Examples of implementation of DCC for P2G units in Germany and Denmark.

Lessons learned and implications at EU-level

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Network Code on Demand Connection in Denmark

ENERGINET

Technical regulation 3.4.3

TECHNICAL REGULATION 3.4.3 - REQUIREMENTS FOR TRANSMISSION-CONNECTED DEMAND FACILITIES

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Network Code on Demand Connection in Denmark

Categorisation of demand facilities

- Only P2G facilities of over 200 MW (category 7) have to comply with FRT, PFAPR, LFSM-U and load shedding.
- It applies to all demand facilities (not limited to P2G units).

4.6 Facility category and expansion plans

Demand facilities in the transmission grid are divided into the categories 3, 4, 5 and 7.

Categories

- 3: A facility where it can be demonstrated at the time of obtaining the ION/FON that the full power draw assigned can be utilised from day one.
- 4: A facility where it cannot be demonstrated at the time of obtaining the ION/FON that the full power draw assigned can be utilised. Category 4 facilities require the preparation of an escalation plan during the maturation phase.
- 5: A facility where it can be verified that the full power draw can be utilised, but with 500 or fewer full-load hours in a year.
- 6: This category is used for third-rail current systems for railways.
- 7: A facility with a requested power draw of 200 MW or more. Category 7 facilities are subject to several additional requirements, including PFAPR, LFSM-U (see under protection) and FRT.

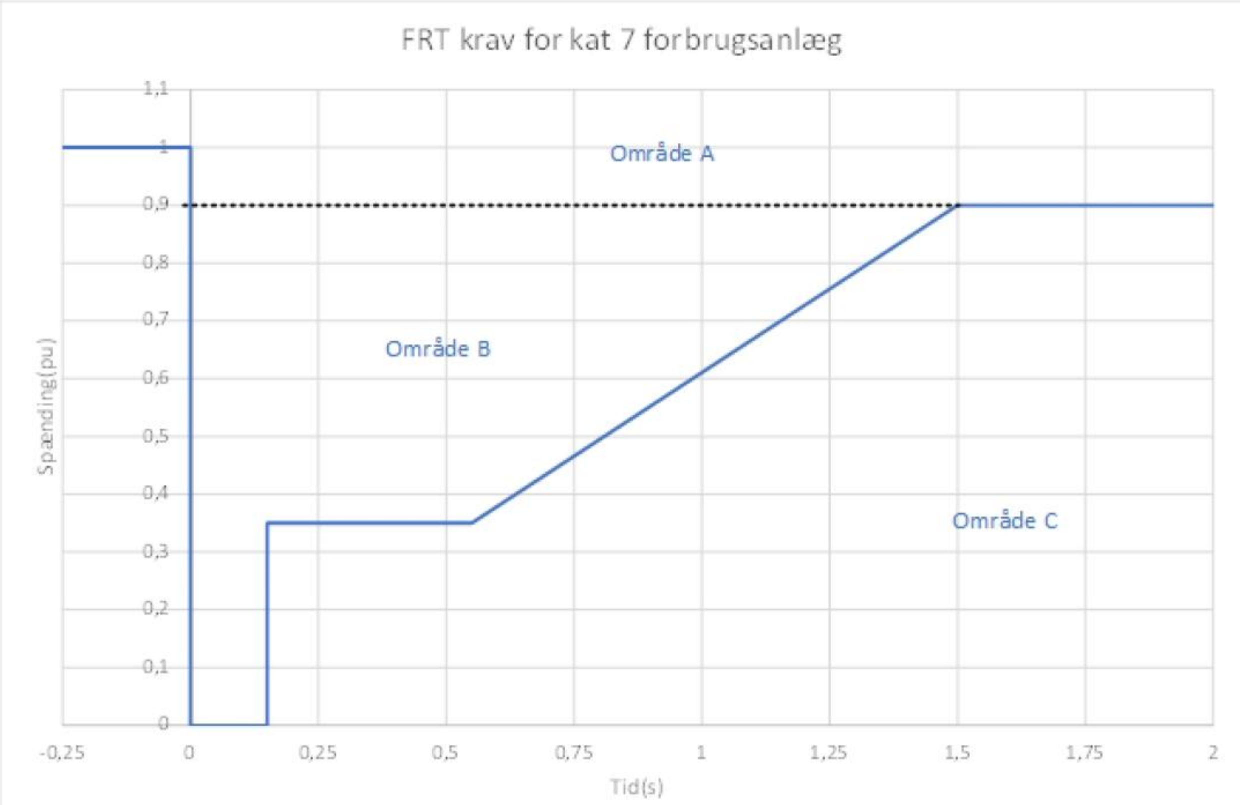
Map of operational P2G projects by end-use. Source: HE Monitor

- There are currently no ELY projects in DK of >200 MW.
- Kassoe Project with SE got grid access permission now, 50 MW, handed over to customer

Network Code on Demand Connection in Denmark

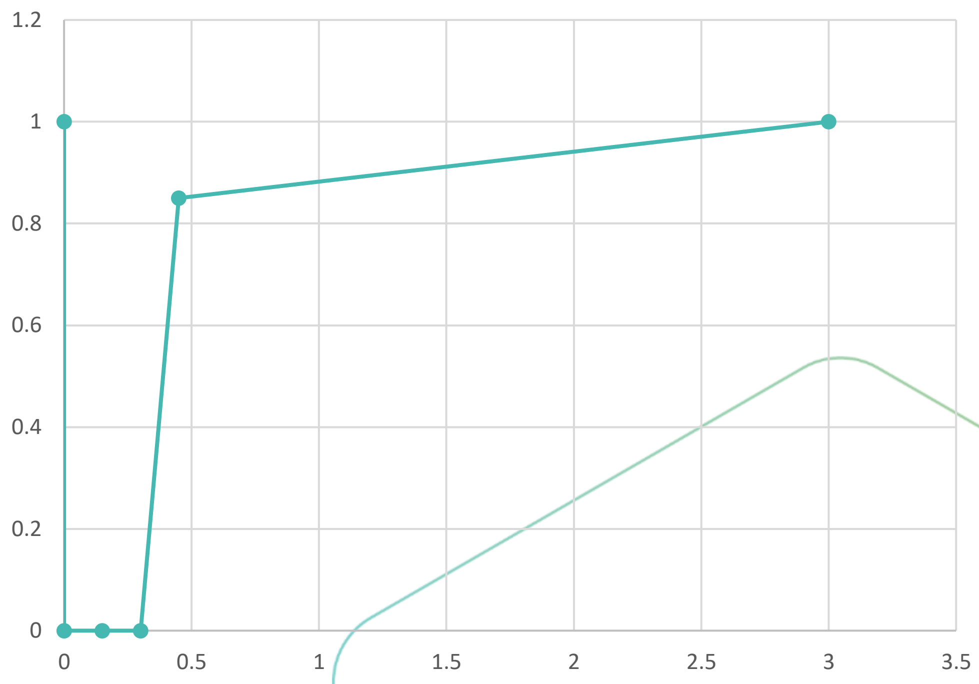
Fault Ride Through Capabilities

FRT curve in DK NCDC



DK's FRT curve only has to withstand 1,5 seconds of FRT curve vs. EU's 3 seconds – doubling the difficulty for P2G units.

FRT curve in EU DCCs



Voltage parameters (pu)

U_{ret}:	0
U_{clear}:	0
U_{rec1}:	0
U_{rec2}:	0,85

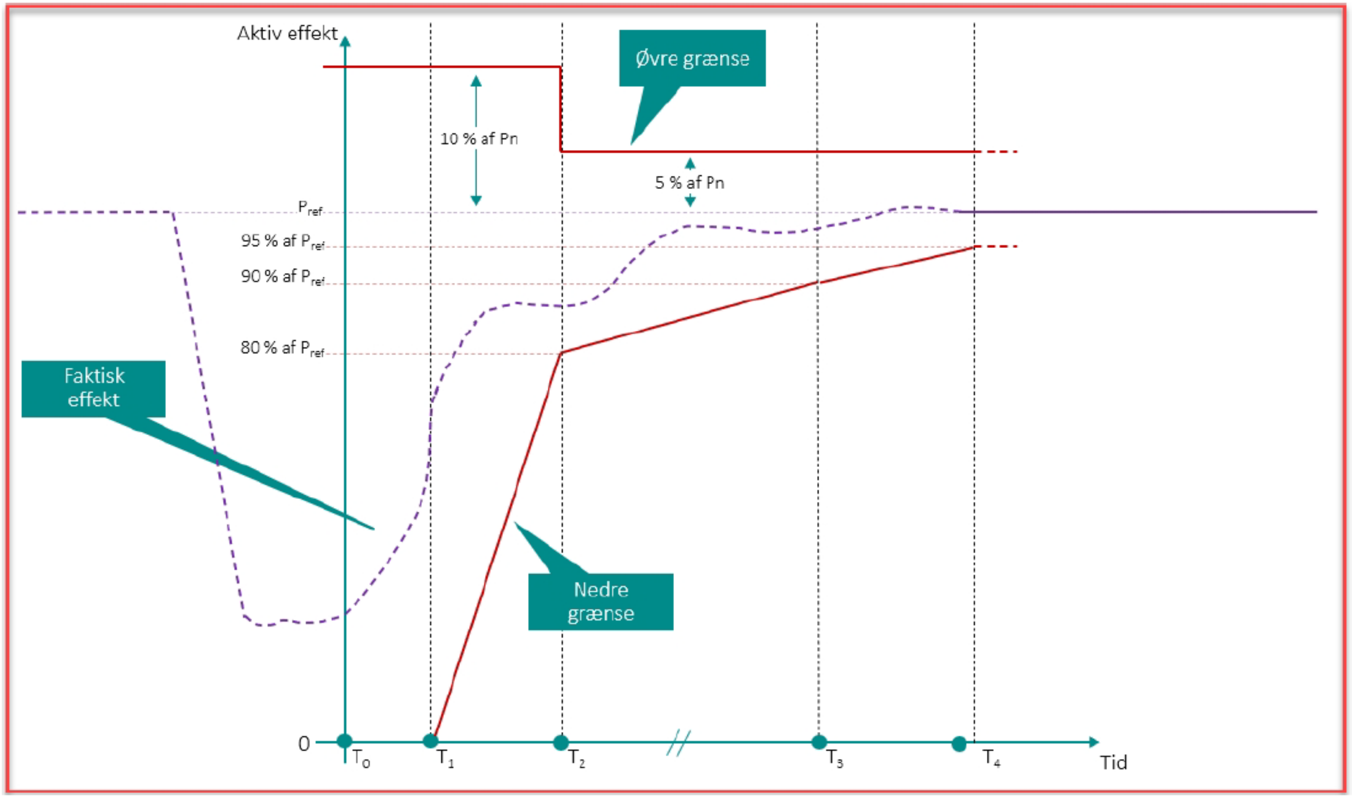
Time parameters (seconds)	
t_{clear}:	0,15
t_{rec1}:	0,15
t_{rec2}:	0,15
t_{rec3}	3,0

Network Code on Demand Connection in Denmark

Post Fault Active Power Recovery

Category 7 facilities must be able to resume facility operations following a grid fault.

- Within 5 seconds of grid normalisation, the facility must be operational, drawing at least 80% of power used prior to the grid fault.
- After 30 seconds, the facility must be operated at 90% of power used prior to the grid fault
- In the event of a ST generation facility disconnection or tripping/reclosing of a transmission line, this requirement helps to **ensure that the transmission grid maintains a certain amount of load compared to before the fault**. This is intended to prevent overvoltages due to lack of demand.



- T_0 is the time when the operating conditions in the connection point are back in the continuous operation .range
- T_1 is 1 second after T_0.
- T_2 is 5 seconds after T_0.
- T_3 is 20 seconds after T_0.
- T_4 is 30 seconds after T_0.

Not present in ACER's proposal

Compromise for technical requirements for the connection of electrolysis systems to the German grid

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Technische Anforderung für den Anschluss von Elektrolyseanlagen

Technical requirements for the connection of electrolyser facilities

in Zusammenarbeit mit

H2 DWV Deutscher Wasserstoff-Verband

Hydrogen Europe

German technical compromise for ELYs

New findings o

Hydrogen Europe

Initial 4-TSO Paper (2023)	Compromise Paper (2025) – *in final coordination*
• Focused mainly on **Fault Ride-Through (FRT) capability** and **modelling requirements**. • Provided an **initial positioning** of the transmission system operators (TSOs) on key technical challenges. • Requirements developed with input from scientific community, but no OEMs involved	• Developed in **collaboration with the German Hydrogen Association (DWV)** through engagement with the 4 TSOs. • Represents a final compromise agreement, **expanding from FRT capabilities** and having a **broader scope** and more comprehensive technical requirements • It provides a **common position of the TSOs** in view of the expected expansion of electrolyser facilities and provides an **outlook on further developments**. • Background info: The requirements often mimic the upcoming mandatory requirements 1:1 (for VDE 4130 update)

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4-ÜNB-Positionspapier zu

Fault-Ride-Through- und Modell-anforderungen an Elektrolyseanlagen

4-TSO position paper on
Fault-Ride-Through and modelling requirements for electrolyser facilities

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Technische Anforderung für den Anschluss von Elektrolyseanlagen

Technical requirements for the connection of electrolyser facilities

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German technical compromise for ELYs

New terms and definitions

Electrolyser Unit:

- The **smallest independently operable unit** for producing hydrogen or other gases via electrolysis.
- *Vs. EU DCC proposal:* ***'power-to-gas demand unit' means a demand unit that converts electricity to gases (such as hydrogen or, with subsequent methanation, synthetic methane or other gases).***

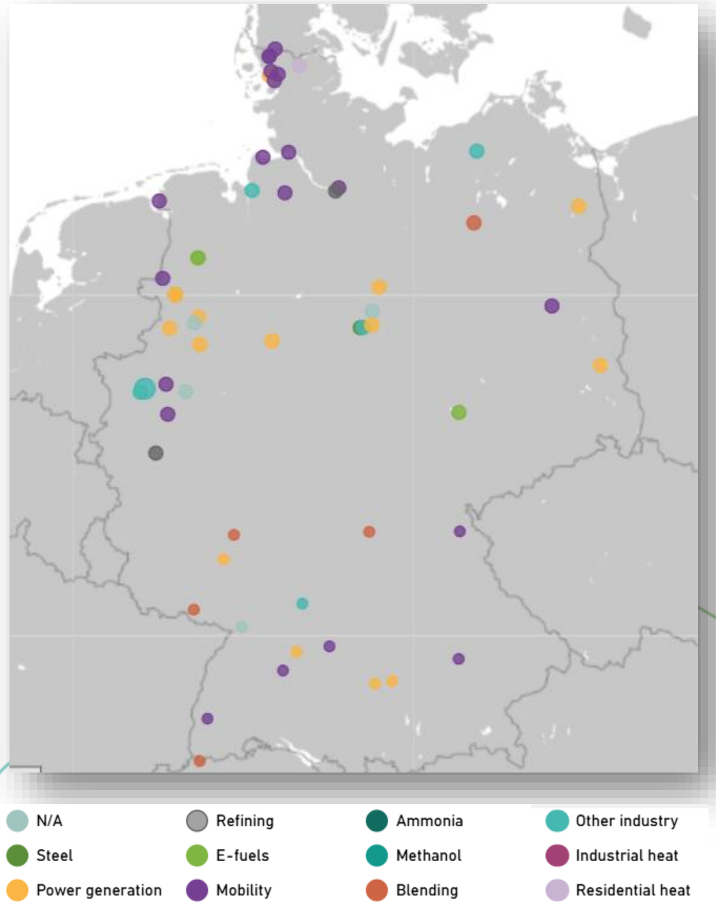
Electrolyser Facility:

- A system for **hydrogen or gas production via electrolysis**, composed of **one or more electrolyser units**.

Split between electrolysis and „regular loads“:

- The requirements apply to the electrolysis plant as a whole, **including all ancillary systems required for the maintenance of the electrolysis process** (e.g. cooling, compressors). → Excluding new requirements for downstream chemical plant

Map of operational P2G projects by end-use. Source: HE Monitor



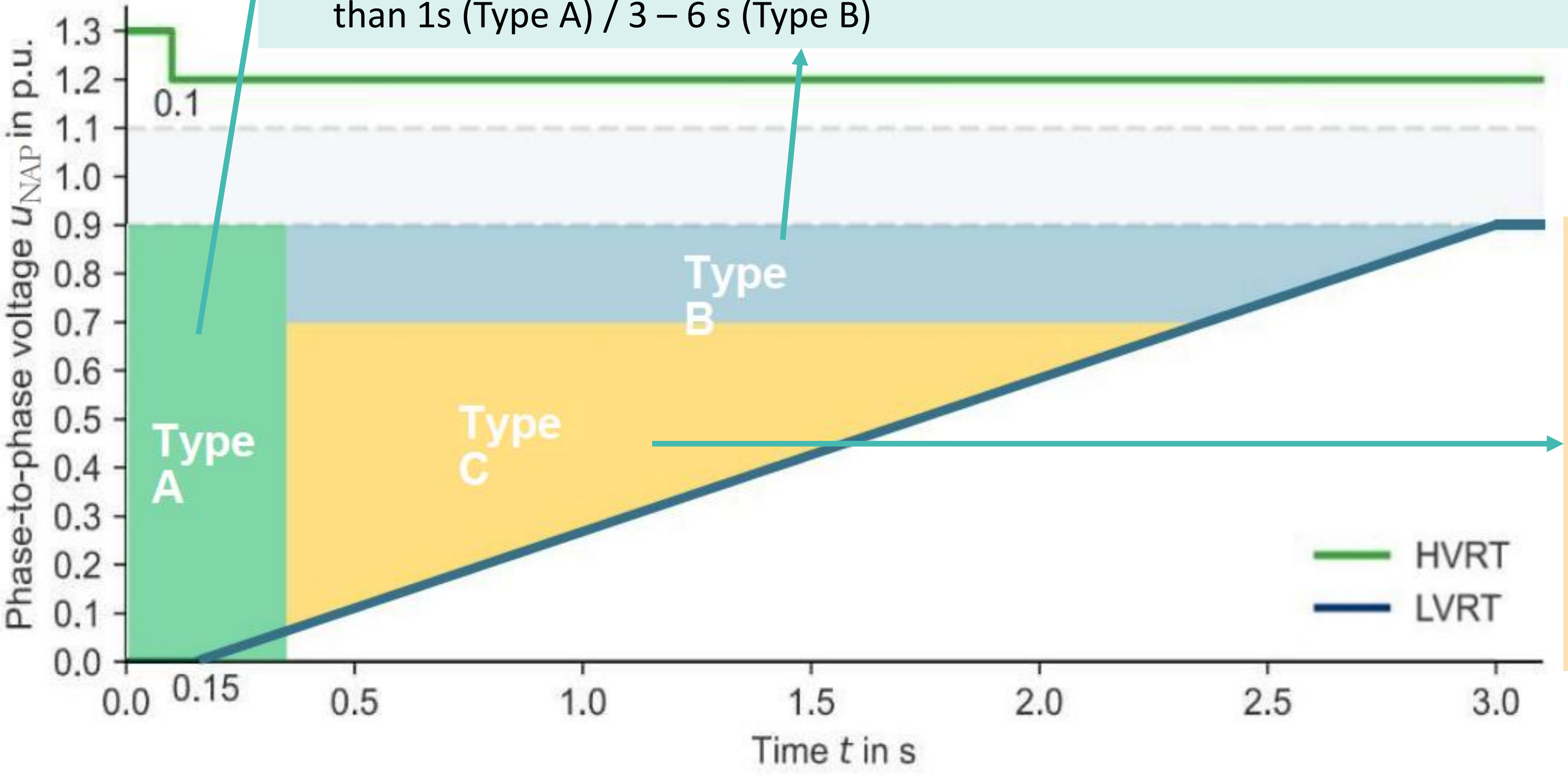
Biggest ELY water electrolysis project in DE is 20 Mwel.
Currently in execution e.g. 280 MW in Emden

German technical compromise for ELYs

More Comprehensive Technical Requirements

- The exception rule differentiates the FRT capability and the recovery of active power consumption into **three sub-areas for three different fault types** (type A, B and C) until updated VDE 4130 will become mandatory by 2027/28.
- These must be agreed and implemented on a **project specific basis** with the respective TSO
- Only applicable for first 2-3 GW

- Electrolysis system must be able to **run through grid fault completely**.
- Recovery of the active power consumption on recovery of the main voltage within Uref +-10% must be faster than 1s (Type A) / 3 – 6 s (Type B)



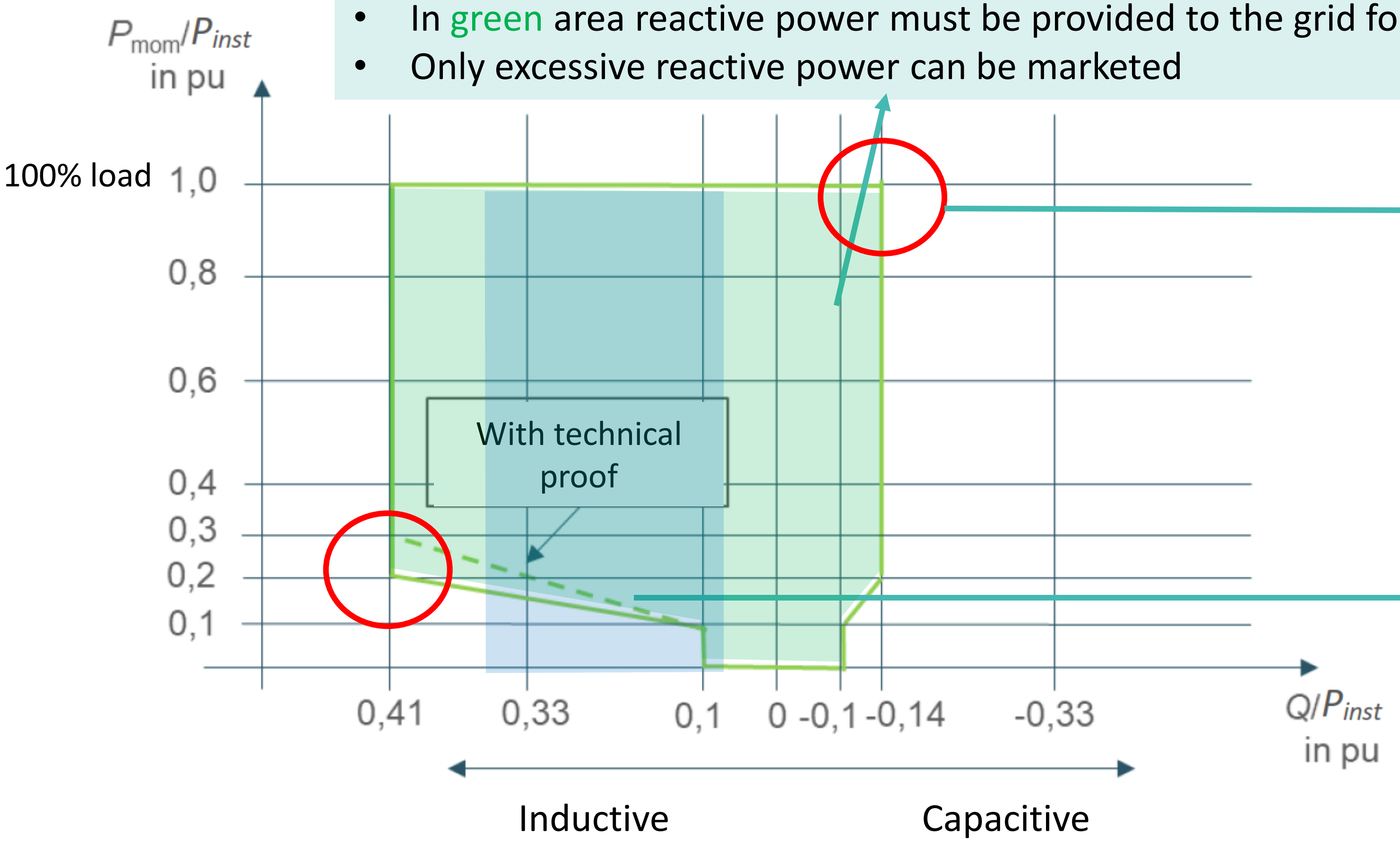
- **Area must be driven through according to skill and ability**
- Recovery of the active power consumption on recovery of the main voltage within Uref +-10% must be faster than 3 – 6 s, **if technically possible**
- **Most critical part of curve for process**

German technical compromise for ELYs

More Comprehensive Technical Requirements

- Intensive discussions on reactive power requirements
- Requirement shifted to inductive side to keep rectifier technologies open (Thyristor and IGBT)
- STATCOM operation required
- TSO can decide not to request reactive power as specified below (for example in case of nearby HVDC terminal)

- In green area reactive power must be provided to the grid for free = “minimum requirement”
- Only excessive reactive power can be marketed



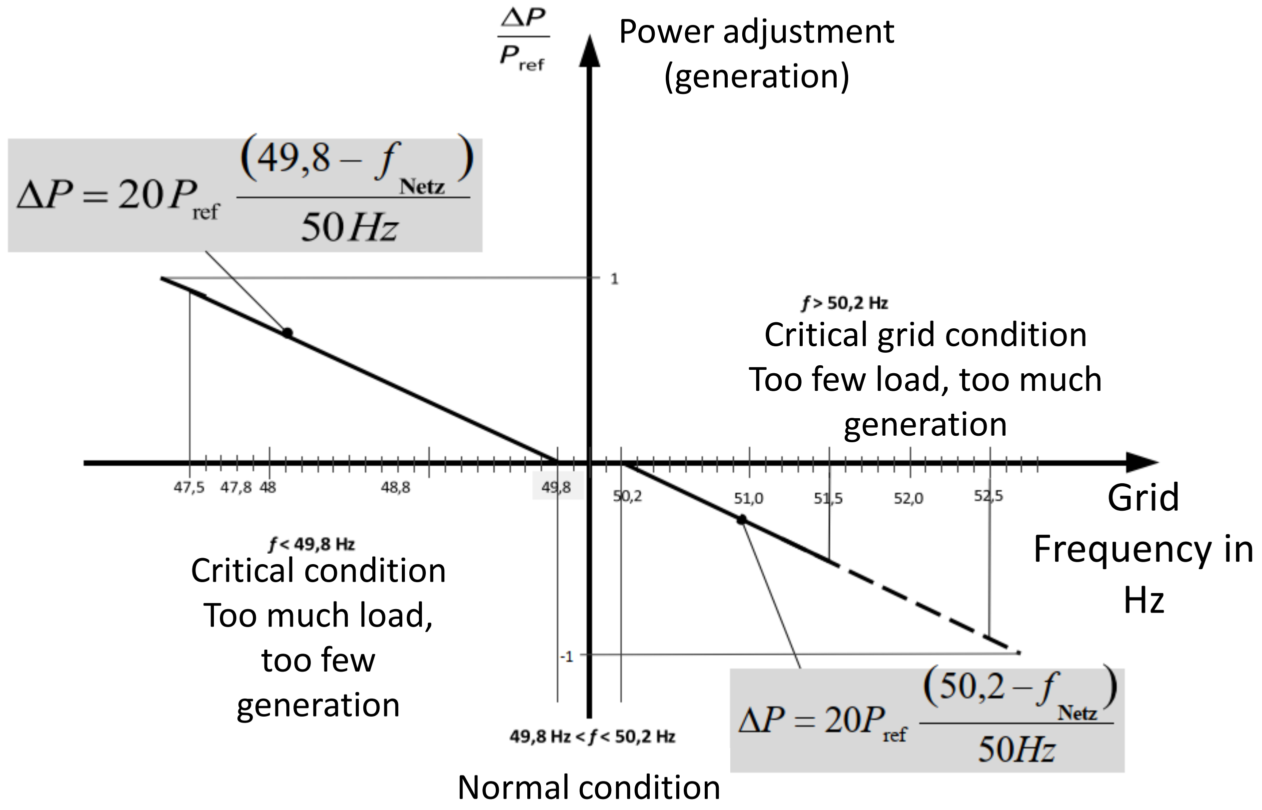
- Red circles indicate the cost-drivers for plant

- Blue area shows typical limit for existing codes for reactive power consumption (cos(phi) = 0.95), which would be “provided for free”

German technical compromise for ELYs

More Comprehensive Technical Requirements

- Limited Frequency Sensitivity Mode defined (LFSM)
- Option to choose load shedding instead of LFSM
- Demanding for chemical plant: 5% static → ΔP 40%/second



- **Consumption power increase:** Step response time ≤ 10 s and settling time ≤ 30 s for a ΔP ≤ 50 % of Pinst
- **Consumption power reduction:** Step response time ≤ 2 s and settling time ≤ 20 s for a ΔP ≤ 50 % of Pinst

German technical compromise for ELY

Other technical requirements

Requirements for **operation within the minimum and maximum short-circuit power range**.

Specific values for the **rate of change of frequency (RoCoF)** that electrolyser facilities must be able to withstand without disconnecting from the grid.

Detailed **requirements for the speed of active power** increase after fault clearance within defined voltage limits and permissible transient times.

Detailed **regulations for participation in load shedding and/or frequency-dependent adjustment of active power consumption** with specific frequency thresholds, static droops, and time behaviour.

Conditions for automatic or **manual reclosure of facilities or units after a grid disconnection**.

Requirements for **the adjustment of active power operation** upon the grid operator's request (including control speed) and the implementation of **Emergency Power Control** (EPC) functions.

Specific power change rates for setpoint specifications by third parties.

requirements for dynamic reactive current injection and continuous dynamic grid support during voltage fluctuations, including response times and consideration of positive and

Requirements regarding **undesirable interactions with other facilities** and the grid in various frequency ranges.

German technical compromise for ELY

Prioritisation of requirements

- The compromise paper includes a dedicated section on the prioritization of requirements in grid situations where not all requirements can be met simultaneously without conflict:

1. **Protection and grid stability functions come first**, ensuring that damage prevention, automation, and dynamic support take precedence.
2. **Power ramping and voltage control are secondary considerations**, ensuring that grid stability is not compromised by rapid output fluctuations.
3. **Setpoints for active/reactive power are the lowest priority**, meaning they are only followed when all higher-level constraints are met.

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Grid operator interventions are prioritized over standard operation, meaning ELY flexibility must align with real-time grid needs.

German technical compromise for ELY

Gradual Introduction of technical conditions

- Exemptions can only be implemented if **regional limits on cumulative electrolysis capacity are taken into account**. The compromise introduces a development path for a gradual introduction of the technical connection conditions.
- **Project-specific requirements are necessary** – to be done in close coordination between the respective TSO and plant operator.
  - Examples of this are locations where electrolysis connected to the transmission grid at grid nodes with an already high local concentration of offshore wind turbines in the GW range.

Follow-up contract		
Project-specific	**Regional**	**National**
Grid operator determines	< 2 GW	< 3 GW

Minimum requirements

Exceptions for FRT capability and the return of active power consumption can be agreed with the grid operator.

German technical compromise for ELY

Extended Modelling Requirements

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Two Simulation Models Required:

- **Detailed Model:** High-fidelity simulations for compliance testing and local grid studies.
- **Aggregated Model:** Simplified model for system-wide studies, combining multiple electrolyser units.

Modeling Scope & Capabilities:

- Must represent **full electrolyser behaviour at the grid connection point**.
- Covers frequency response, voltage variations, power recovery, protection mechanisms, and grid stability support.

Technical Specifications:

- Electromagnetic Transient (EMT) & Root Mean Square (RMS) models required.
- Dynamic response simulations must have millisecond-level precision.
- Models must be maintained and updated over the electrolyzer’s lifetime.
- Open data exchange is required for grid operator studies.
- Detailed models can be manufacturer-specific (black-box) or generic (open-parameter).

Main takeaways and implications for the EU context

Hydrogen Europe

ACER
European Union Agency for the Cooperation of Energy Regulators

COMMISSION REGULATION (EU) .../...

of ...

establishing a Network Code on Demand Connection

(Text with EEA relevance)

Lessons learned for the EU DCC framework

What can we learn from the experience with DCCs in DE and DK

More flexibility of technical requirements implementation at local level

- Allow **local grid operators more flexibility in the final agreement for P2G units connection**, ensuring requirements reflect actual regional grid needs instead of a one-size-fits-all requirements (while ensuring reasonable and minimum harmonisation alignment with EU DCC).
- Allow for some **flexibility in requirements for certain regions of the FRT curve where meeting these requirements may be technically challenging for P2G units** –especially where the grid needs might allow for such FRT curves. Final approval between the local grid operator and plant operator can determine which parts of the curve must be met and under what conditions.

Simplified and scaled-down modelling:

- Use **simplified, scaled-down models for modelling testing**. These models should be theoretical and later validated through on-grid testing, this will significantly reduce the cost and complexity of initial technical

A more delimited P2G unit scope

- Define the technical **scope of a P2G unit more precisely**, limiting the scope of compliance to the minimum set of components critical for functionality. This will reduce the burden of making every part of the facility adhere to DCC requirements.

Phased FRT Implementation:

- Allow **Member States to introduce a phased implementation of the DCC conditions** based on regional and national P2G capacities rollout. *This phased implementation could be introduced on the premises of power-to-gas facilities of over 20 MWs are an emerging technology (biggest ELY in Europe is 20 MW & there are < 400 MWel installed in Europe vs. 173.6 GW of heat pumps and 2.8 GW of batteries, for instance*). This would enable smoother integration of electrolysers into the grid and allow for gradual testing and modifications as technology mature.

Implications at EU level from existing DK and DE technical requirements

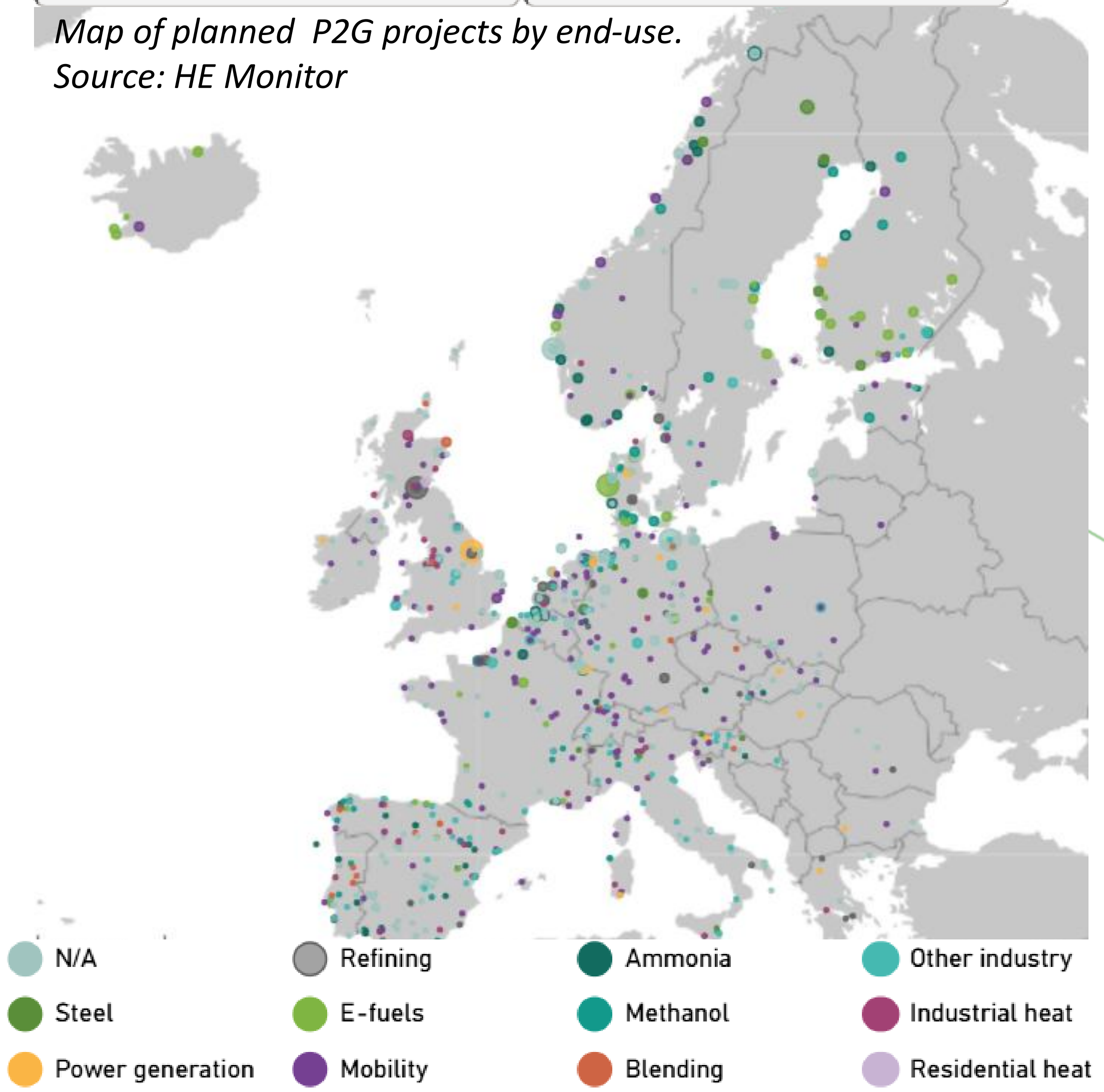
Greater discretion for TSOs/DSOs to tailor technical requirements reduces unnecessary constraints but it will require **more available information of local grid needs for project developers**.

Applying FRT only to ELY > 200 MW in DK could **accelerate projects in DK** but **might displace investment signals for other countries** where P2G projects are also needed.

Modelling guidance in Germany will **help develop testing and modelling procedures** for scaling-up P2G projects.

Limiting **DCC requirements to essential components will simplify integration** and DCC requirements will have **less impact on other parts of the ELY supply chain** (compressors, valves, etc.)

13.875.774	1.125
Total production capacity (tonnes/year)	Nr of Clean installations



Map of planned P2G projects by end-use.
Source: HE Monitor

Thank You

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