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VDE-FNN GFM Requirements: Technical requirements for grid-forming capabilities incl. provision of inertia

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Agenda

1. Background

2. Document structure

3. Requirements for inverter-based units

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Background

Securing system stability in Germany

In 2023 the German government approved the Roadmap System stability

- **It defines milestones and processes to ensure system stability during the path to a 100% renewable system**
- **It has a strong focus to integrate grid-forming capabilities**

The German TSOs must show the needs and ways to fulfill them in the “Grid Development Plan”

Currently the realization of the system needs is based on three pillars:

- **TSO Assets (HVDC, STATCOM, Grid-Booster,…)**
- **Market based procurement**
- **Definition of minimum requirement**

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Background

- **To start the the market-based procurement of Bundesnetzagentur (German regulatory authority) published the regulatory framework for procurement of local inertia mid of 2025**
  - Procurement started January 2026
- **The VDE-FNN is responsible for the definition of technical requirements**
  - Are defined in the FNN-guideline "Technical requirements for grid-forming capabilities incl. provision of inertia"[1]
  - The third version (2.1) was published in January 2026
  - This is an addition to the Technical Connection Rules VDE AR-N-41XX.
- **The third pillar, the definition of minimum requirements is planned to be implemented via the European law via the update of the "regulation for generators" (RfG)**
  - ACER prosed for the amendment of the RfG to enable the TSOs and national RSO to require grid-forming capabilities from basically all generation and storage.
  - The ENTSO-E technical group "Grid forming Capabilities" published a report [2] proposing the technical details requirements for the national implementations.

[1] https://www.vde.com/resource/blob/2449052/c8ce370b91478bd39f69cab440399f67/vde-fnn-hinweis-netzbildende-eigenschaftenv2-1-data.pdf
[2] https://eepublicdownloads.blob.core.windows.net/public-cdn-container/clean-documents/Reports/2025/TG_GFC_Version_2.pdf

Technical requirements for grid-forming capabilities incl. provision of inertia

Document Structure

Requirement and verifications for grid-forming units and systems

1. **Introduction**
2. **Scope of application**
3. **Terms and abbreviations**
4. **Requirements for grid-forming units and systems**
   1. Requirements for Type 1 units (synchronous)
   2. Requirements for inverter-based units (type 2, non-synchronous, generation, storage and controllable loads)
5. **Verification of electrical properties of grid forming units**
   1. Principles of the verification process
   2. Prototype certificates of grid forming units and systems
   3. Transferability of measurements to other units
   4. Test and validation for Type 1 units (synchronous)
   5. Test and validation for inverter-based units (type 2, non-synchronous)
   6. …

Requirements for inverter-based units

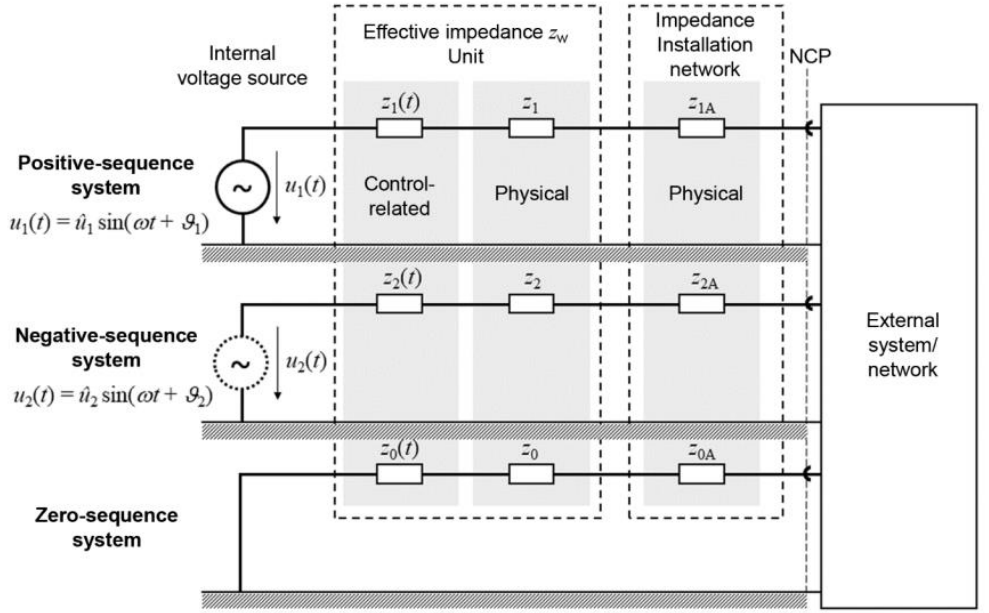
Basic Requirements: Voltage Source behaviour

- **Permanently behave as an inertial voltage source behind a mainly inductive impedance (Thevenin-Source)**
  - This is defined by

  → An amplitude change leads to a mainly reactive current change

  → A phase angel change leads to a mainly active current change
  - For $r_{w,1} \ll x_{w,1}$The active ($i_{P1,PGU}$) and reactive currents ($i_{Q1,PGU}$) of the positive sequence are given by (1) and (2)
  - In asymmetric conditions the reactive currents ($i_{Q1,PGU}$) of the negative sequence is given by (4)

- **Negative sequence components in the voltage source are allowed, if**
  - It enables a symmetric voltages at the connection point
  - or to limit asymmetric currents to $> 3\% I_r$



$$i_{P1,PGU} = \frac{p_{1,PGU}}{u_{1,PGU}} \approx -\frac{1}{x_{w,1}} \sin(\delta_1) \quad (1)$$

$$i_{Q1,PGU} = \frac{q_{1,PGU}}{u_{1,PGU}} \approx \frac{1}{x_{w,1}} (u_{1,PGU} - u_1 \cos(\delta_1)) \quad (2)$$

$$\delta_1 = \varphi_{u1,PGU} - \varphi_{u1} \quad (3)$$

$$i_{Q2,PGU} = \frac{q_{2,PGU}}{u_{2,PGU}} \approx \frac{1}{x_{w,1}} (u_{2,PGU} - u_2 \cos(\delta_2)) \quad (4)$$

$$\delta_2 = \varphi_{u2,PGU} - \varphi_{u2} \quad (5)$$

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Requirements for inverter-based units

Basic Requirements: Voltage Source behaviour

- **The effective impedance z_w must be partly physical and may be additionally be controller based.**
  - The effective impedance (without current limitation) shall be smaller than
    - $0.27\ p.u.$ without unit transformer (low voltage side)
    - $0.35\ p.u.$ including unit transformer (medium voltage side)
  - In normal operation the negative sequence impedance must be the same as the positive sequence impedance
- **The voltages source behaviour must be a general behaviour, also during limitations**
  - During disturbances (step vice changes of angle or amplitude) for 40 ms current clipping is acceptable
  - It is allowed to limit the current to 95% of the current that leads to current clipping (minimum I_r)
- **The active current response $\Delta i_{P1,PGU}$ within its current capabilities to a phase jump must be**
  - Al least 50% of $\Delta i_{P1,PGU,max}$ in procured direction, the power change may be limited to $\geq 45\% P_{Emax}$
  - Al least 5% of $\Delta i_{P1,PGU,max}$ in procured direction, the power change may be limited to $\geq 5\% P_{Emax}$

  Where $\Delta i_{P1,PGU,max} = -\frac{1}{z_{w,max}}(\sin(\delta_{n1}) - \sin(\delta_{v1}))$ with δ_{v1} angle before and δ_{n1} after the change
- **DC-components in the current shall be reduced to 10% of its initial change value within 100 ms.**

Requirements for inverter-based units

Basic Requirements: Stable operation

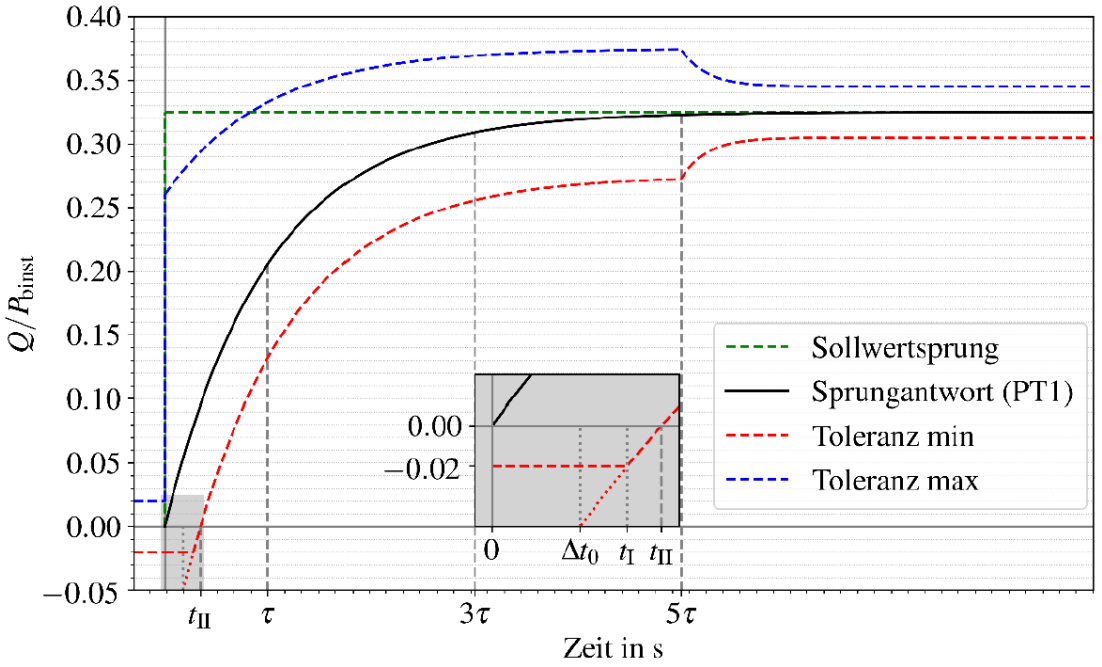
- **Behavior in the sub- and super synchronous frequency range**
  - The device must dampen oscillations in the frequency range of $3 \ldots 50\ Hz$ in the rotating reference frame
- **Behavior in the harmonic frequency range**
  - The device must act passive in the frequency range of $100\ Hz \ldots 2.5\ kHz$ in the stationary reference frame
- **Damping of Power-Frequency oscillations**
  - The GFM-unit must dampen power-frequency oscillations in the frequency range of $0.05 \ldots 10\ Hz$ in the rotating reference frame.
  - The damping ratio D must be ≥ 0.5 for SCR values of 3 and higher.
- **Ability to operate in parallel with the mains**

  → Parallel operation with synchronous, GFM non-synchronous and GFL non-synchronous units @ SCR values of 1.0, 3.0 and 25.0.
- **The synchronization of the voltage source needs to be kept in all design relevant event in the guideline.**
  - Below 20% of residual voltage as far as possible

Requirements for inverter-based units

Basic Requirements: Reactive power provision

- **Reactive power provision at the grid connection point**
  - The provision follows control modes defined in the applicable VDE AR-N-41XX.
  - The control behavior must follow a first order system that as shown in the figure
  - The damping must be within the defined tolerances for SCR values in the range of 10 to 50.



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Requirements for inverter-based units

Basic Requirements: Voltage source control

Gives the control requirements regarding the voltage amplitude

- **Voltage control of GFM devices**
  - Must de based on the voltage source behavior on a controlled voltage source behind an impedance z_w.
  - Must have a linear proportional behavior especially for amplitude steps

    → double step size of the amplitude change must lead to double the current reaction

  - Dynamic response
    - Setpoint change: response time ≤ 1 s
    - Change of voltage: response time (90%) ≤ 10 ms, settling time ≤ 60 ms, Damping D ≥ 0.3
  - During limitation
    - Stability of the voltage source behavior needs to be kept
    - R/X must not change
    - As soon as no limitation is necessary: immediate response to normal operation

Requirements for inverter-based units

Basic Requirements: Voltage source control → Fault operation

- **The robustness against over- and under voltage events follows the requirements of the applicable VDE AR-N-41XX**
  - If applicable also single-phase faults need to be rode through
- **If current limitation is necessary, the limitation must be based on an amplitude limitation**

  → prioritize between active and reactive current is not allowed
  - As soon as no limitation is necessary: immediate response to normal operation
  - The active power need to return within less than 1 s

- **Additional requirements for connection in medium voltage grids**
  - Limited voltage source control during faults
    - the units must be able to stop the voltage source control.
    - reduce its current to <20% I_r after 210 ms and <10% I_r after 250 ms after the voltage is lower than 70%
    - For 150 ms the voltage control must be kept.
  - If the voltage rises above >1,35 p.u. the current must be reduced within 40 ms to less than 5% I_r

Requirements for inverter-based units

Basic Requirements: Inertia provision

The market-based procurement allows unidirectional inertia provision to enable the participation of renewable generation and controllable loads, therefore products are defined for:

- Positive inertia provision (power increase during negative RoCoF)
- Negative inertia provision (dower reduction during positive RoCoF)

For both directions, a "Premium" (>90% availability) and a "Basic" (>30% availability) product are defined.

- **Definition of the inertial constant**
  - For inertia provision in positive and negative direction $T_A = T_{A,pos} = T_{A,neg}$
  - Derating for positive inertial response is allowed.
  - After the supply of inertia, the unit can recharge the internal storage from the grid.
    - The energy for recharging must be smaller than 1.5 of the supplied inertial energy.
  - Within the current limits the GFM device must supply the inertia over the whole operation range.
  - It must be stated by the manufacturer in which power range the full provision of inertia is possible.

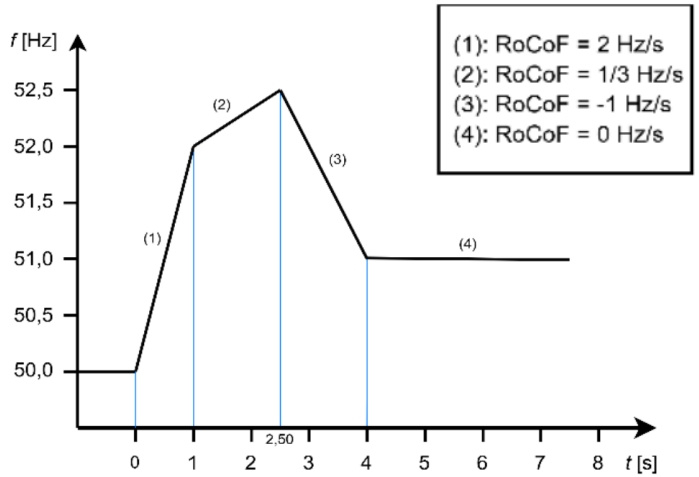
$$T_A = 2H = \frac{\left(\Delta P / P_{rE}\right)}{\left(\frac{\Delta f / f_n}{\Delta t}\right)}$$

Requirements for inverter-based units

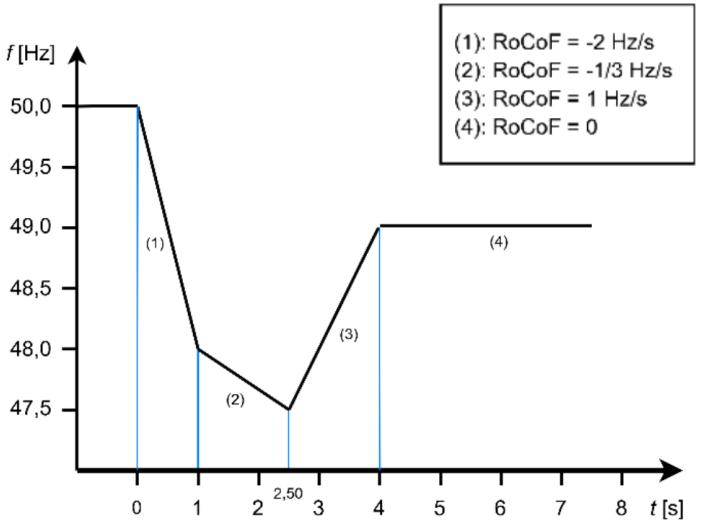
Basic Requirements: Inertia provision

- **Requirements for inertial power and energy**
  - The defined T_A must be suppled during the reference frequency curves (see figure), for unidirectional provision also the curve for the other direction must be shown with limited provision
  - Can be limited when
    - Reaching current limits
    - Requirements to voltage control / FRT, LFSM and reference frequency curves are fulfilled
    - To keep transient stability
  - The power provision defined by the reference curves must be reached within:
    - 800 ms for $T_A \leq 10$
    - 1.3 s for $T_A > 10$

Market-based procurement of negative inertia



Market-based procurement of positive inertia



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Requirements for inverter-based units

Additional Requirements

- **Behavior during over- and under frequency (LFSM)**
  - Technology specific droop settings (standard setting typically 5%)
  - Technology specific requirements for control dynamic and damping
    - Damping must be reached in the closed loop operation (fictious island operation)
    - For renewable generation only in over frequency
- **Priority of the different requirements**
  - Grid-Forming requirements (Voltage Source behavior and Inertia) are of highest priority directly after safety
  - Differentiation between transmission and distribution connected devises
    - For Transmission connected: LFSM has higher priority as power limitation from grid operator
    - For distribution connected: the LFSM has lower priority as power limitation from grid operator
- **Additional requirements on power generation system level**
  - Definition of maximum effective impedances on system level $z_{w,A}$
    (0.5 p.u. for high voltage connection, 0.4 p.u. for extra high voltage connection)
  - For transmission connection the requirements in the sub- and super synchronous as well as the harmonic frequency range are applicable on system level.

Contact

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Thank You for Your Attention!