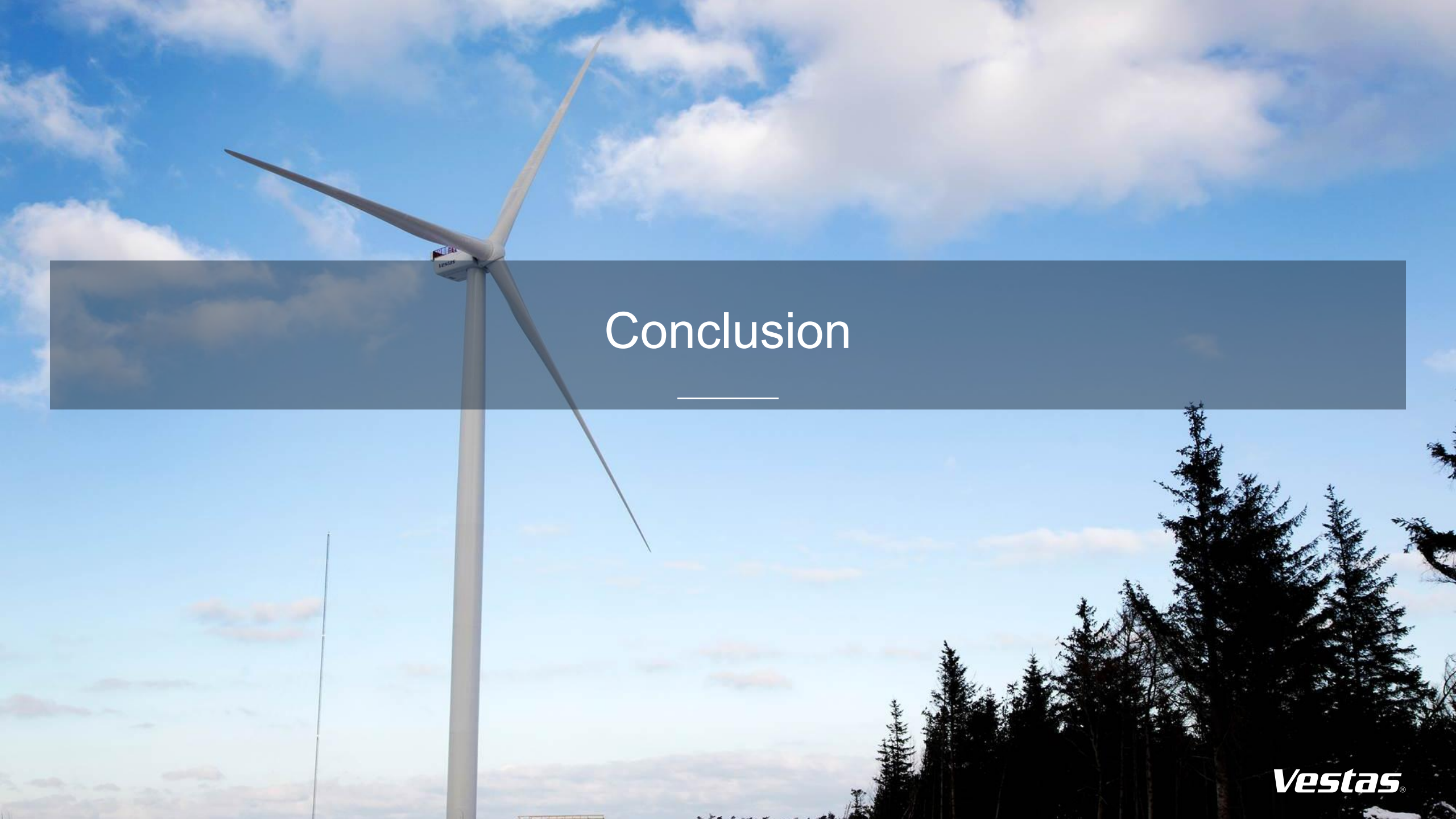


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Conclusion

Conclusion

Grid-forming wind: requirements, physical capability and verification

01 **Requirements are converging** through NC RfG 2.0, ENTSO-E guidance, standards and national implementation – the national implementations are still open though.

02 **Performance has physical limits** related to converter current, DC-link energy and wind-turbine mechanical loads.

03 **The control concept is technically credible** integrating converter, turbine and plant controls without additional storage.

04 **Verification must be proportionate** combining EMT studies, control-hardware testing, load assessment and full-scale converter testing.

Classification: Public