TOP.5 - Technical Group on Grid Forming Capability (TG GFC): Main Outcomes of the Report

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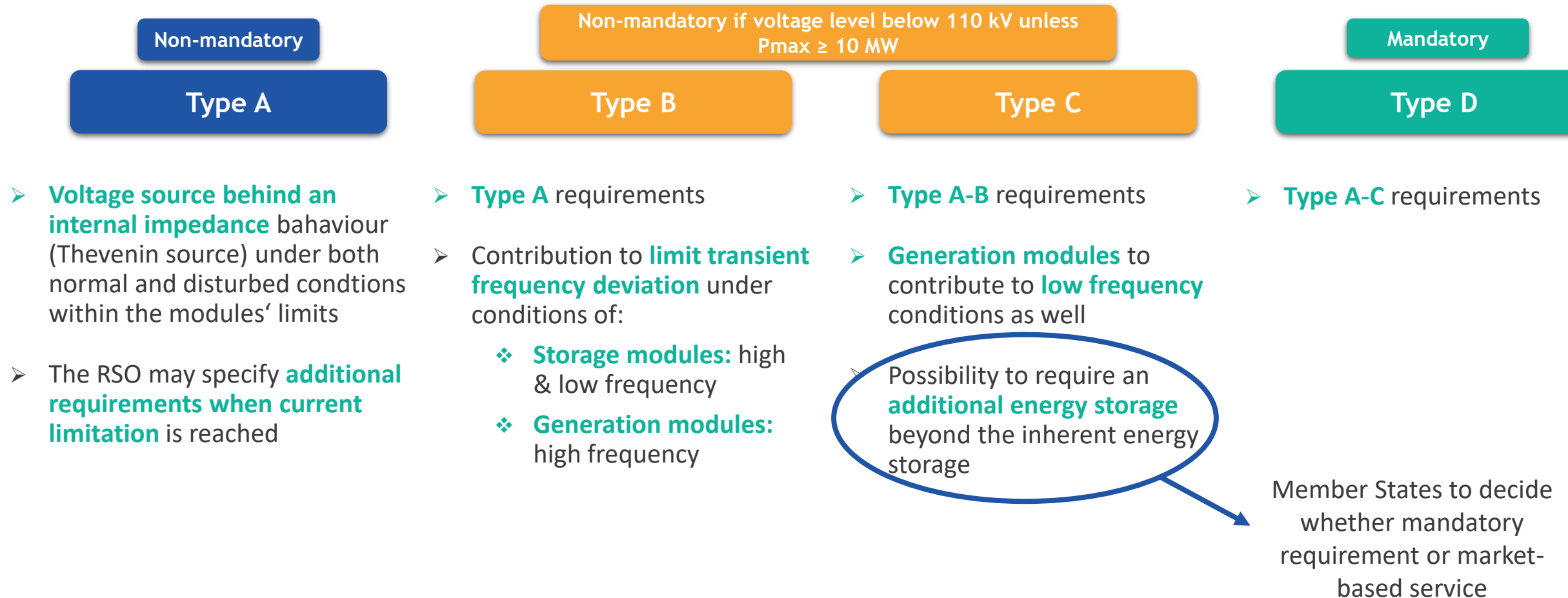
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Agenda

1. **Introduction & Background**

2. **TG GFC proposed exhaustive requirements**

    ➢ **Voltage source behaviour**

    ➢ **Inertial response**

    ➢ **When capability limits are reached**

3. **Evaluation of compliance**

1. Introduction & Background

The draft NC RfG 2.0 defines non-exhaustive GFM requirements

ACER's recommendations on NC RfG 2.0 includes non-exhaustive Grid Forming (GFM) requirements for Power Park Modules (PPMs)

Non-mandatory

Type A

Non-mandatory if voltage level below 110 kV unless Pmax ≥ 10 MW

Type B

Type C

Mandatory

Type D

- ➤ **Voltage source behind an internal impedance** bahaviour (Thevenin source) under both normal and disturbed condtions within the modules' limits

- ➤ The RSO may specify **additional requirements when current limitation** is reached

- ➤ **Type A** requirements

- ➤ Contribution to **limit transient frequency deviation** under conditions of:
  - ❖ **Storage modules:** high & low frequency
  - ❖ **Generation modules:** high frequency

- ➤ **Type A-B** requirements

- ➤ **Generation modules** to contribute to **low frequency** conditions as well

  Possibility to require an **additional energy storage** beyond the inherent energy storage

- ➤ **Type A-C** requirements

Member States to decide whether mandatory requirement or market-based service

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Definition of exhaustive GFM requirements

Phase I: ENTSO-E Interim Report

➢ To facilitate the national implementation, ENTSO-E will release an Implementation Guidance Document (**IGD**) proposing **exhaustive GFM requirements** after the publication of the updated regulation

➢ To advance the work on this IGD, ENTSO-E published in **May 2024** an ENTSO-E technical report (Phase I) **providing recommendations on:**

❖ The exhaustive definition of GFM connection requirements for PPMs

❖ The compliance verification procedure for GFM requirements in PPMs

Phase II: TG GFC Report

➢ In order to address the stakeholders' comments on the Phase I technical report, ENTSO-E established a Technical Group on Grid Forming Capability (**TG GFC**) in **June 2024** aiming to:

❖ Develop and express a common understanding among EU stakeholders on GFM technical requirements

❖ Publish a second consolidated version of the report (Phase II) **considering the stakeholders' feedback** (CENELEC, Energy Storage Europe, EU DSO entity, SolarPower Europe and Wind Europe)

➢ This report is an **ENTSO-E report endorsed by all the involved associations** and was **published in early November**

Phase III: IGD

➢ ENTSO-E is planning to already start **working** on an IGD on GFM **after the Christmas break**, which will be based on the TG GFC report

➢ This is a **non-binding guidance** to support the national implementation, which is a **legal mandate** for ENTSO-E and will be published **within six months** after the entry into force of the NC RfG 2.0

➢ This will be an **ENTSO-E document** that will be **publicly consulted** prior to its publication

2. TG GFC proposed exhaustive requirements

Circuit equivalent: PPM represented as a Thevenin source

➢ Requirements are defined solution agnostic

➢ Requirements are based on an equivalent circuit

  ❖ PPM represented as a voltage source behind an impedance according draft NC RfG 2.0 Article Y(7)
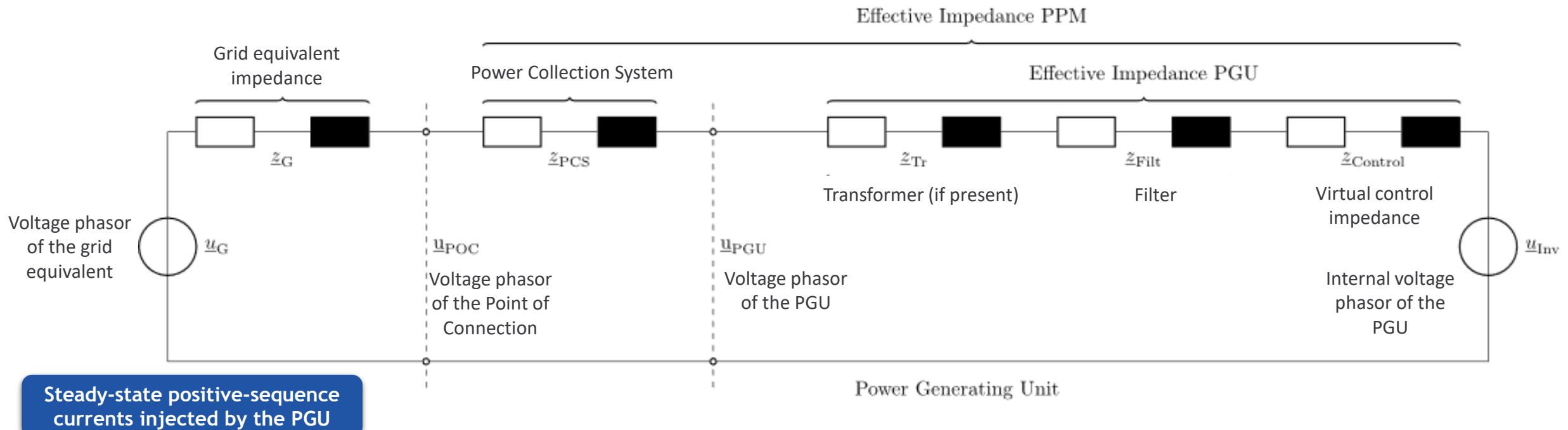
$$i_{P,PGU} = \frac{p_{PGU}}{u_{PGU}} \approx -\frac{u_{Inv}}{x_{Eff\_PGU}} sin(\delta)$$

$$i_{Q,PGU} = \frac{q_{PGU}}{u_{PGU}} \approx \frac{1}{x_{Eff\_PGU}} \left(u_{PGU} - u_{Inv} \cdot cos(\delta)\right)$$

➢ $\delta = \varphi_{U\,PGU} - \varphi_{U\,Inv}$

➢ Assuming that $r_{Eff} << x_{Eff}$

Voltage source behaviour

The effective impedance plays a key role

➢ The GFM requirements must be met by each PGU of a PPM

➢ Current response to disturbances (voltage amplitude, voltage angle and frequency) is based on the previous equations **defined by the effective impedance**

➢ The following requirements are defined:

  ❖ On the **effective impedance** of the PPM and the PGU: to ensure enough fault current contribution & stability

  ❖ Voltage **amplitude & angle jumps**: to ensure instantaneous reaction under disturbances

Requirements on the effective impedance

- ➢ **Maximum value** for PGU and PPM defined:
  - ❖ The difference between both are the power collection system's impedance

- ➢ **Positive real part** for 100 Hz < f < 1000 - 2500 Hz

- ➢ **Virtual control impedance** is neither required not forbidden. However, if present, the PGU impedance shall always be positive

Max PGU effective impedance

Point of reference for evaluation	Max value of $z_{\mathrm{Eff,GU}}$
Low voltage terminals	0.27
Medium voltage terminals	0.35
High voltage terminals	0.45

Max PPM effective impedance

Point of reference for evaluation	Max value of $z_{\mathrm{Eff,GP}}$
Medium voltage PoC	0.35
High voltage PoC	0.50
Extra High voltage PoC	0.50

Reaction to voltage angle & amplitude jumps

Voltage angle jumps

Voltage amplitude jumps

- ➢ **Reaction time:** 50% of estimated peak value must be reached within 10 ms

- ➢ Based on the estimated formula:

$$\Delta i_{P,PGU,Peak} \approx \frac{1}{x_{Eff\_PGU}} \left(sin(\delta + \gamma) - sin(\delta) \right)$$

  - ❖ δ: phase difference prior to the phase jump event
  - ❖ γ: angle change applied

- ➢ **Reaction time**: 90 % of expected value must be reached within 10 ms

- ➢ **Settling time**: current must be within a defined tolerance band within 60 ms

- ➢ Based on the current formulas presented before

- ➢ Minimum **damping ratio** 5% (for 0.1Hz < f < 10Hz)

Inertial response

Mechanical starting time used as reference

➢ The **mechanical starting time** $T_{M,PPM}$ $(= 2H)$ is defined as reference based on a simplified swing equation:

$$T_{M,PPM} = \frac{\left(\dfrac{\Delta P}{P_{Rated}}\right)}{\left(\dfrac{d(f/f_{Rated)})}{dt}\right)} = \frac{\Delta p_{pu}}{\left(\dfrac{df_{pu}}{dt}\right)}$$

➢ The required active power change as **inertial response** is consequently defined as:

$$\Delta P = T_{M,PPM} \cdot \frac{df/f_{Rated}}{dt} \cdot P_{Rated}$$

➢ *ΔP* at the PPM terminals may be provided by **either all or some PGUs within the PPM or by additional equipment**

Inertia contribution within inherent storage capability limits of a PPM

➤ **While made possible** by the inherent energy storage or the available primary energy, the PPM shall provide **inertia response**:

   ❖ TSO specifies $T_{M,PPM}$

   ❖ ΔP is evaluated at PoC

   ❖ Once inherent storage capability limits are reached the generating unit may limit its contribution to synthetic inertia

> **"Low hanging fruits" with no, or very little additional cost for the plant manufacturer/operator**

➤ **No power headroom** is required beyond the continuous operating points of the generating plant

➤ For generating plants **without inherent energy storage** (or with very limited inherent energy storage):

   ❖ Only negative power changes required

   ❖ Not required to absorb active power

   ❖ Minimum regulating level respected

➤ **Availability** of inertia is **limited**: it depends on operating point and available energy

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Inertia contribution beyond inherent storage capability limits of a PPM

➤ **The TSO may require** the provision of additional energy beyond the inherent energy storage, which must be approved by the national regulating authority

➤ In the TG GFC report no proposal is made **how additional storage capability is mandated**
   - ❖ Inertia markets
   - ❖ Grid connection mandatory requirement

➤ In this case, the PPM's **inertia response** shall be as follows:
   - ❖ TSO specifies $T_{M,PPM}$
   - ❖ ΔP is evaluated at PoC
   - ❖ ΔP shall be provided without limitation up to a RoCoF defined by the TSO and up to 2Hz/s
   - ❖ ΔP headroom shall be available for any continuous operating point
   - ❖ The same headroom shall be available for phase jump power and amplitude jump power

➤ Headroom does **not count towards maximum capacity** of a PPM

➤ **Availability** of inertia is **guarantied**

➤ In both cases, the **dynamic** of the inertial contribution is defined by the voltage source dynamic

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When capability limits are reached

Additional requirements may be defined under capability limitations

- **GFM** behaviour is **only required within the capability** of the PPM and PGU

- Once the specified GFM response would result in a **violation of the design limits**:
  - ❖ Design limits shall be respected
  - ❖ The TSO may specify limitation requirements

- Under this condition, the TG GFC proposes the following requirements:
  - GFM behaviour shall be maintained
  - Compared to the unlimited response (**red arrow**), **only the amplitude may be reduced** (**green arrow**)
  - **No priority is given to any current component**: neither active/reactive current nor positive/negative sequence
  - If **only active power limits are reached** while the current limits are not reached, only the active power component shall be reduced
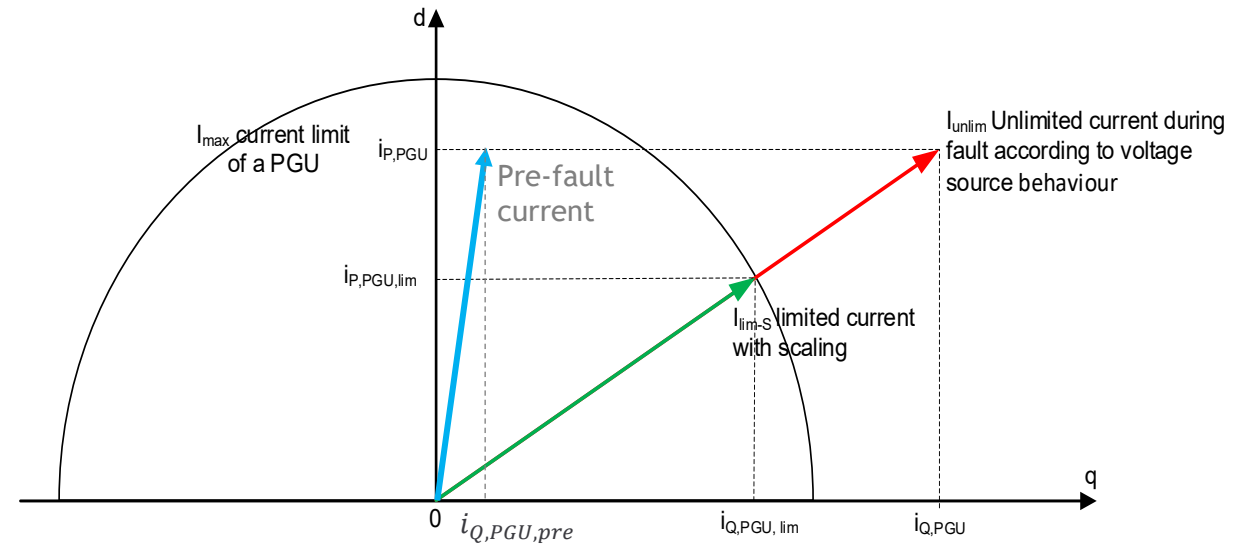
- **Current clipping** allowed during the first 40 ms

- Same **dynamic behaviour** as for unlimited response

3. Evaluation of compliance

Scope

➢ **Additional tests and simulations are needed for GFM**

   ❖ Equipment certificates (if used) and PGU simulation models shall be validated by PGU test

   ❖ PPM evaluation at PoC by simulation as defined by the RSO/TSO

➢ Characteristics to be **additionally evaluated on PGU level**

   ❖ Voltage source

   ❖ Effective impedance

   ❖ Behaviour when reaching capability limits

   ❖ Synthetic inertia (if applicable)

   ❖ Damping

   ❖ Interaction behaviour (controller interactions)

➢ Characteristics to be **additionally evaluated on PPM level**

   ❖ Effective impedance

   ❖ Synthetic inertia

   ❖ Damping

PGU test setup

➢ PGU test setup is **based on** today's setup used for **grid following** PGU

➢ In addition, **load emulation** is needed for several tests

➢ Today's simplification applied regarding Equipment Under Test (EUT) also apply for GFM, e.g. nacelle or converter test bench

➢ Control Hardware In the Loop (**C-HIL**) may be applied for some evaluation or technologies
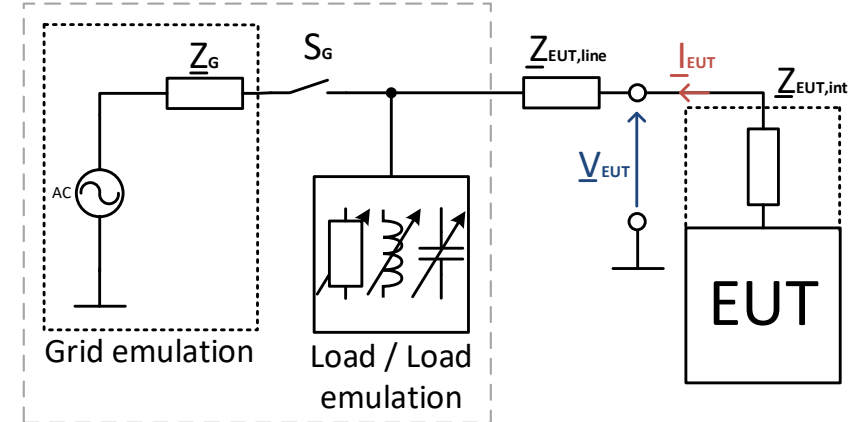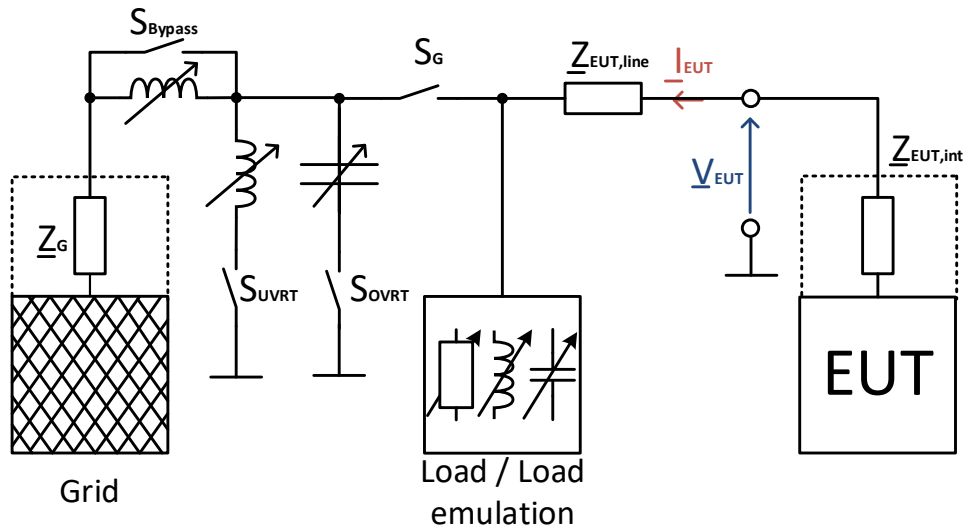
CENELEC is developing its 50744-1 in line with the principles of the report

THANK YOU FOR YOUR ATTENTION