CONNECTION CODES – KEY ISSUES

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ENTSO-E's Workshop with Stakeholders on the Connection Network Codes national implementation.

25 February 2016

Vienna

entsoe

Reliable Sustainable Connected

1 The need of network codes and their development

2 Key technical requirements for power generating modules (NC RfG)

3 Key technical requirements for demand connection (NC DCC)

4 Key technical requirements for HVDC systems and DC-connected power park modules (NC HVDC)

5 The way towards implementation

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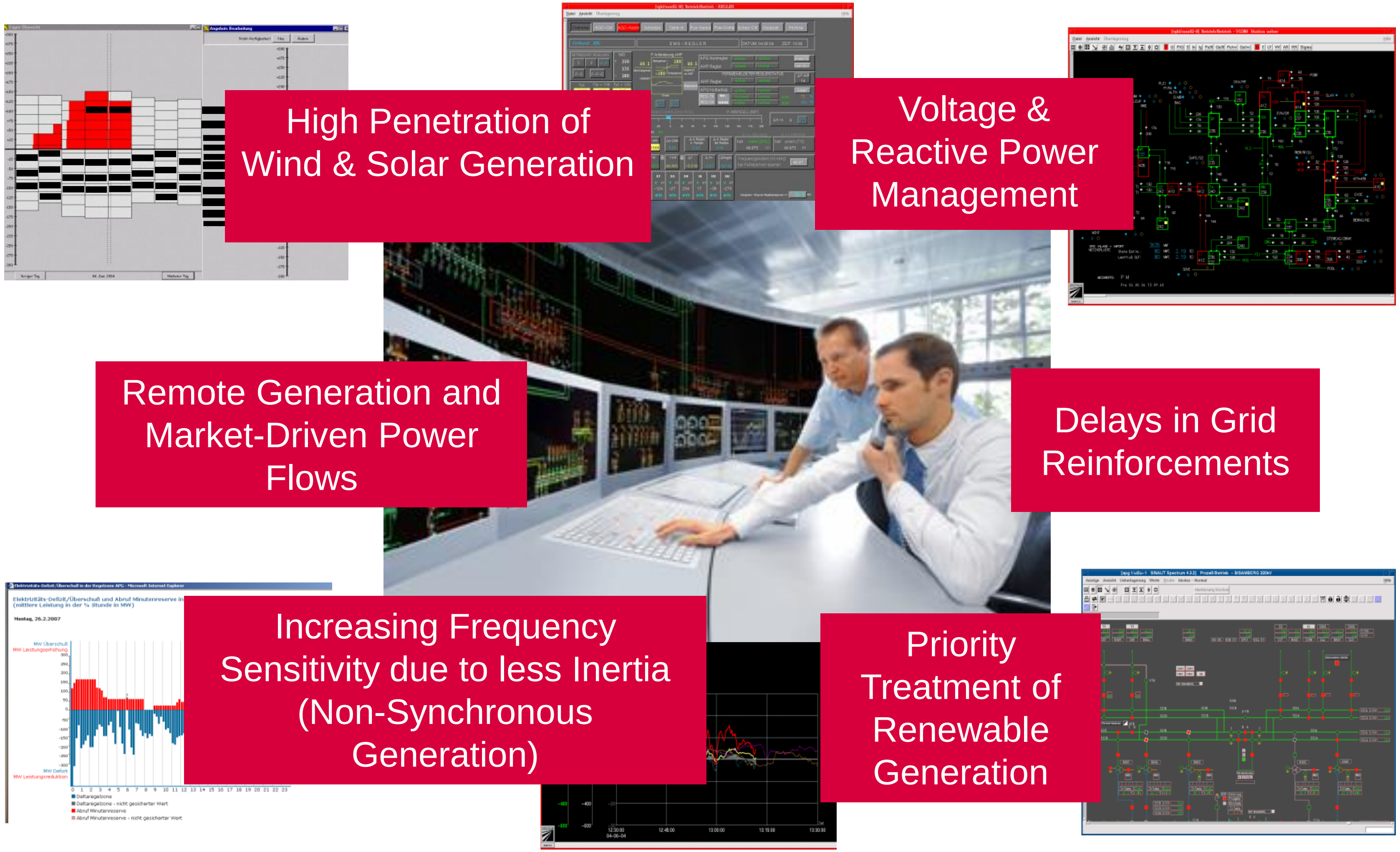
5 The way towards implementation

Secure system operation – it‘s getting harder



High Penetration of Wind & Solar Generation

Voltage & Reactive Power Management

Remote Generation and Market-Driven Power Flows

Delays in Grid Reinforcements

Increasing Frequency Sensitivity due to less Inertia (Non-Synchronous Generation)

Priority Treatment of Renewable Generation

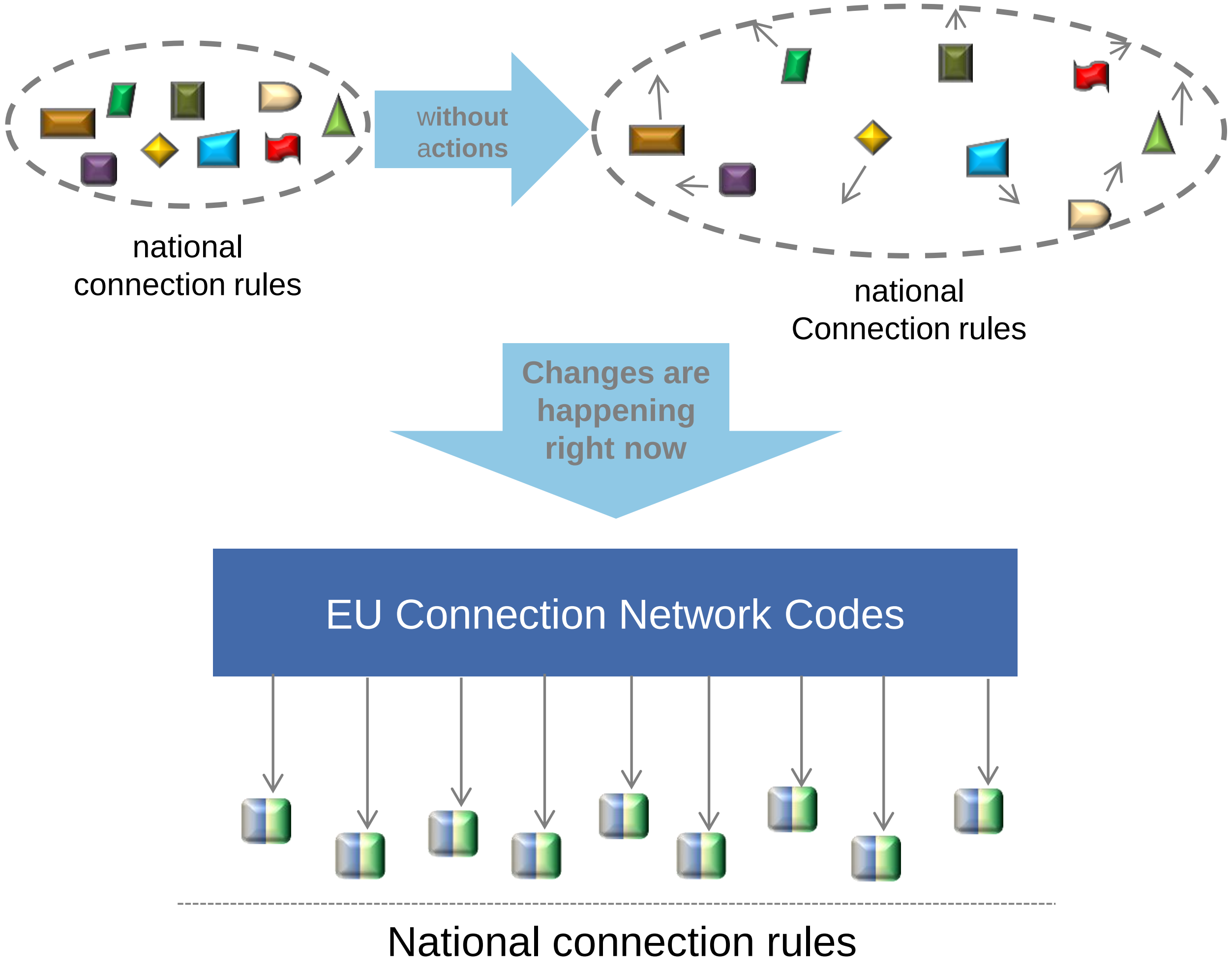
What are the crucial aspects of system security?

Build and maintain transmission networks for long-distance power flows

Implementation of market mechanisms to facilitate a single European electricity market

Continuous evolution and coordination of system operation

Stable operation, robustness of and provision of ancillary services by system users



Why do we need connection requirements?

- From a systems engineering approach, the transmission systems and their users (transmission and distribution systems, power generating modules, demand facilities, etc.) need to be considered comprehensively

- They shall cooperate closely during normal and disturbed operating conditions in order to preserve or restore system security

- In particular, power generating modules and “active” installations play an important role with their ability to provide ancillary services for:
  - system balancing / frequency control
  - voltage control
  - robustness against disturbances → stable operation
  - system restoration after blackouts

1. The need of network codes and their development
2. Key technical requirements for power generating modules (NC RfG)
3. Key technical requirements for demand connection (NC DCC)
4. Key technical requirements for HVDC systems and DC-connected power park modules (NC HVDC)
5. The way towards implementation

Significant users

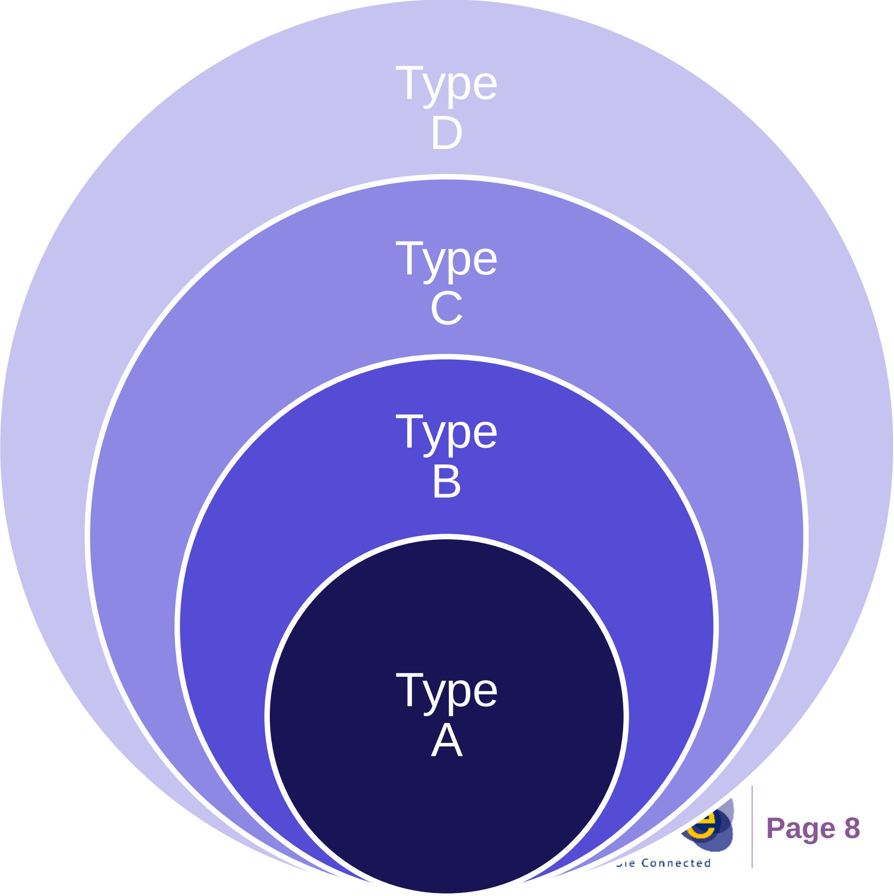
- Generator capabilities are defined from a system performance perspective and are therefore largely independent from technology
- Need to be sustainable to cope with evolutions in generation mix
- Significance is regarded per requirement

Wide-scale network operation and stability including European-wide balancing services

Stable and controllable dynamic response capabilities covering all operational network states

Automated dynamic response and resilience to operational events including system operator control

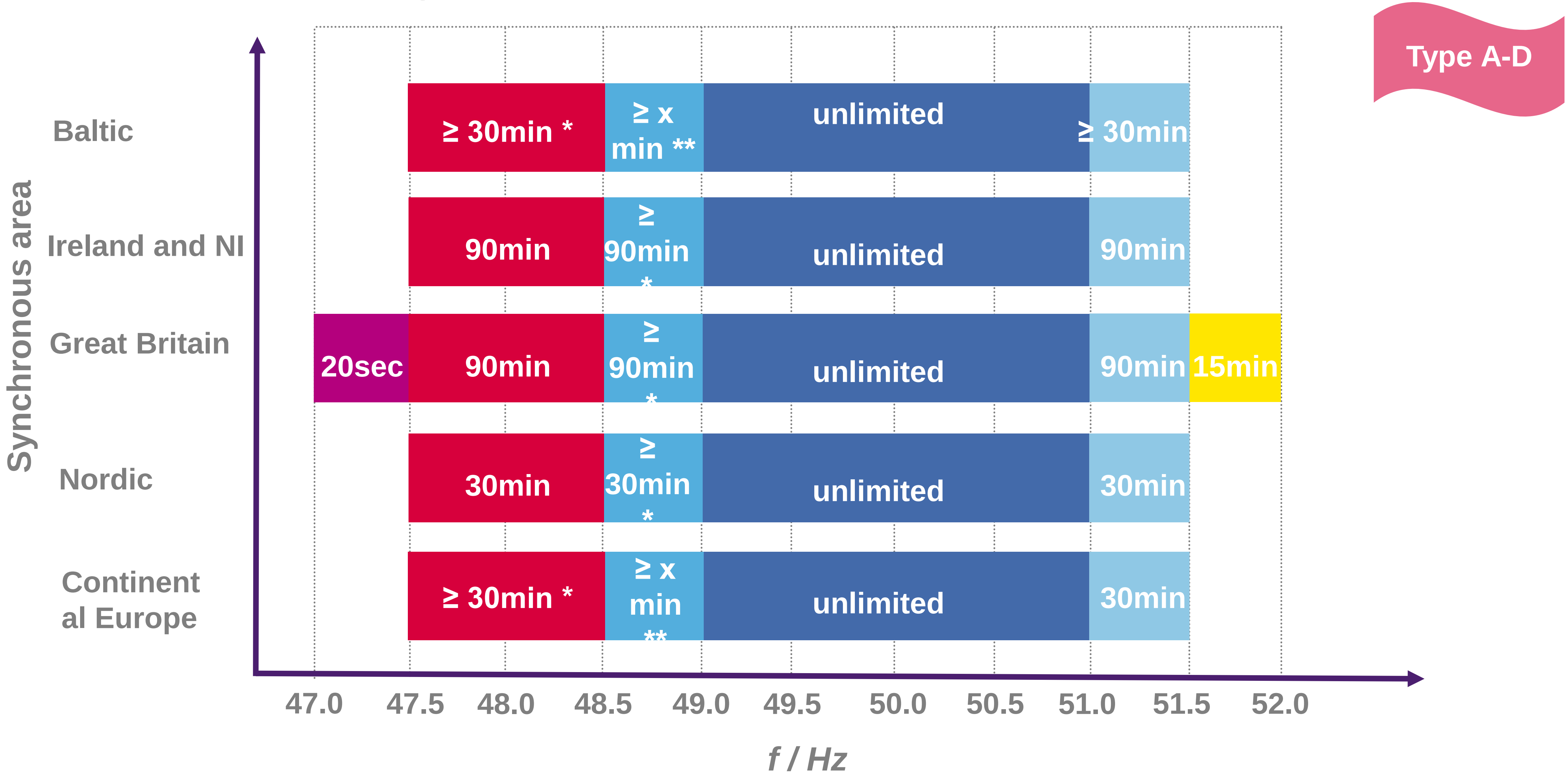
Basic capabilities to withstand wide-scale critical events; limited automated response/operator control



Categories of power generating modules

Synchronous area	Lower threshold for Type A	Maximum lower threshold for Type B	Maximum lower threshold for Type C	Maximum lower threshold for Type D
Continental Europe	0.8 kW	1 MW	50 MW	75 MW
Nordic	0.8 kW	1.5 MW	10 MW	30 MW
Great Britain	0.8 kW	1 MW	50 MW	75 MW
Ireland and NI	0.8 kW	0.1 MW	5 MW	10 MW
Baltic	0.8 kW	0.5 MW	10 MW	15 MW
	and	and	and	or
Voltage level	< 110 kV	< 110 kV	< 110 kV	≥ 110 kV

Frequency Ranges

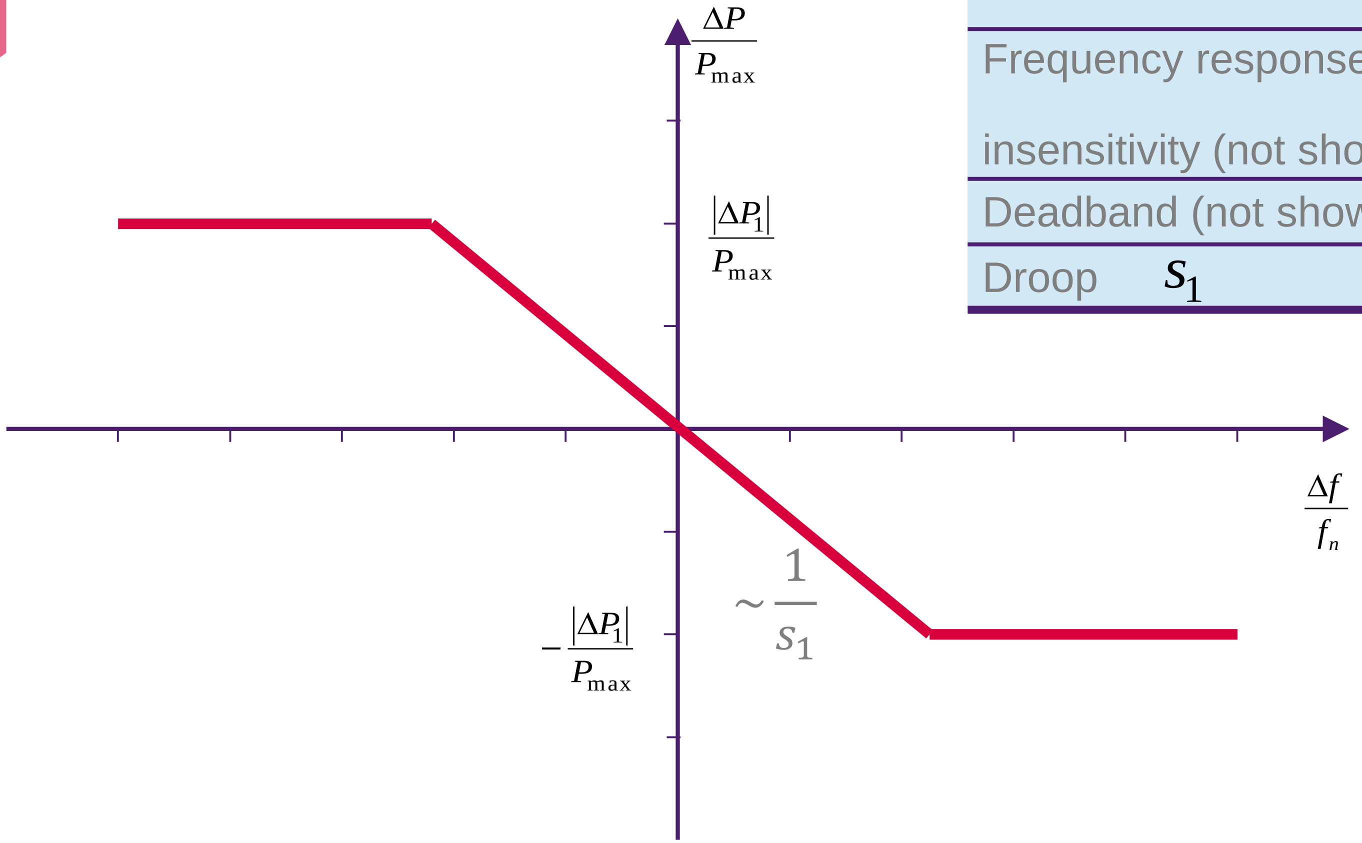


* to be determined by the relevant TSO

** to be determined by the relevant TSO; ≥ time of **47.5 - 48.5 Hz**

Frequency Sensitivity Mode

Type C-D

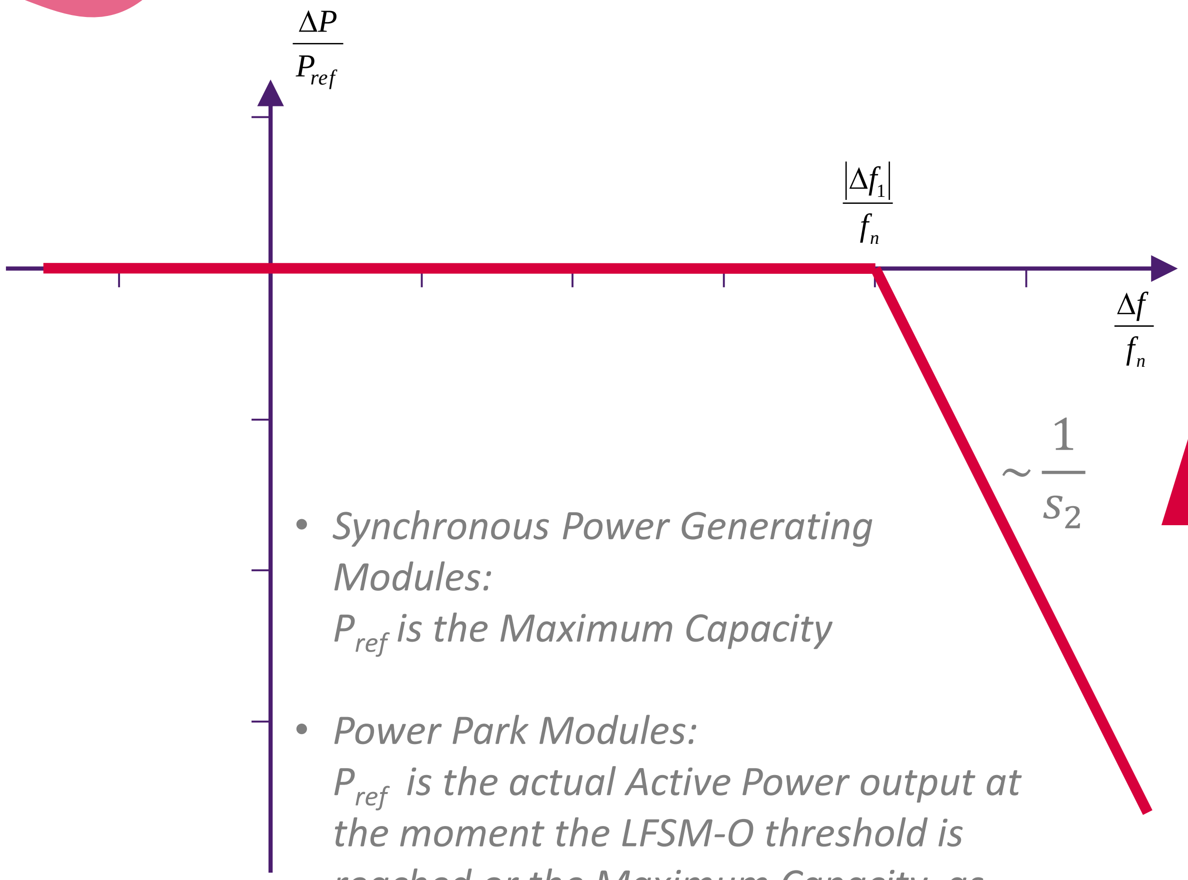


Parameter	Range
Active Power range $\frac{\lvert\Delta P_1\rvert}{P_{max}}$	1.5 – 10 %
Frequency response insensitivity (not shown) $\frac{\lvert\Delta f_i\rvert}{f_n}$	0.02 – 0.06 %
Deadband (not shown)	0 – 500 mHz
Droop s_1	2 – 12 %

$$s_1[\%] = 100 \cdot \frac{|\Delta f|}{f_n} \cdot \frac{P_{ref}}{|\Delta P|}$$

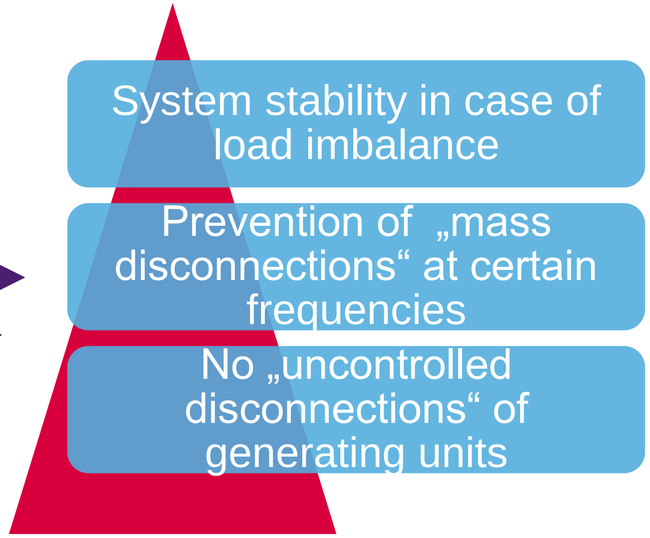
Limited Frequency Sensitivity Mode - Overfrequency

Type A-D



- *Synchronous Power Generating Modules:*
  P_{ref} is the Maximum Capacity

- *Power Park Modules:*
  P_{ref} is the actual Active Power output at the moment the LFSM-O threshold is reached or the Maximum Capacity, as defined by the Relevant TSO



$$s_2[\%] = 100 \cdot \frac{|\Delta f| - |\Delta f_1|}{f_n} \cdot \frac{P_{ref}}{|\Delta P|}$$

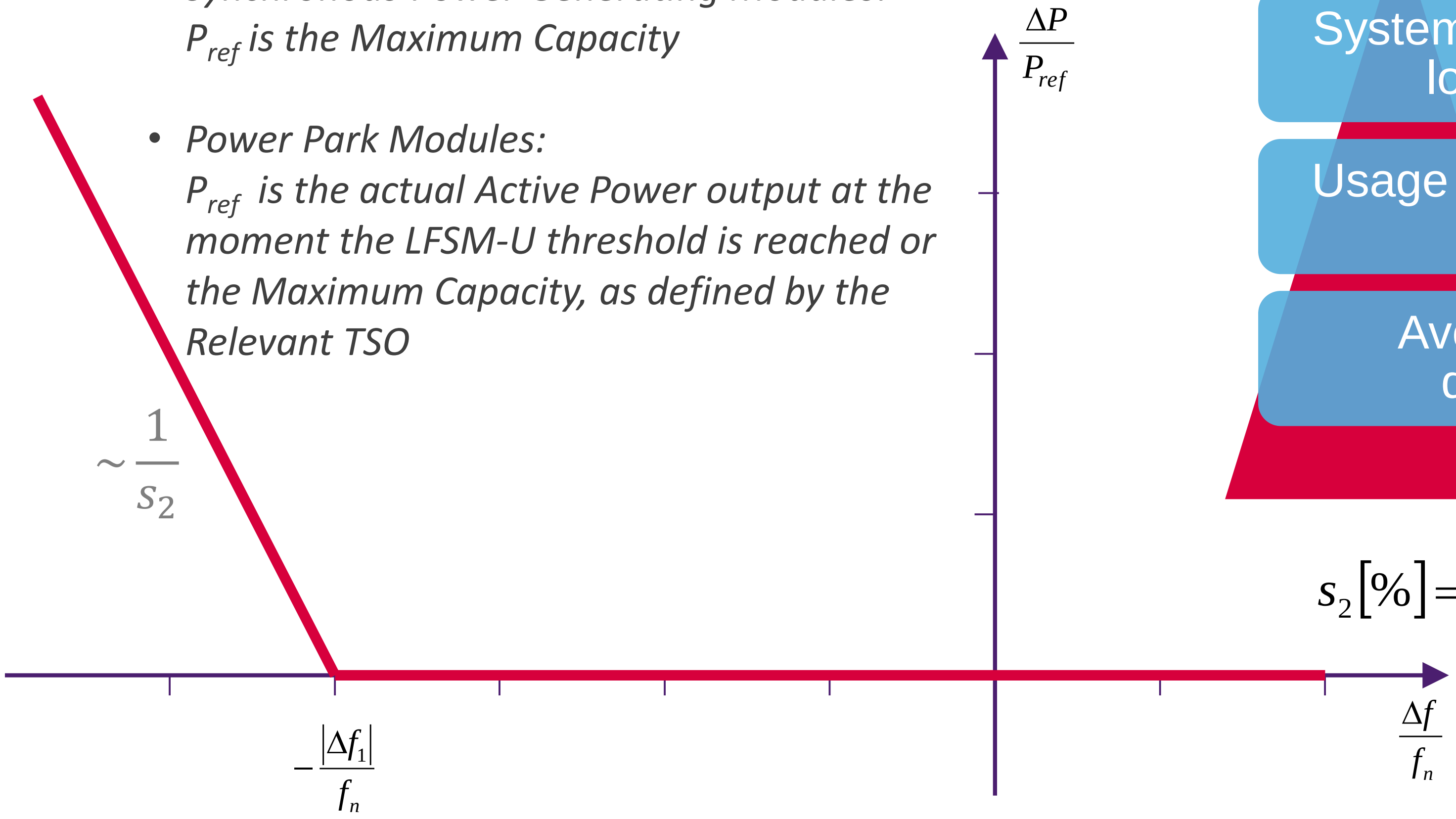
$$\frac{\Delta f_1}{f_n} = 0{,}4 - 1\%$$

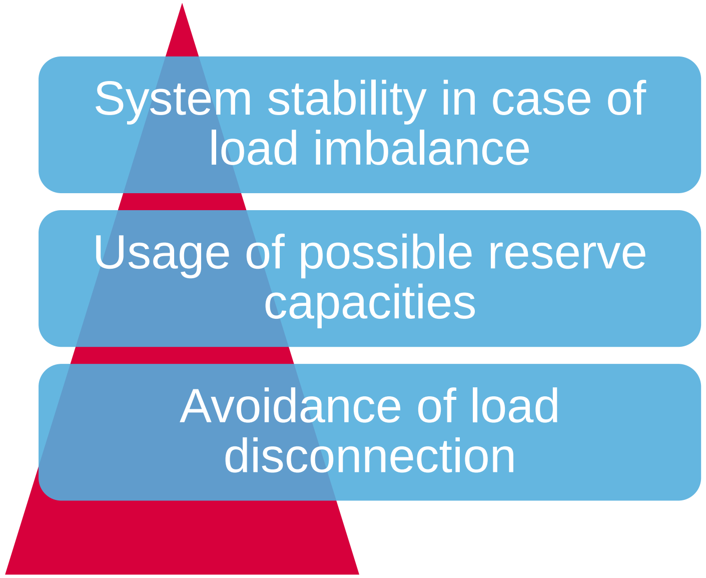
$$s_2 = 2 - 12\%$$

Limited Frequency Sensitivity Mode - Underfrequency

Type C-D

- *Synchronous Power Generating Modules:*
  P_{ref} is the Maximum Capacity
- *Power Park Modules:*
  P_{ref} is the actual Active Power output at the moment the LFSM-U threshold is reached or the Maximum Capacity, as defined by the Relevant TSO



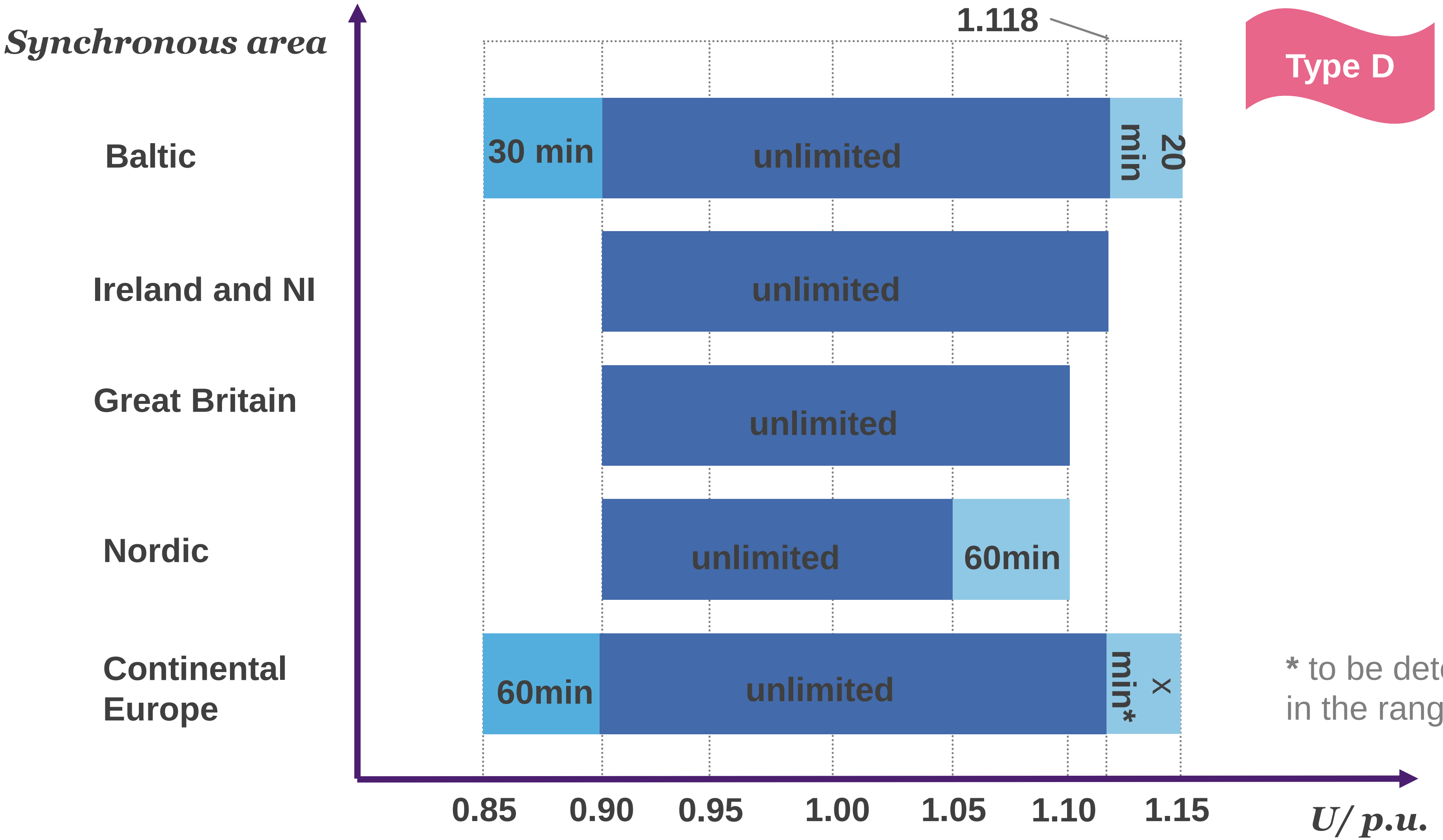


$$s_2[\%] = 100 \cdot \frac{|\Delta f| - |\Delta f_1|}{f_n} \cdot \frac{P_{ref}}{|\Delta P|}$$

$$\frac{\Delta f_1}{f_n} = 0{,}4 - 1\%$$

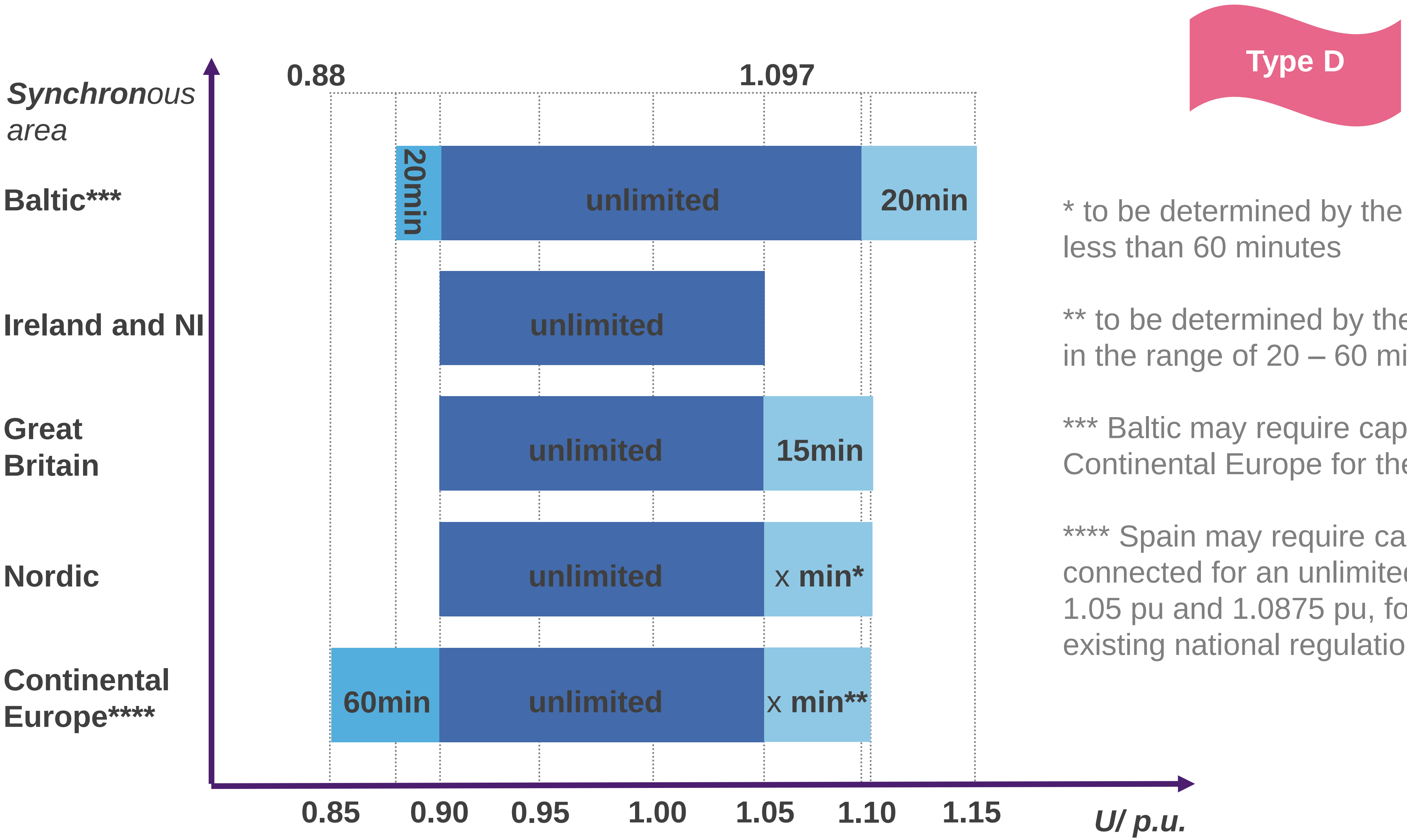
$$s_2 = 2 - 12\%$$

Voltage Ranges (Voltage levels 110 kV ≤ U < 300 kV)



* to be determined by the relevant TSO in the range of 20 – 60 minutes

Voltage Ranges (Voltage levels 300 kV ≤ U ≤ 400 kV)



* to be determined by the relevant TSO, but less than 60 minutes

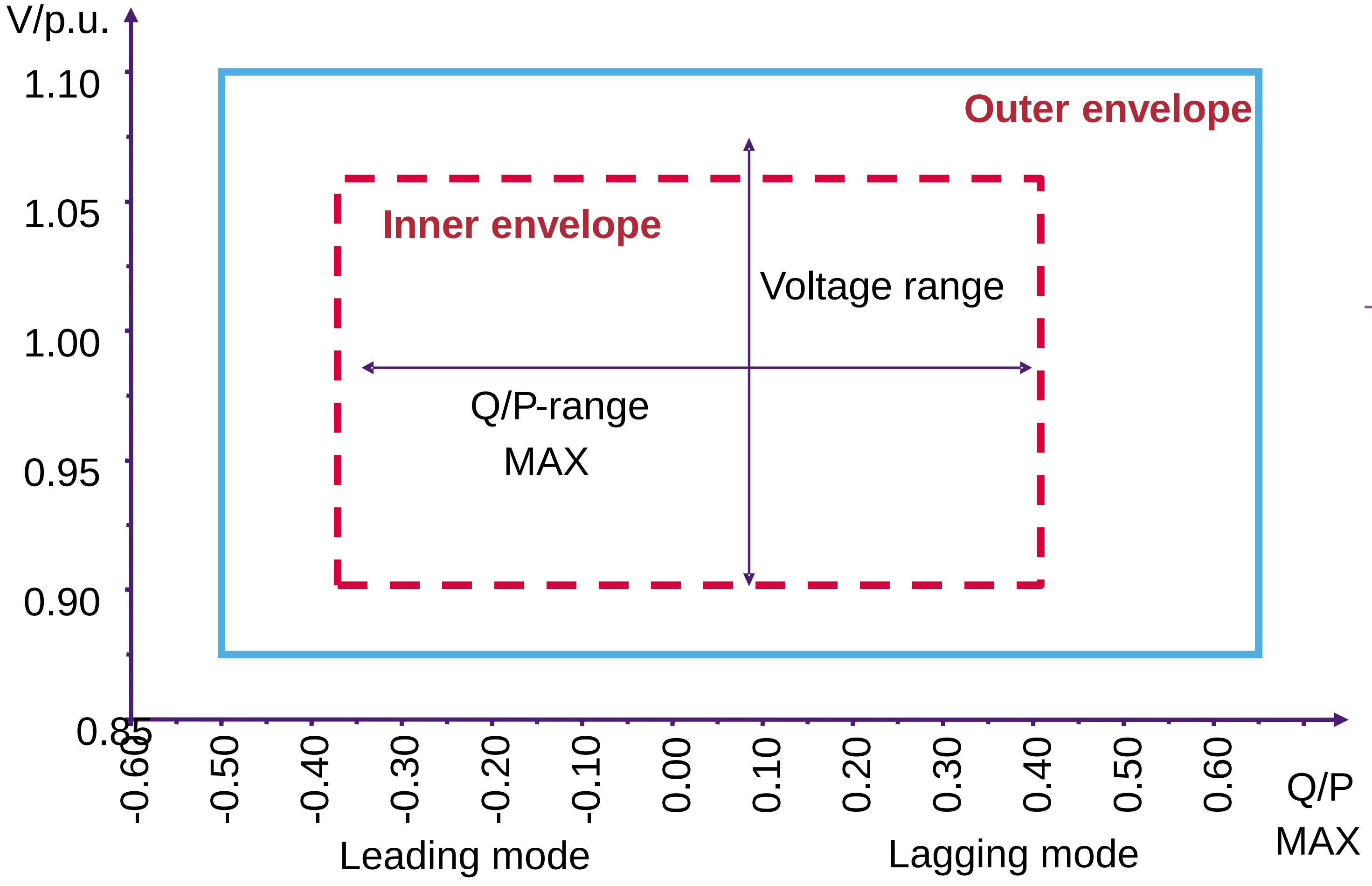
** to be determined by the relevant TSO in the range of 20 – 60 minutes

*** Baltic may require capabilities as of Continental Europe for the 400 kV level

**** Spain may require capability of remaining connected for an unlimited period between 1.05 pu and 1.0875 pu, for consistency with existing national regulation

Reactive Power Capability at Maximum Active Power

Type C-D



Synchronous Power Generating Modules

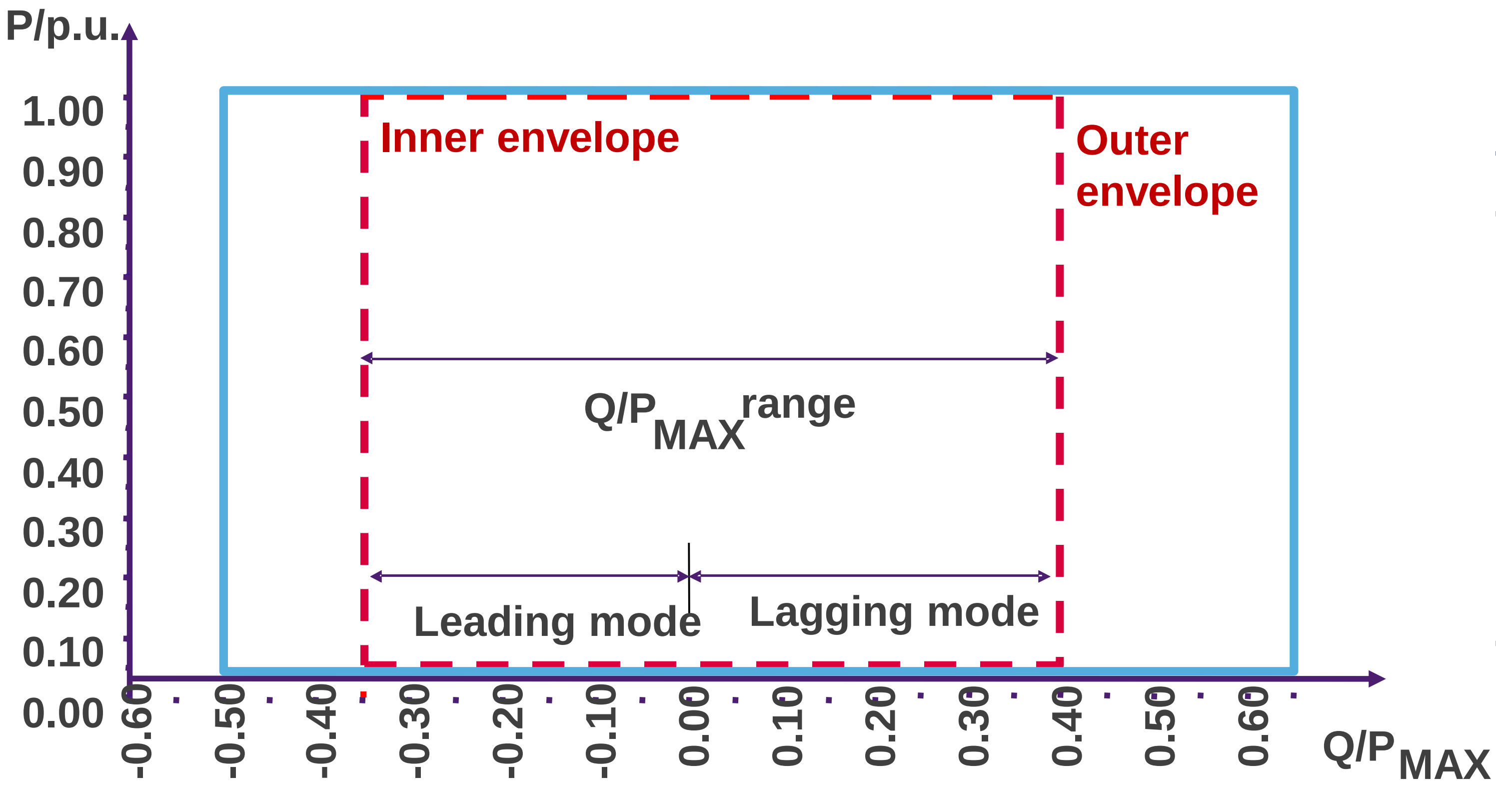
Synchronous area	Max. Q/P_{max}-range	Voltage range [p.u.]
Continental Europe	0.95	0.225
Nordic	0.95	0.150
Great Britain	0.95	0.225
Ireland + NI	1.08	0.218
Baltic States	1.0	0.220

Power Park Modules

Synchronous area	Max. Q/P_{max}-range	Voltage range [p.u.]
Continental Europe	0.75	0.225
Nordic	0.95	0.150
Great Britain	0.66	0.225
Ireland + NI	0.66	0.218
Baltic States	0.80	0.220

Reactive Power Capability below Maximum Active Power

Type C-D

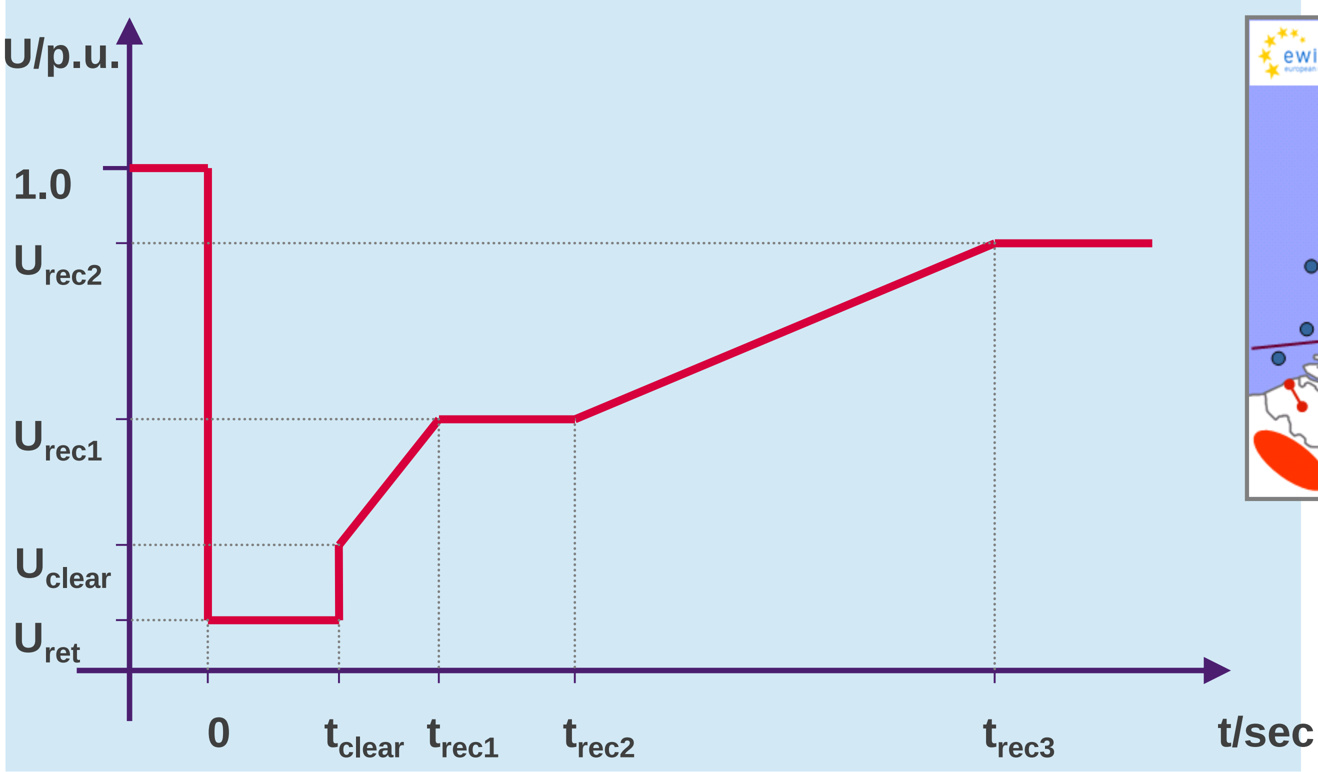


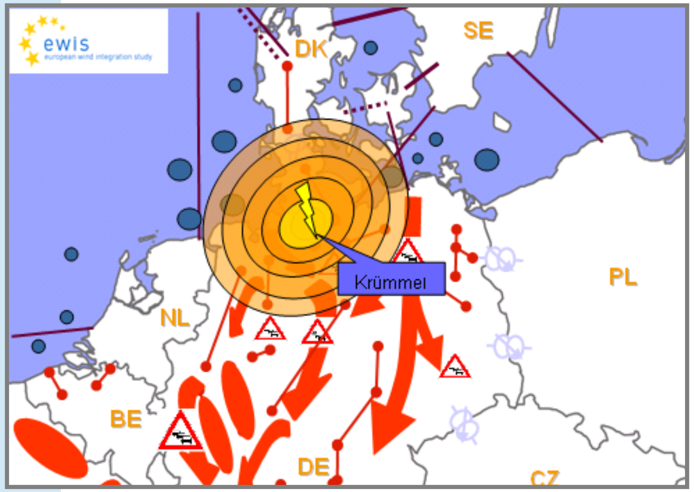
Power Park Modules

Synchronous area	Max. Q/Pmax-range
Continental Europe	0.75
Nordic	0.95
Great Britain	0.66
Ireland + NI	0.66
Baltic States	0.80

Fault-Ride-Through Requirements (I)

- the power generating module shall be capable of remaining connected to the network and continuing to operate stably when the actual course of the phase-to-phase voltages on the network voltage level at the connection point before, during and after a symmetrical fault, remain above the lower limit specified by a voltage-against-time profile





Type B-D

Fault-Ride-Through Requirements (II)

Type B-D

- Voltage-against-time profile parameters

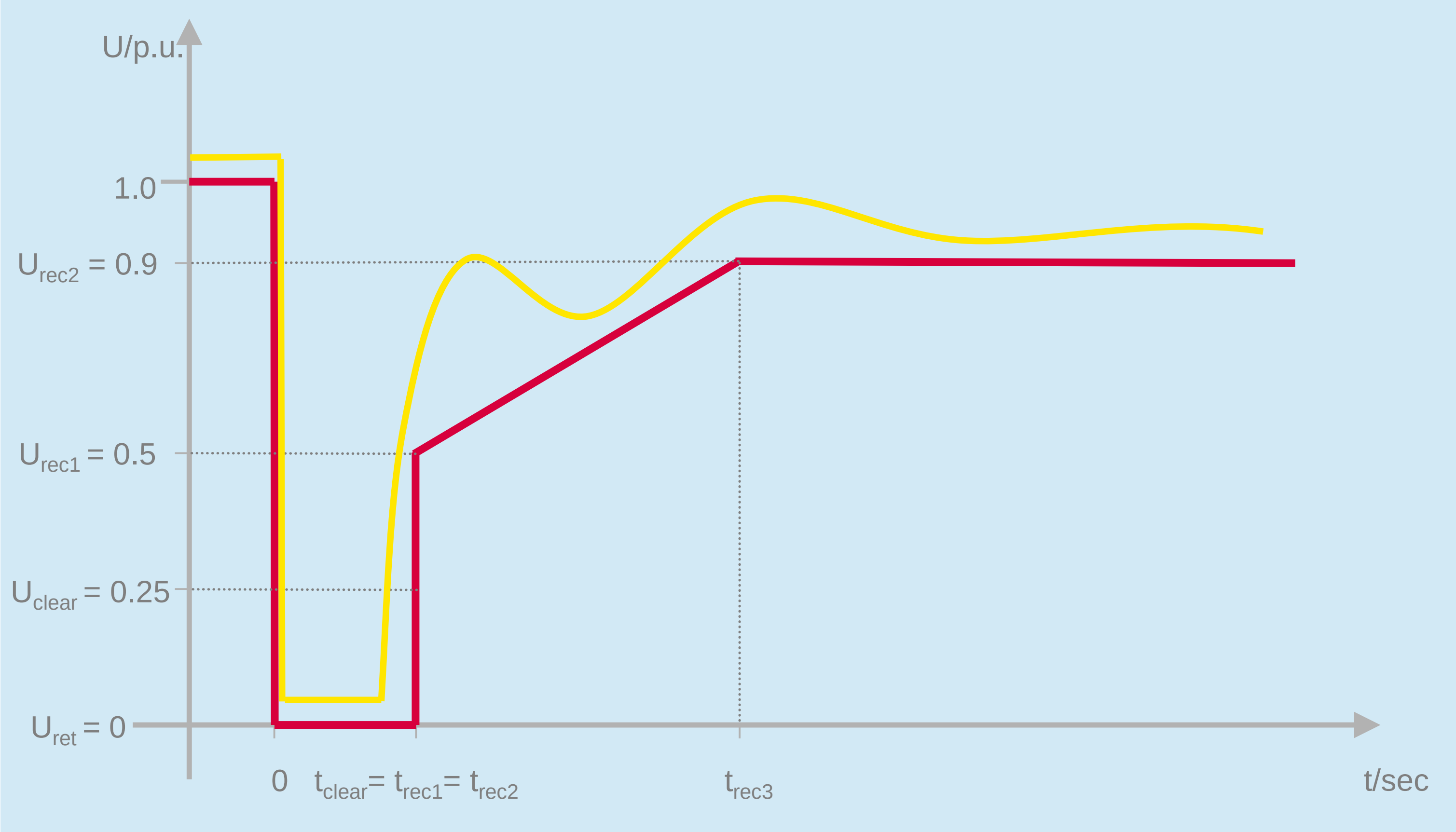
	synchronous power generating modules				power park modules			
Type B/C	voltage parameters [pu]		time parameters [sec]		voltage parameters [pu]		time parameters [sec]	
	U_{ret}:	0.05 – 0.3	t_{clear}:	0.14 – 0.15*	U_{ret}:	0.05 – 0.15	t_{clear}:	0.14 – 0.15*
	U_{clear}:	0.7 – 0.9	t_{rec1}:	t_{clear}	U_{clear}:	U_{ret} – 0.15	t_{rec1}:	t_{clear}
	U_{rec1}:	U_{clear}	t_{rec2}:	t_{rec1} – 0.7	U_{rec1}:	U_{clear}	t_{rec2}:	t_{rec1}
	U_{rec2}:	0.85 – 0.9 und ≥ U_{clear}	t_{rec3}:	t_{rec2} – 1.5	U_{rec2}:	0.85	t_{rec3}:	1.5 – 3.0
Type D	voltage parameters [pu]		time parameters [sec]		voltage parameters [pu]		time parameters [sec]	
	U_{ret}:	0	t_{clear}:	0.14 – 0.15*	U_{ret}:	0	t_{clear}:	0.14 – 0.15*
	U_{clear}:	0.25	t_{rec1}:	t_{clear} – 0.45	U_{clear}:	U_{ret}	t_{rec1}:	t_{clear}
	U_{rec1}:	0.5 – 0.7	t_{rec2}:	t_{rec1} – 0.7	U_{rec1}:	U_{clear}	t_{rec2}:	t_{rec1}
	U_{rec2}:	0.85 – 0.9	t_{rec3}:	t_{rec2} – 1.5	U_{rec2}:	0.85	t_{rec3}:	1.5 – 3.0

* or 0.14 - 0.25 if system protection and secure operation so require

Fault-Ride-Through Requirements (III)

Type B-D

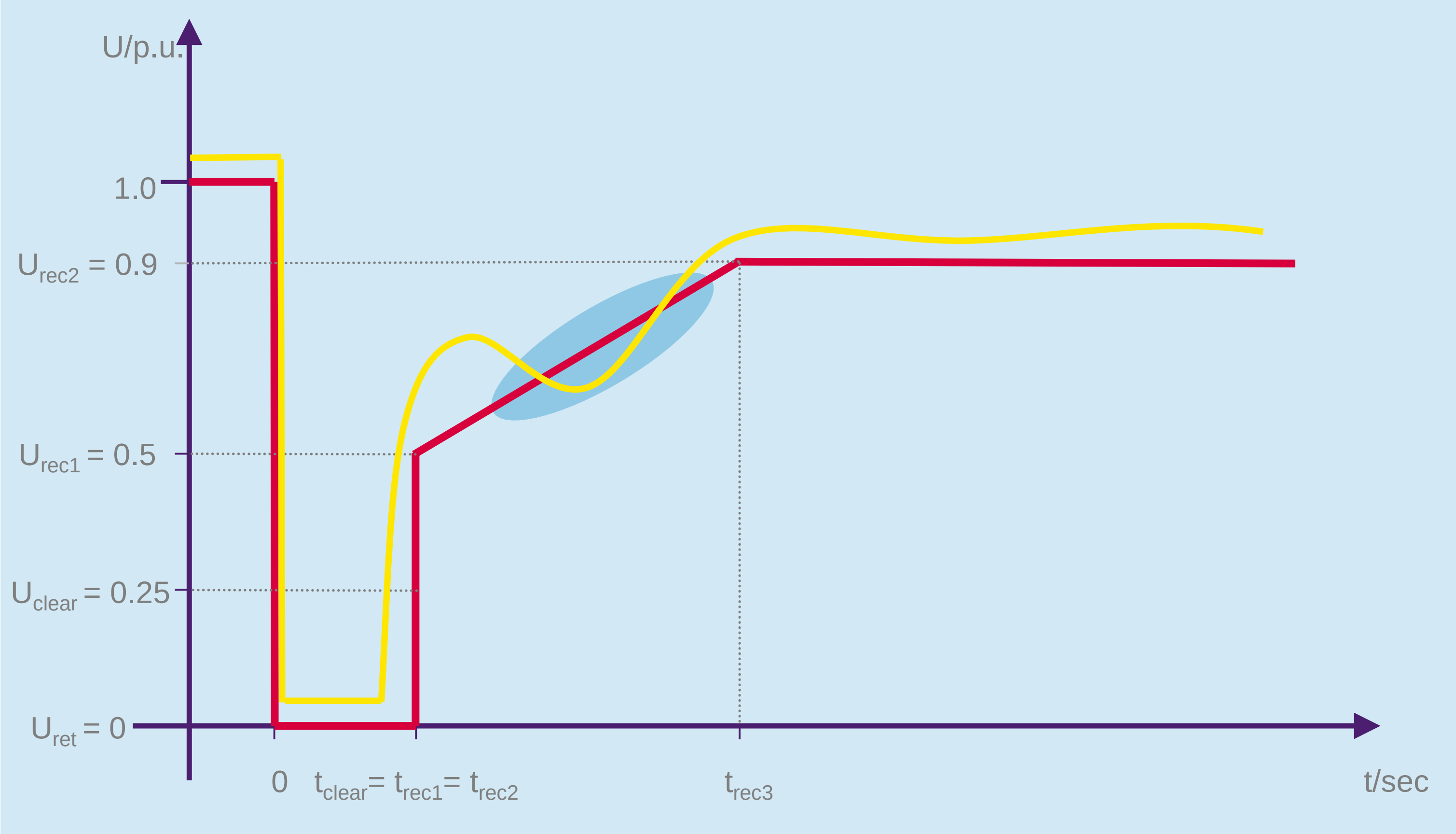
- Disconnection not admissible



Fault-Ride-Through Requirements (IV)

Type B-D

- Disconnection admissible



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Significant users

All demand users directly connected to transmission network are considered to be significant

- transmission-connected demand facilities;
- transmission-connected distribution facilities, and;
- distribution systems, including new closed distribution systems

All demand units used by users to provide DSR services suitable for transmission use are considered significant:

- Active Power Control (APC)
- Reactive Power Control (RPC)
- Transmission Constraint Management (TCM)
- System Frequency Control
- Very Fast Active Power Control)

All singularly or collectively can have a cross border influence on the Transmission Network

However requirements only apply to demand facilities, system and/or demand units that are:

- New
- Above 1000V and have been modified to such an extent that its connection agreement must be substantially revised

Demand Side Response – The Objective

Reserve capability is required due to uncertainty ahead

- Demand and unscheduled position for generation
- Increasing forecasting errors due to high penetration of RES

⇒a bigger volume of reserve will be needed to ensure system security.

Reserves are typically required when an incident occurs until replacement power can be produced defined as reserve ancillary services

- During high RES production, synchronous generation could be displaced, the most economic service for providing reserves

⇒ Risk of a lack of services during high RES production periods

Reactive Power Requirements

Static

- **Applies to:**
  - Transmission Connected Demand Facilities
  - Transmission Connected Distribution Systems
- **Reactive power range requirements are:**
  - TSO specified: Maximum range is 48% (0.9PF) of maximum import or export capability whichever is larger
  - At the connection Point
  - Net of on-site generation at connection point

Network charging

- **Applies to:**
  - Transmission Connected Distribution System
- **Reactive power range requirements are:**
  - Requirement at TSO request (A justified and agreed alternative is possible)
  - At 25% of maximum import and 1PU voltage no mvar export
  - Static point - compliance by simulation

Active

- **Applies to:**
  - Transmission Connected Distribution System
- **Active (Dynamic)Reactive power range requirements are:**
  - Requirement at TSO request (DSO can request TSO to consider applying requirement)
  - Control method to be agreed – SoS to be ensured to TSO/DSO networks
  - Roadmap with timelines to be in justification

Demand Side Response

Demand response services requirements are distinguished based on the following categories:

(a) remotely controlled:

(i) demand response Active Power Control (APC);

(ii) demand response Reactive Power Control (RPC), and;

(iii) demand response Transmission Constraint Management (TCM)

(b) autonomously controlled:

(i) demand response System Frequency Control (SFC), and;

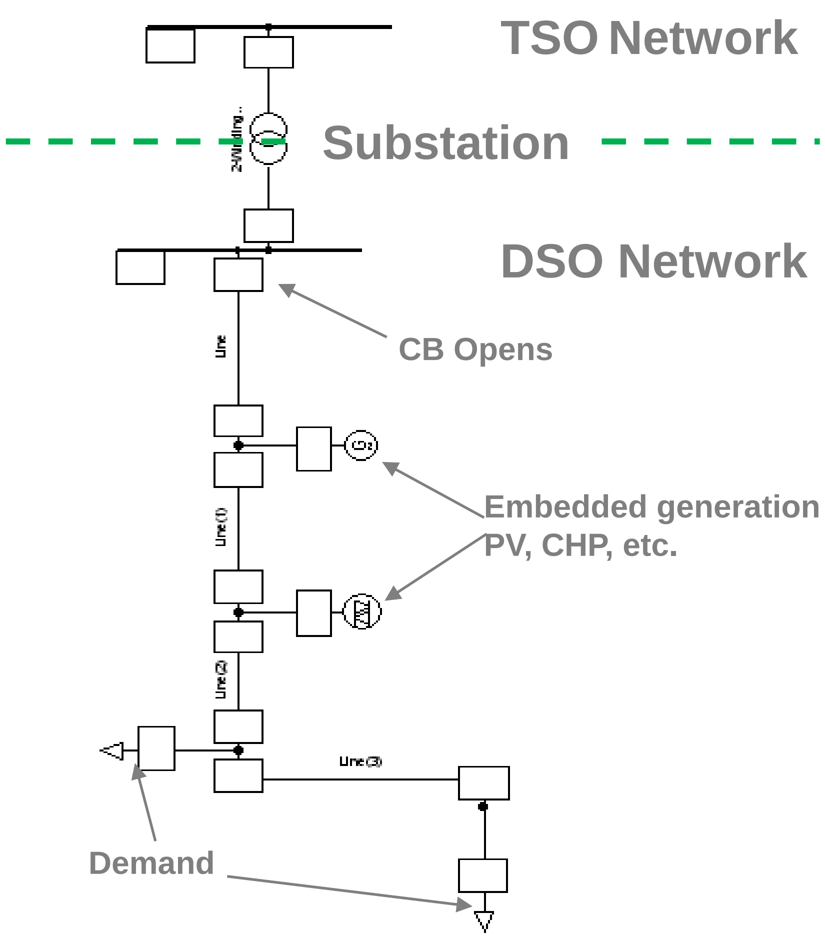
(ii) demand response Very Fast Active Power Control (VFAPC)

Other services excluded as they do not have a cross-border impact

Demand Side Response Remote controlled

- **Frequency and Voltage requirements met by all remote controlled demand units (APC, RPC, TCM)**
- **Below 110kV connection point voltage requirements specified by system operator**
- **All demand units providing remote control services primarily must:**
  - Notify the system operator of changes to its capability
  - Be controllable via a signal from system operator
  - Through aggregation be able to control the static reactive devices for RPC at each facility
  - Be able to withstand a RoCoF set by TSO at 110kV and above and following a stakeholder consultation also below 110kV

DSR SFC – The Objective



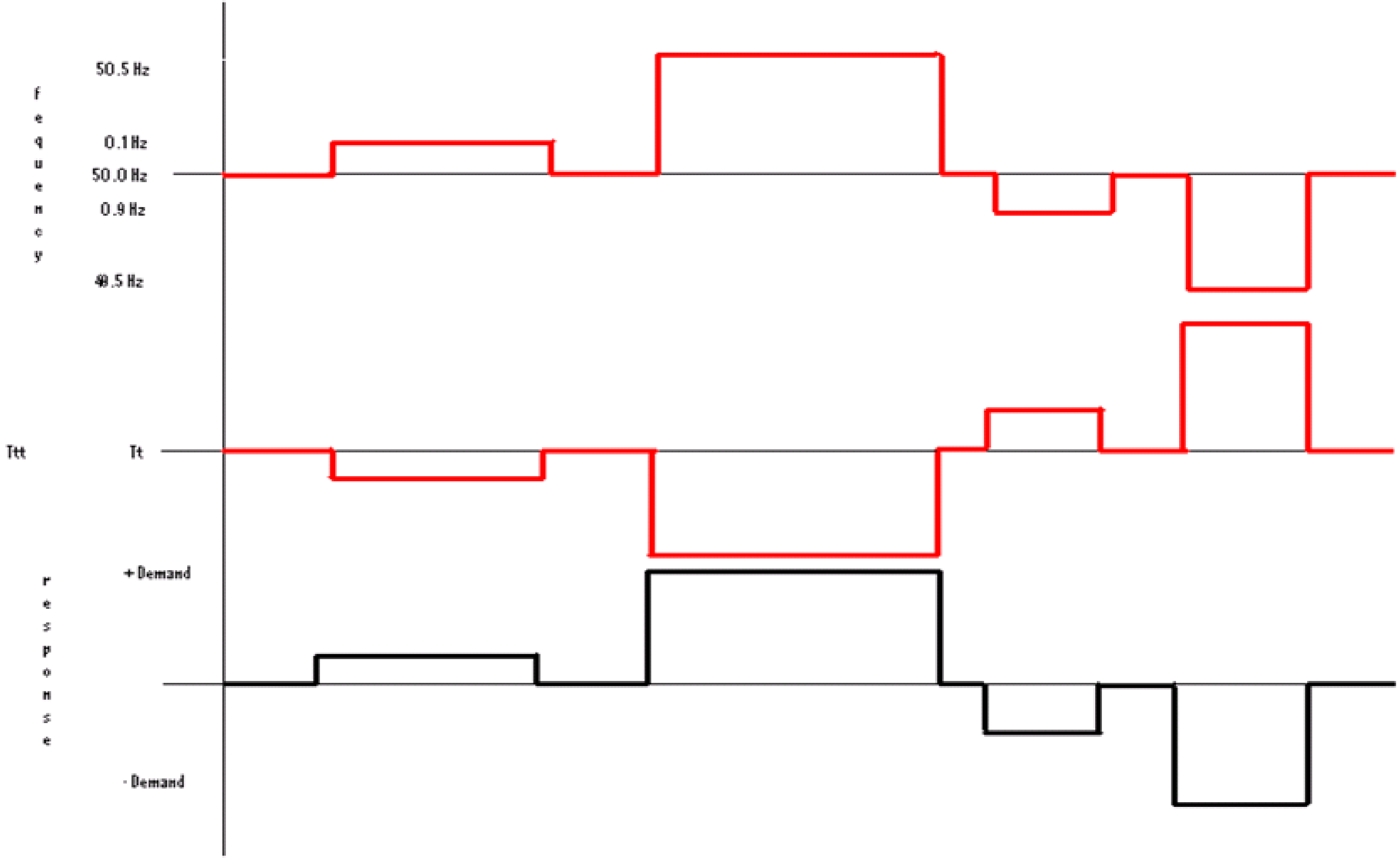
Problems in future with existing Low Frequency Demand Disconnection (LFDD)

LFDD disconnects demand to restore frequency from low levels

Embedded Generation means that demand stations can sometimes produce power

Therefore effectiveness of LFDD reduced or counter productive

Demand Side Response System Frequency Control - Example



Demand Side Response Very Fast Active Power Control – The objective

- System inertia opposes rapid changes in frequency and voltage – permits time for other network devices to respond
- Primarily the summated physical mass in machinery in generators provides system inertia
- VFAPC is needed to replace inertia lost when supplying network with physically lighter renewable generation
- Commonly referred to as synthetic inertia

Demand Side Response Very Fast Active Power Control

If demand facility owner or closed distribution system operator enter into a contract with the TSO, the contract will include:

(a) a change of active power related to a measure (i.e. rate-of-change-off-Frequency);

(b) the operating principle of the control system, and;

(c) the response time (no longer than 2 seconds)

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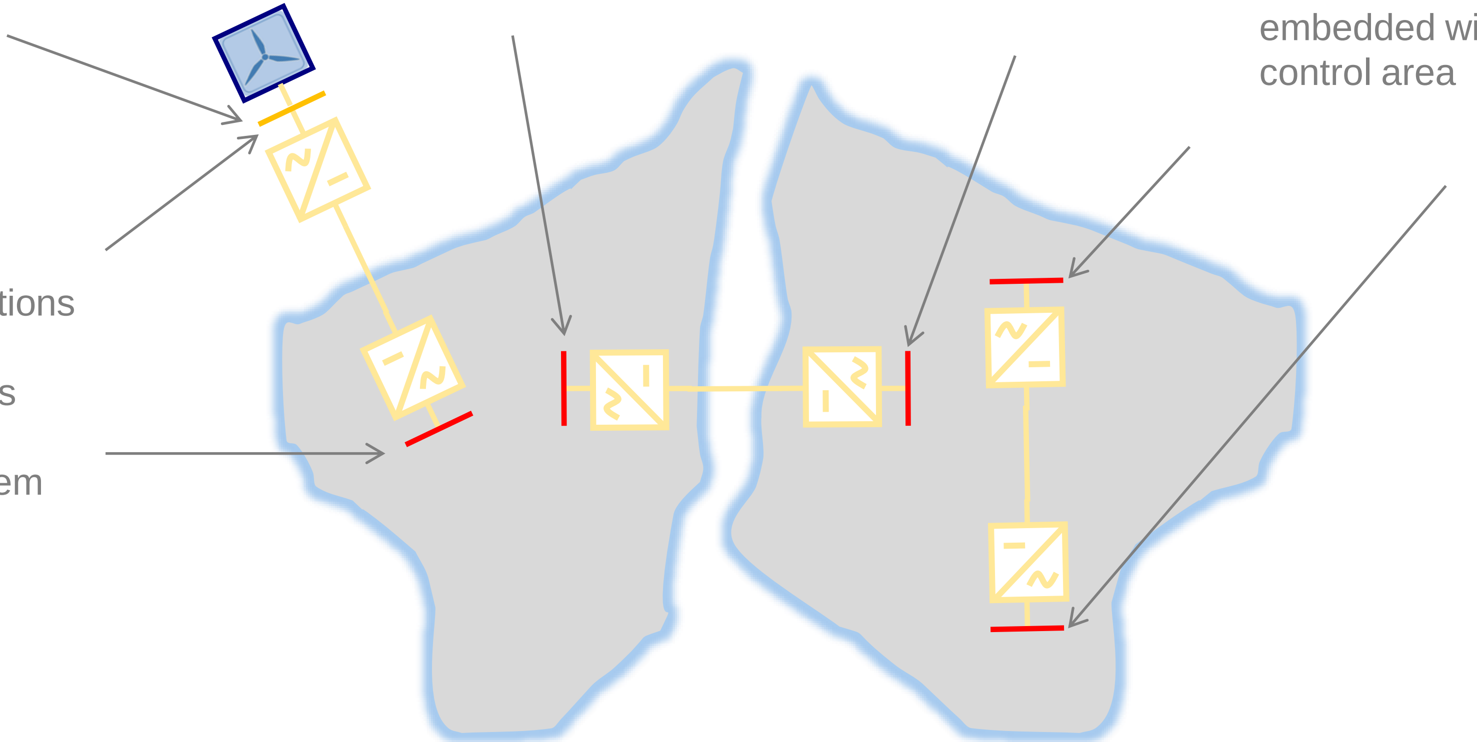
Scope of application

Power Park Module(s) AC collected and DC connected to the main electricity system

HVDC connections between synchronous areas or between control areas including back to back

HVDC connections embedded within one control area



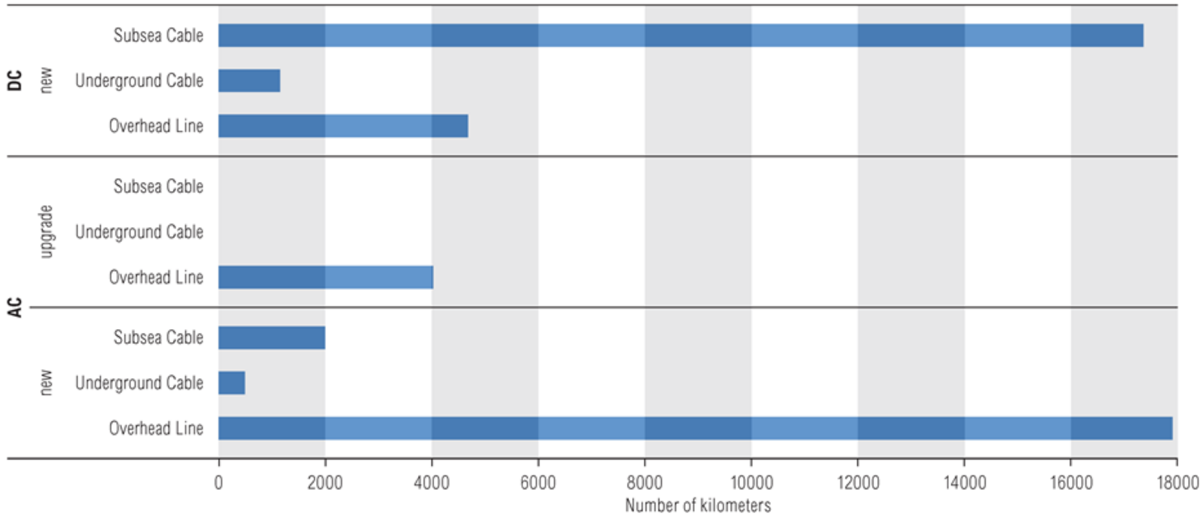
HVDC connections between AC collected PPMs and the main electricity system

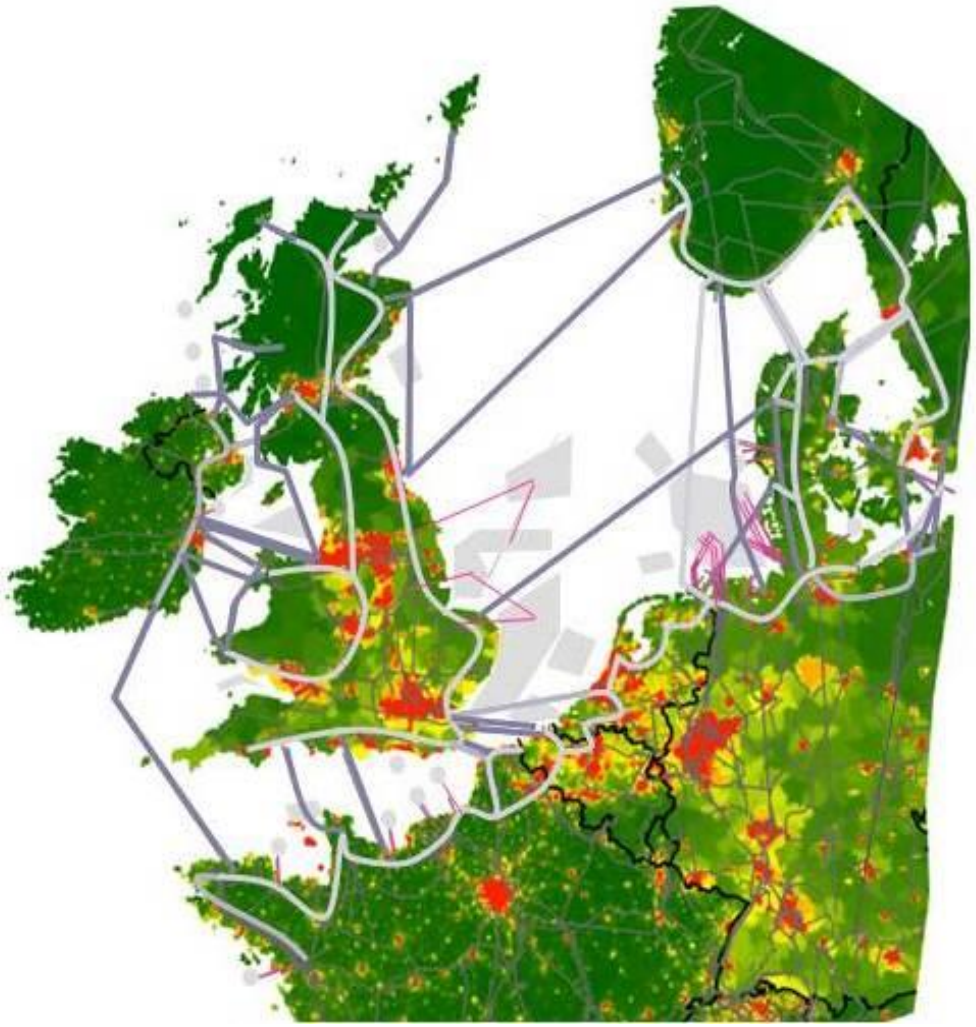
Connection Point(s)

NC HVDC: A view at 2030

TYNDP2014

- *40% of investments (20.000km) DC based*
- *Main drivers are offshore RES, IEM integration of peninsulas, bring remote power to consumption centers*
- *No expectation of offshore meshing commissioned by 2030*





NC HVDC General Approach

Capability of HVDC systems relevant for cross border system security

- make use of HVDC's inherent capabilities – fast active and reactive power control, etc.
- increase grid flexibility, capability and controllability
- maintain system security

DC connected PPMs and associated HVDC connections

- need to have **economic consistent coordinated requirements** so as not to impair requirements at AC onshore transmission connection point
- consider **the long term development** of the network

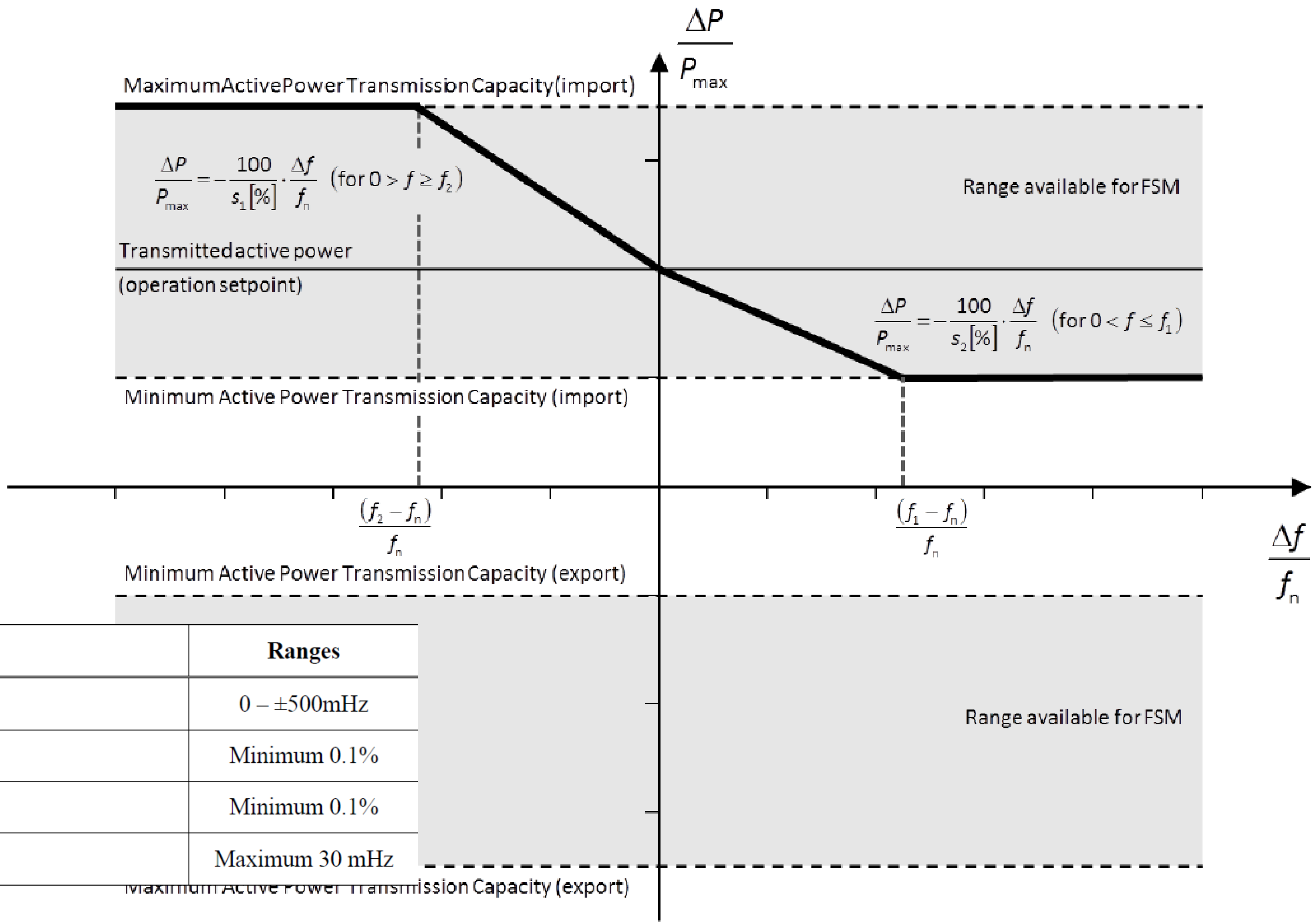
Coping with different technologies

- Requirements should not favour or discriminate technology

Considering potential future DC grids

- no barrier to future expansion into multi-terminal or meshed DC grids

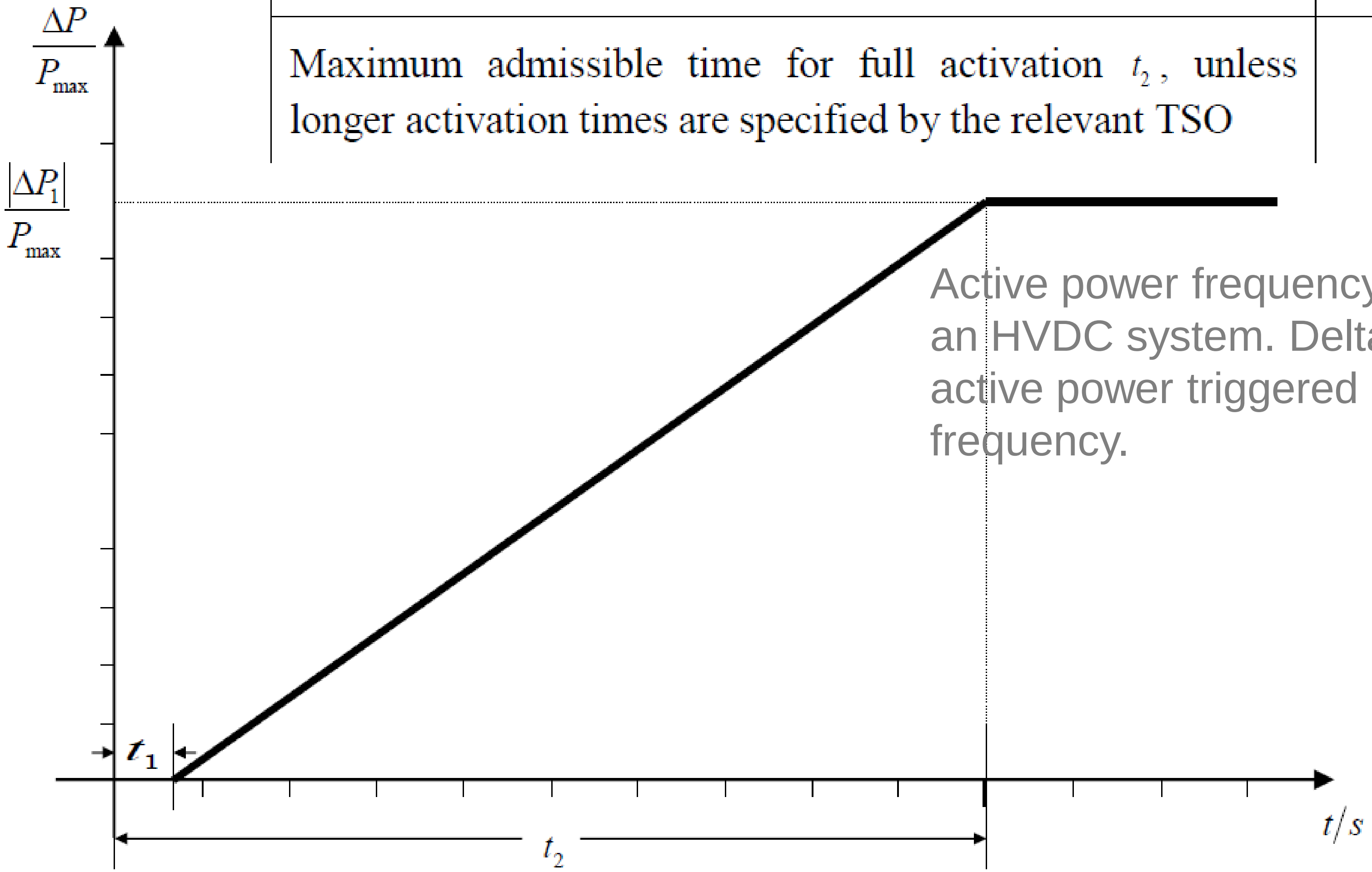
Frequency Sensitivity Mode for HVDC systems



Parameters	Ranges
Frequency response deadband	0 – ±500mHz
Droop s_1 (upward regulation)	Minimum 0.1%
Droop s_2 (downward regulation)	Minimum 0.1%
Frequency response insensitivity	Maximum 30 mHz

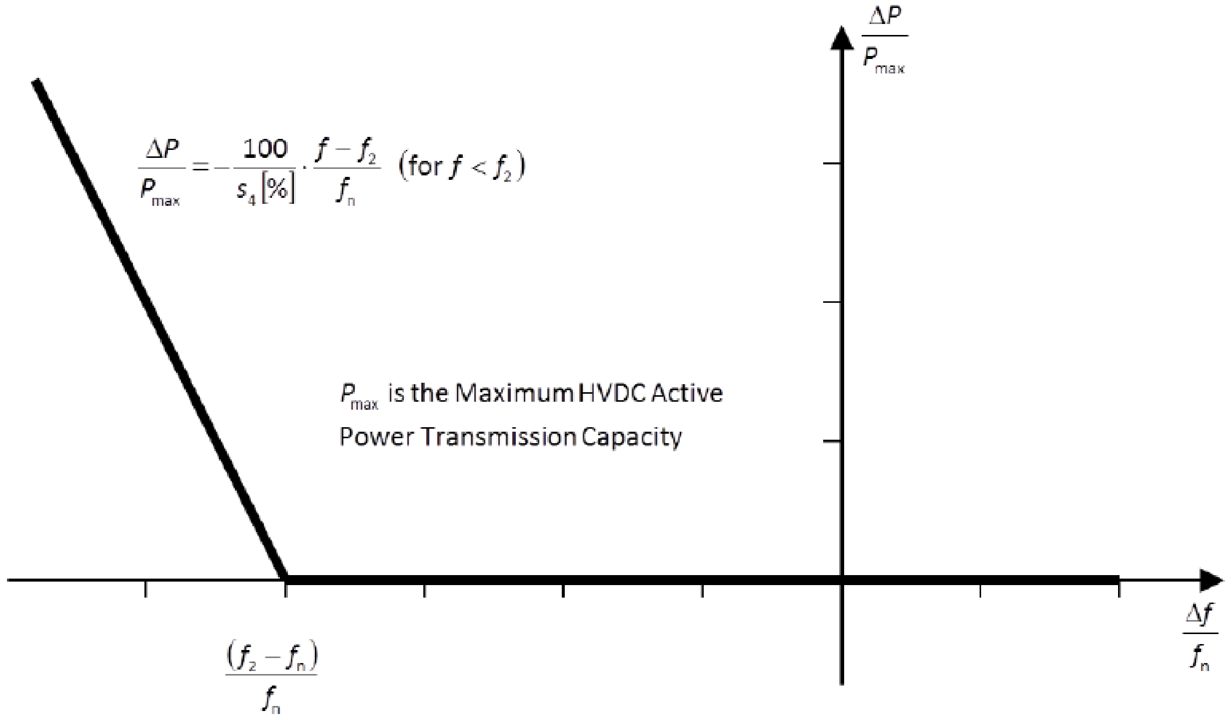
Active Power Response of HVDC systems

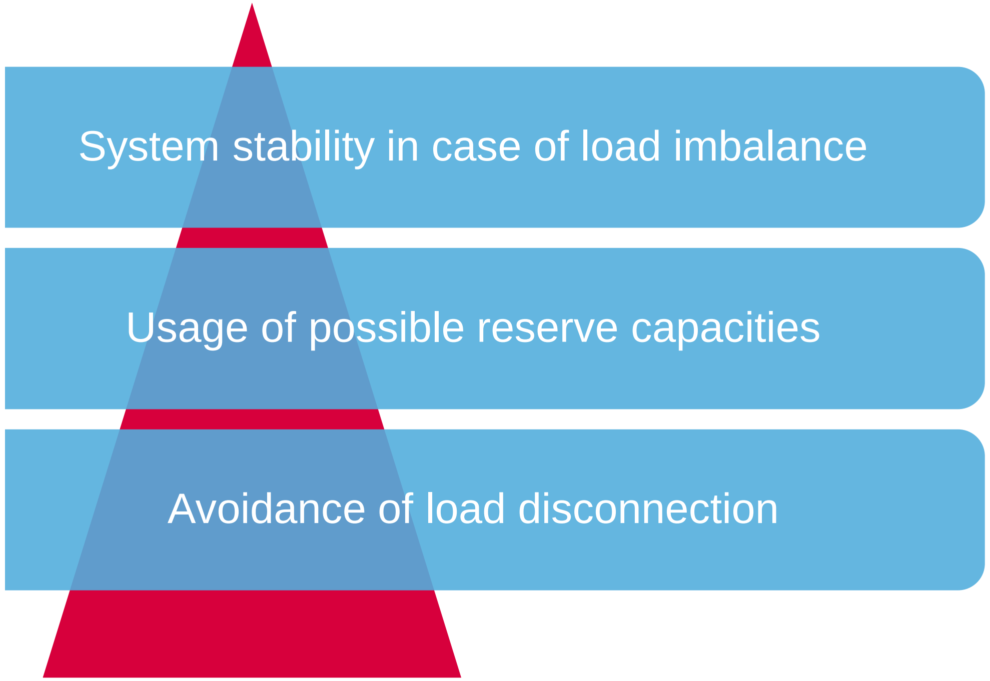
Parameters	Time
Maximum admissible initial delay t_1	0.5 seconds
Maximum admissible time for full activation t_2, unless longer activation times are specified by the relevant TSO	30 seconds



Active power frequency response capability of an HVDC system. Delta P is the change in active power triggered by the step change in frequency.

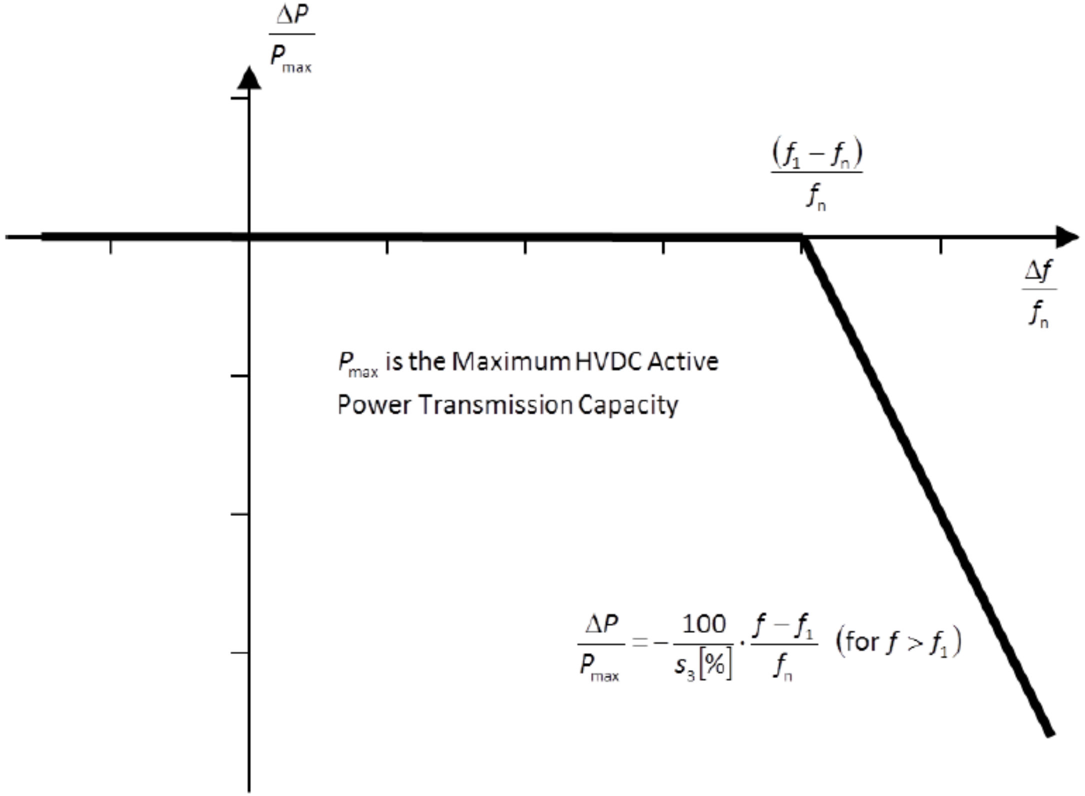
Limited Frequency Sensitivity Mode – Underfrequency for HVDC systems

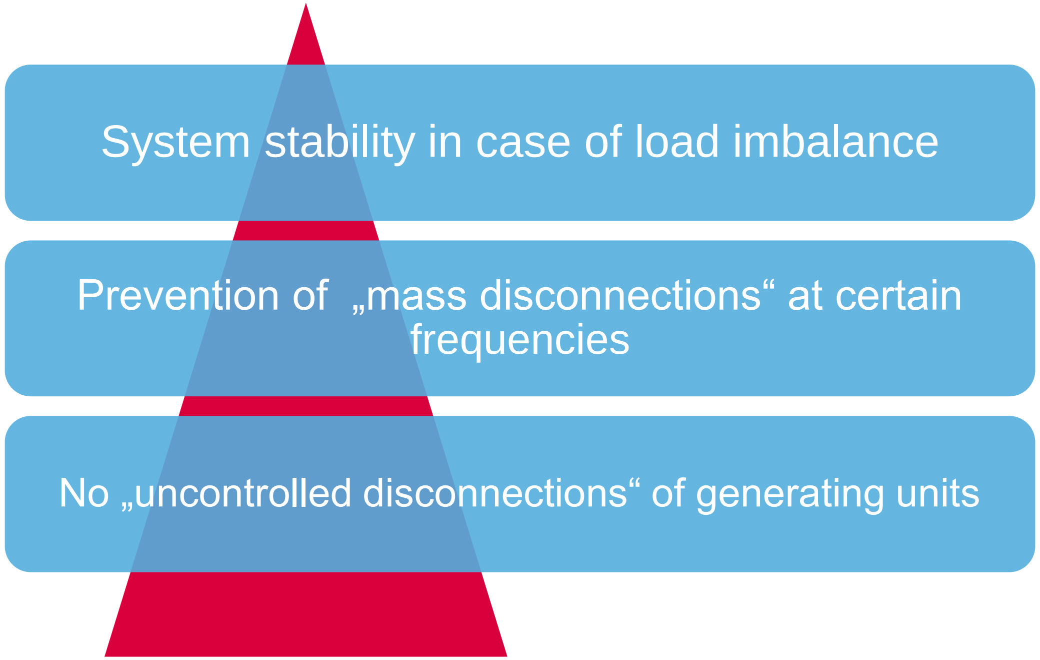




Active power frequency response capability of HVDC systems in LFSM-U. Delta P is the change in active power output from the HVDC system, depending on the operation condition a decrease of import power or an increase of export power. fn is the nominal frequency in the AC network or networks the HVDC system is connected and Delta f is the frequency change in the AC network or networks the HVDC is connected. At under frequencies where f is below f2, the HVDC system has to increase active power output according to the droop *s4*.

Limited Frequency Sensitivity Mode – Overfrequency for HVDC systems





Active power frequency response capability of HVDC systems in LFSM-O. ΔP is the change in active power output from the HVDC system and, depending on the operational conditions, either a decrease of import power or an increase of export power. *f*n is the nominal frequency of the AC network or networks the HVDC system is connected to and Δf is the frequency change in the AC network or networks the HVDC is connected to. At over frequencies where *f* is above *f*1 the HVDC system shall reduce active power according to the droop setting.

Active Power Control and Frequency Support

Coordinated approach for maintaining system security

- Frequency ranges - network assets as HVDC connections should stay connected at minimum as long as generation/demand has to remain connected
- **ROCOF** Withstand capabilities - ensure that network assets remain in operation during severe system events, especially under those conditions which generation and demand have to withstand as well.

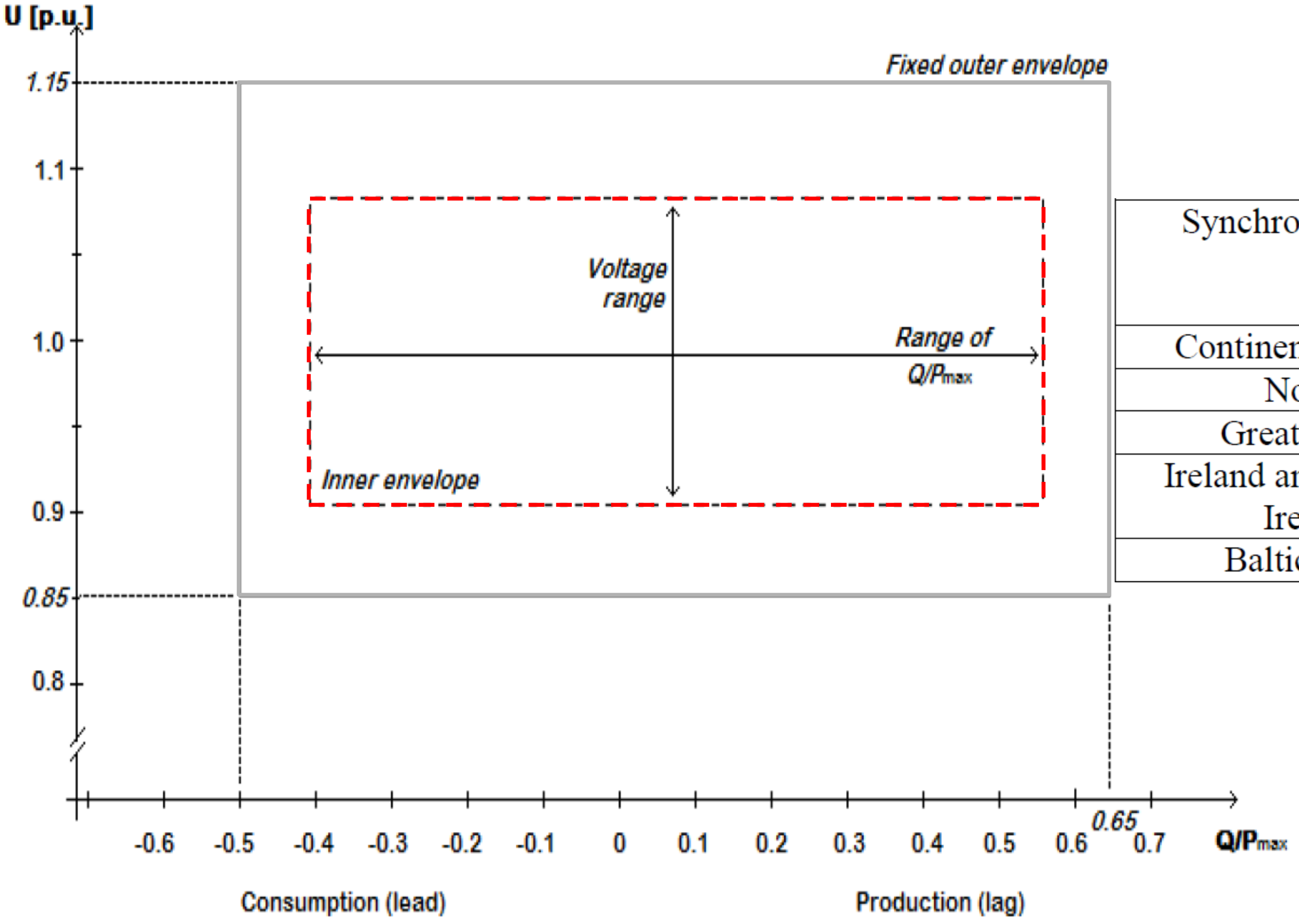
Frequency control functions

- Essential for a future RES based secured transmission system and can help the EU to achieve its energy goals providing more transmission grid flexibility, controllability and capability
  - fast active and reactive power control
  - emergency control actions

Synthetic inertial capability

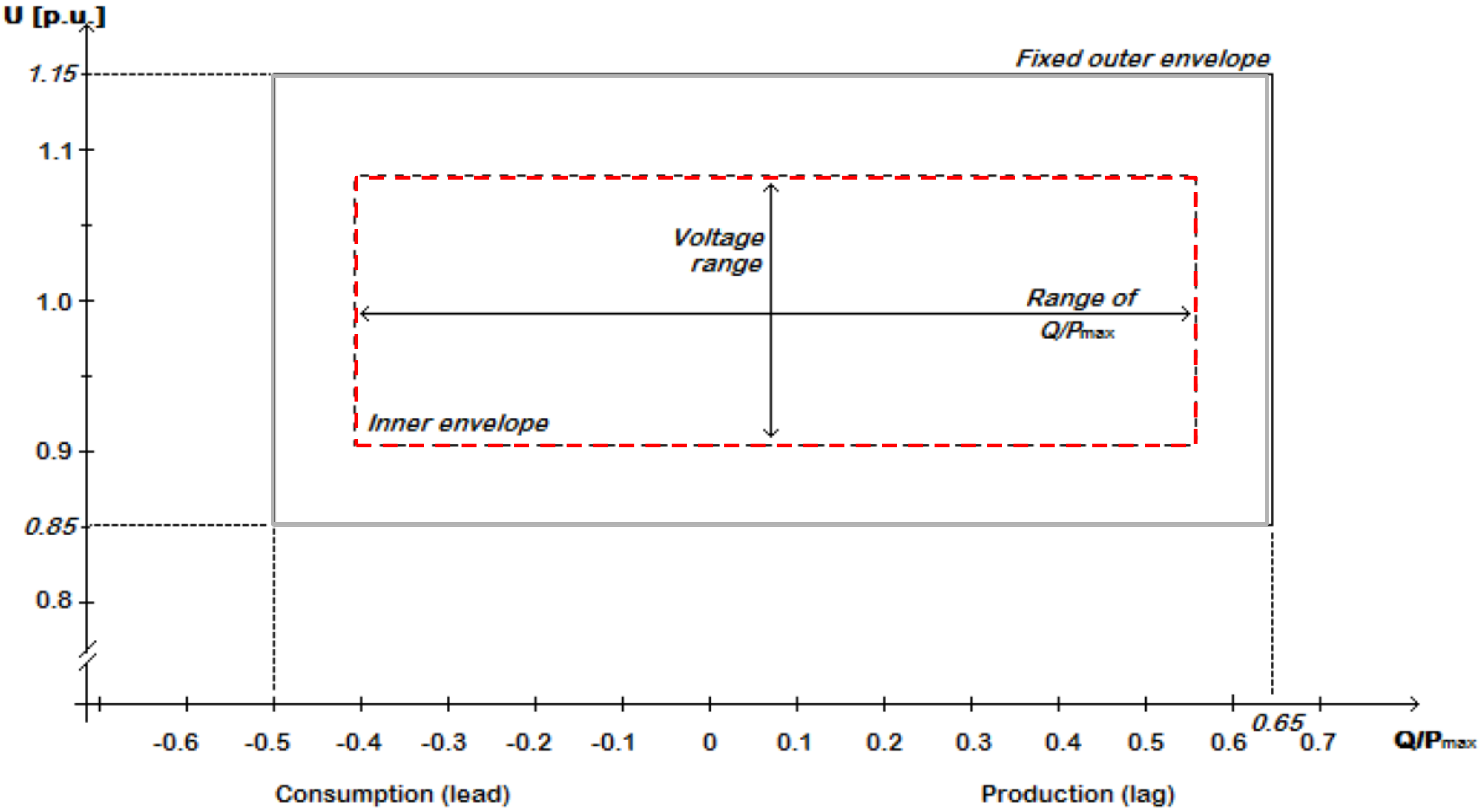
- Synchronous generators have an inherent capability to resist / slow down frequency changes which converter based technologies do not have.
- allow further expansion of RES which does not naturally contribute to inertia,

Reactive Power Capability at Maximum Active Power for HVDC systems



Synchronous Area	Maximum range of Q/Pmax	Maximum range of steady-state Voltage level in PU
Continental Europe	0.95	0.225
Nordic	0.95	0.15
Great Britain	0.95	0.225
Ireland and Northern Ireland	1.08	0.218
Baltic States	1.0	0.220

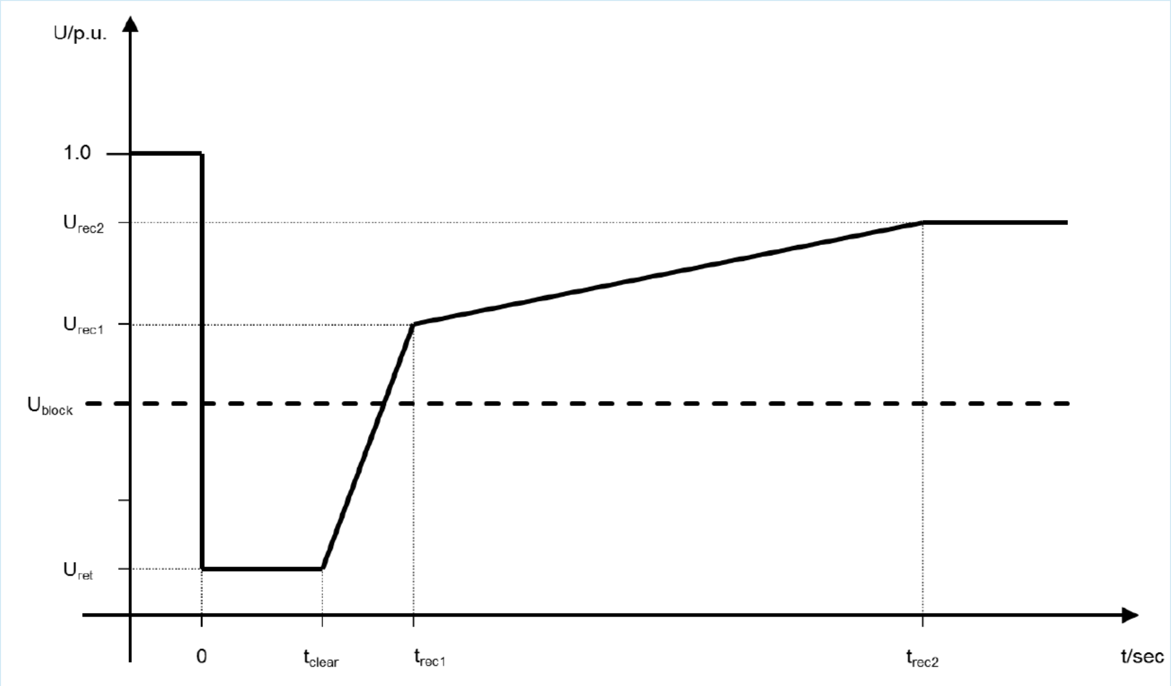
Reactive Power Capability at Maximum Active Power for DC connected PPMs



Range of width of Q/Pmax profile	Range of steady-state Voltage level in pu
0 - 0.95	0.1 - 0.225

bilateral agreement between the DC-connected power park module owner with the owners of the HVDC systems connecting the DC-connected power park module in case of a single connection point on a AC network possible (see Art. 40.2)

Fault-Ride-Through Requirements for HVDC systems



Voltage parameters [pu]		Time parameters [seconds]	
U_{ret}	0.00 – 0.30	t_{clear}	0.14-0.25
U_{rec1}	0.25-0.85	t_{rec1}	1.5 – 2.5
U_{rec2}	0.85-0.90	t_{rec2}	T_{rec1} – 10.0

The diagram represents the lower limit of a voltage-against-time profile at the connection point, expressed by the ratio of its actual value and its reference 1 pu value in per unit before, during and after a fault. Uret is the retained voltage at the connection point during a fault, tclear is the instant when the fault has been cleared, Urec1 and trec1 specify a point of lower limits of voltage recovery following fault clearance. Ublock is the blocking voltage at the connection point. The time values referred to are measured from t fault.

HVDC System Robustness

- Article 29: *Interaction between HVDC systems or other plants and equipment*
- *Article 30: Power oscillation damping*
- *Article 31: Sub synchronous torsional interaction damping capability*
  - *All parties identified by the relevant TSO as relevant to each connection point, including the relevant TSO, shall contribute to the studies and shall provide all relevant data and models as reasonably required to meet the studies.*

- Article 32: Network characteristic
  - The HVDC system shall be capable of operating within the range of short circuit power and network characteristic specified

- Article 33: HVDC system robustness
  - The HVDC system shall be capable of finding stable operation points during and after any planned or unplanned change in the HVDC system or AC network to which it is connected.
  - The HVDC owner shall ensure that the tripping or disconnection of an HVDC converter station, as part of any multi-terminal or embedded HVDC system does not result in transients at the connection point beyond the limit specified by the relevant TSO.
  - The HVDC system shall withstand transient faults on HVAC lines in the network adjacent or close to the HVDC system

1 The need of network codes and their development

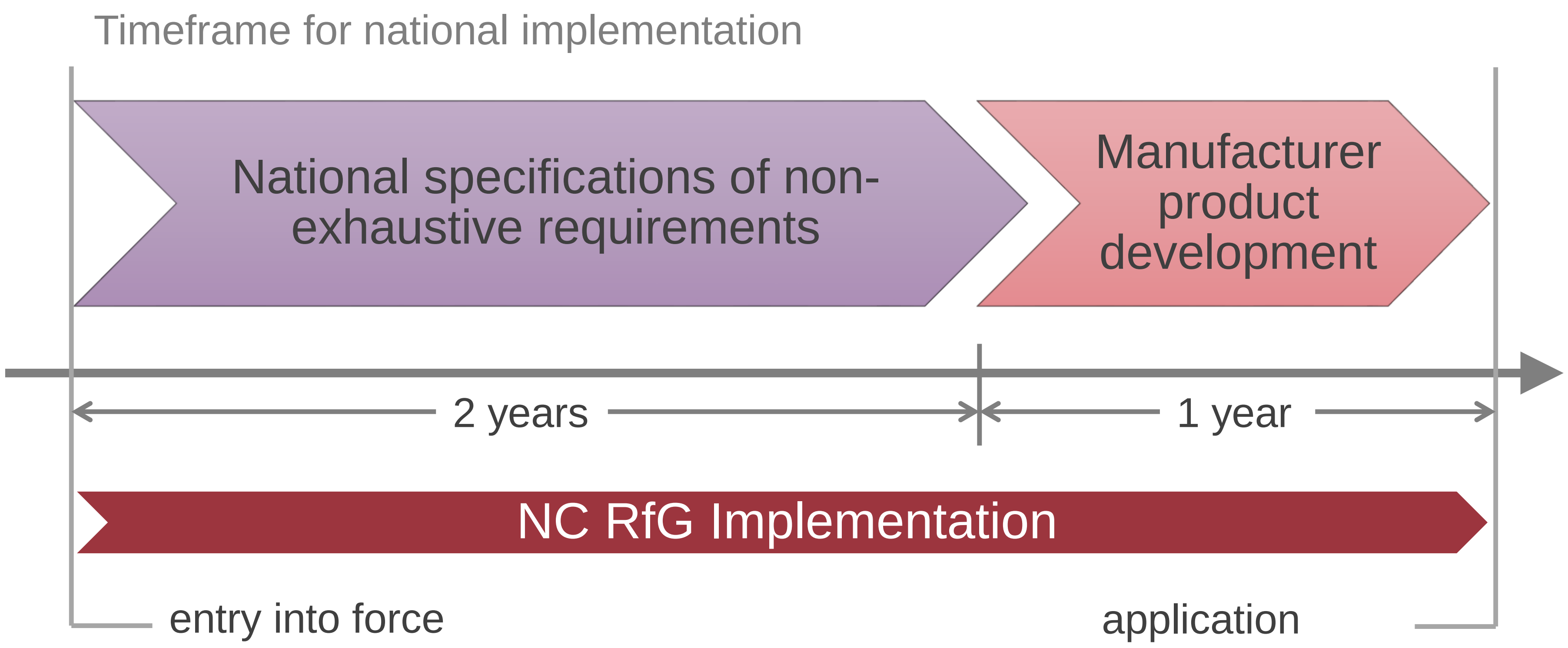
2 Key technical requirements for power generating modules (NC RfG)

3 Key technical requirements for demand connection (NC DCC)

4 Key technical requirements for HVDC systems and DC-connected power park modules (NC HVDC)

5 The way towards implementation

The challenge of NC RfG national implementation



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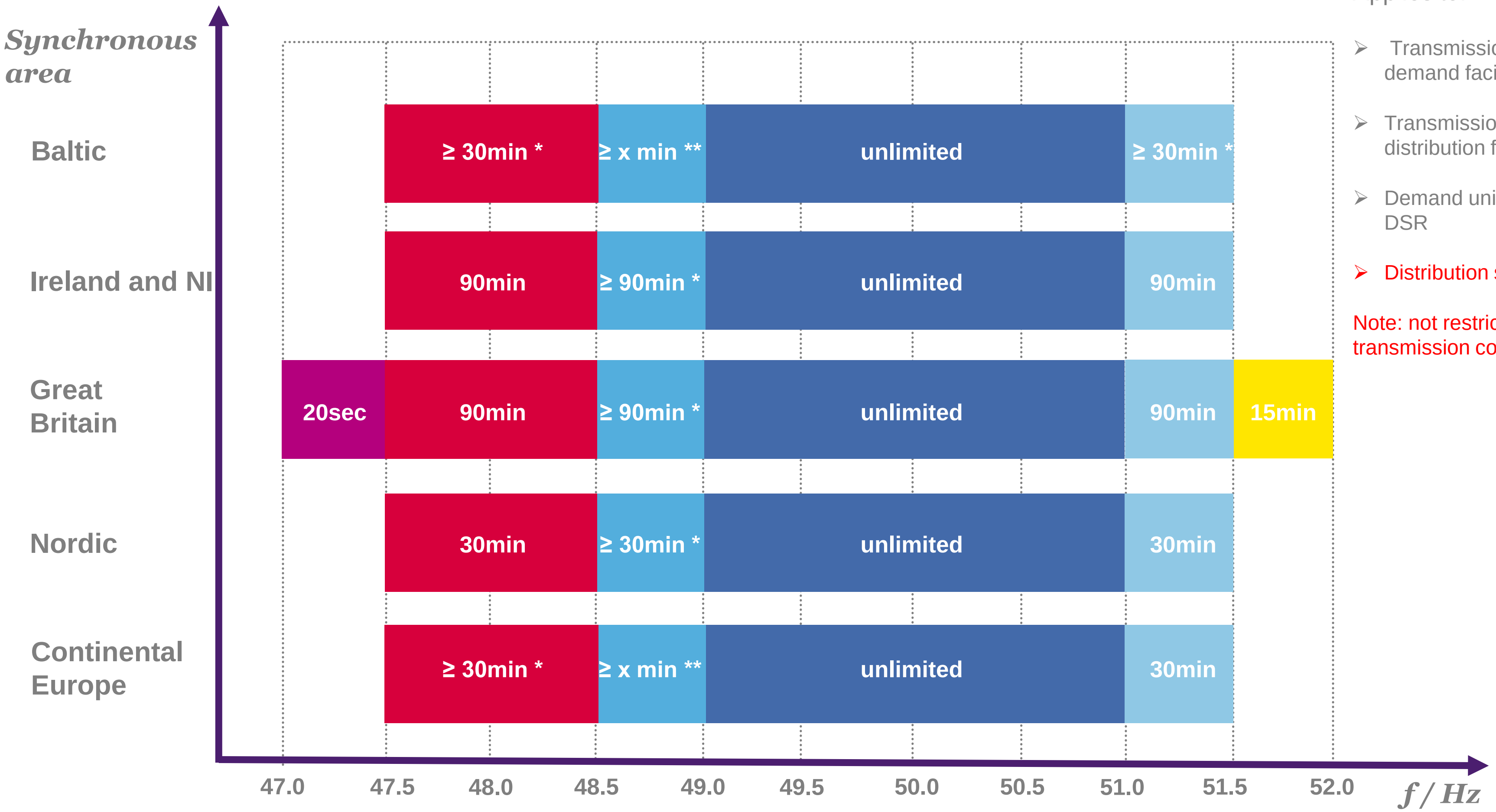
Reliable Sustainable Connected

DCC Frequency Ranges



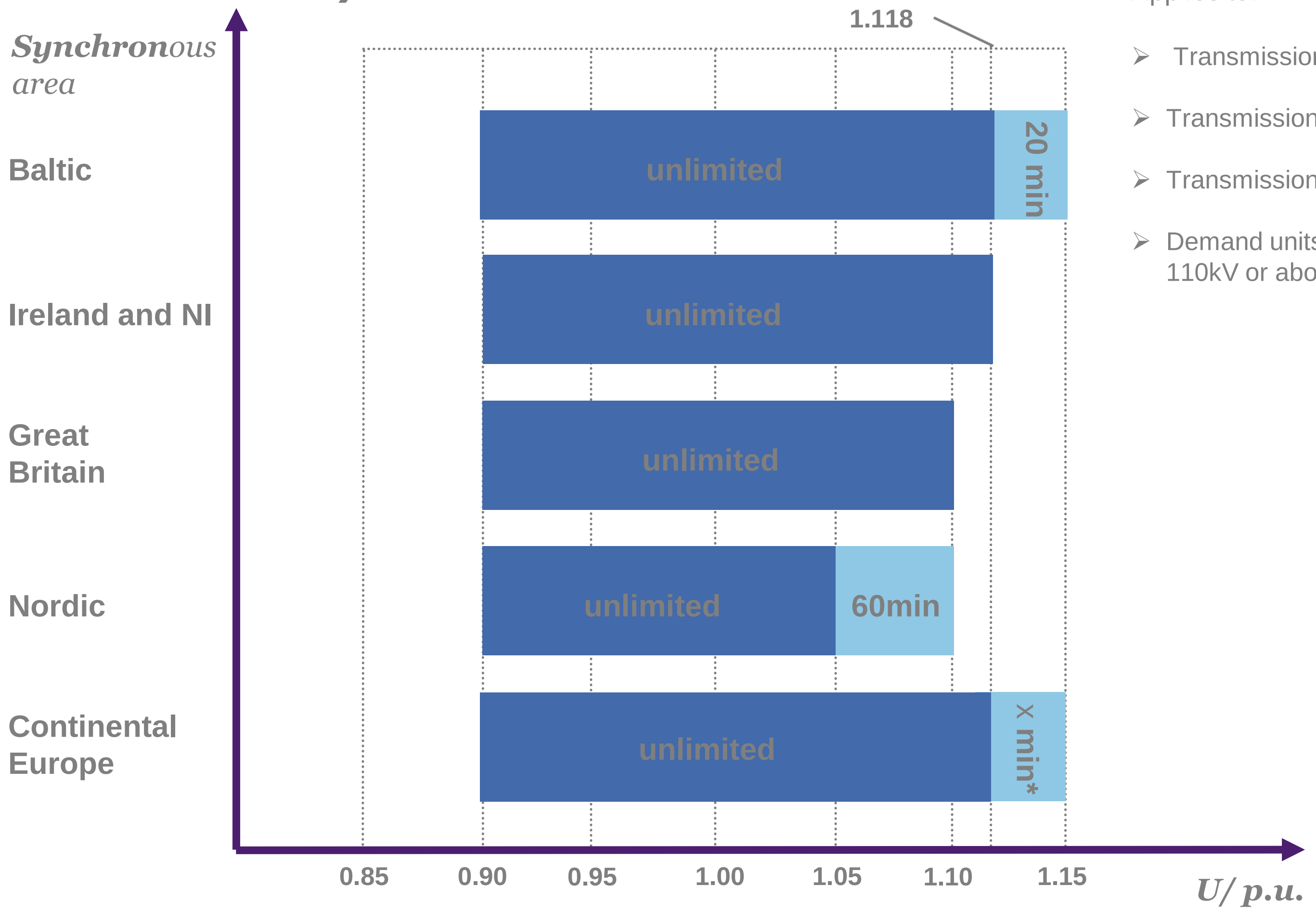
* to be determined by the relevant TSO ** to be determined by the relevant TSO; ≥ time of **47.5 - 48.5 Hz**

Applies to:

- Transmission-connected demand facilities,
- Transmission-connected distribution facilities
- Demand units providing DSR
- Distribution systems

Note: not restricted to transmission connected

DCC Voltage Ranges (Voltage levels 110 kV ≤ U < 300 kV)

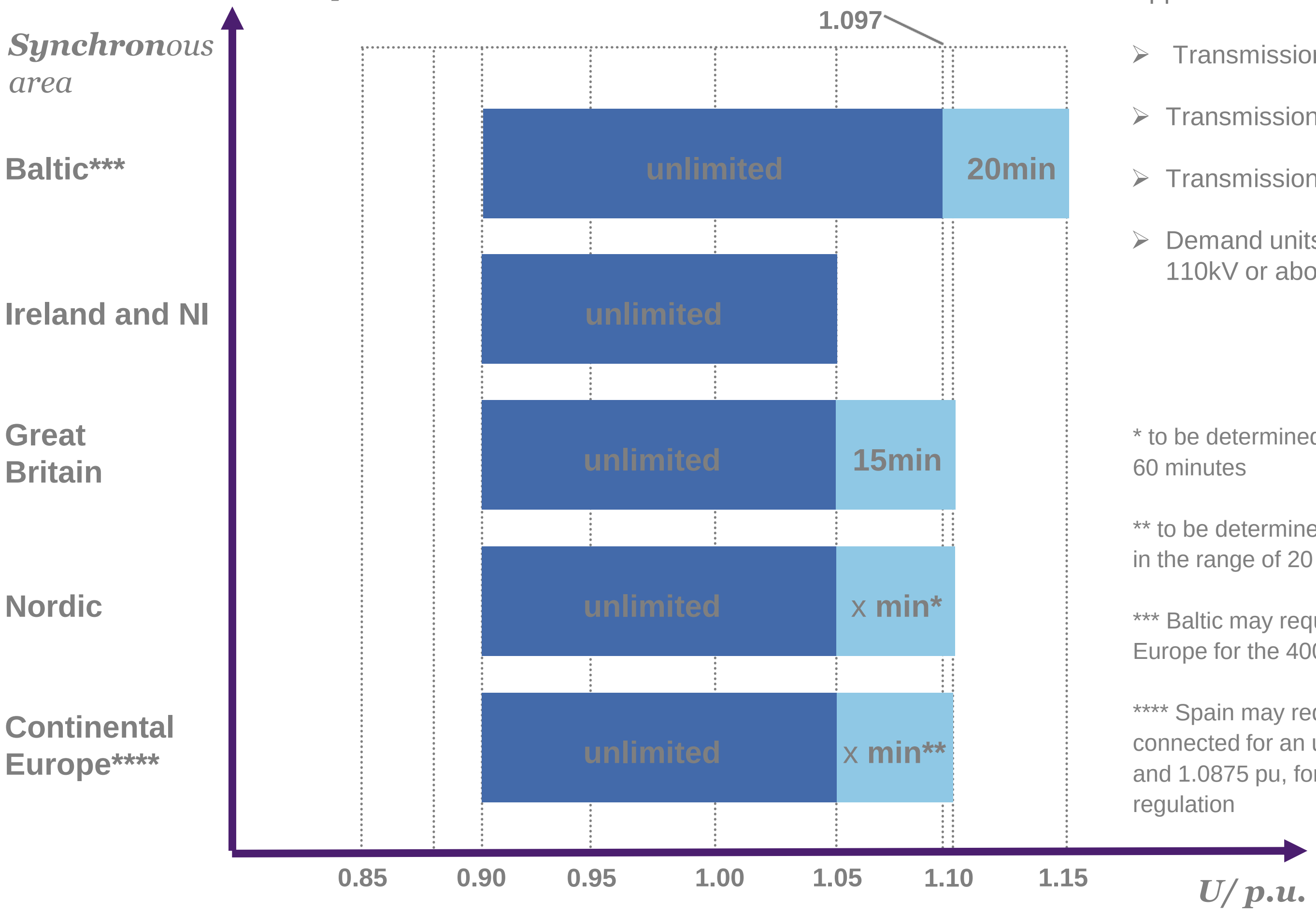


* to be determined by the relevant TSO in the range of 20 – 60 minutes

Applies to:

- Transmission-connected demand facilities,
- Transmission-connected distribution facilities
- Transmission-connected distribution systems
- Demand units providing DSR connected at 110kV or above

DCC Voltage Ranges (Voltage levels 300 kV ≤ U ≤ 400 kV)



Applies to:

- Transmission-connected demand facilities,
- Transmission-connected distribution facilities
- Transmission-connected distribution systems
- Demand units providing DSR connected at 110kV or above

* to be determined by the relevant TSO, but less than 60 minutes

** to be determined by the relevant TSO in the range of 20 – 60 minutes

*** Baltic may require capabilities as of Continental Europe for the 400 kV level

**** Spain may require capability of remaining connected for an unlimited period between 1.05 pu and 1.0875 pu, for consistency with existing national regulation

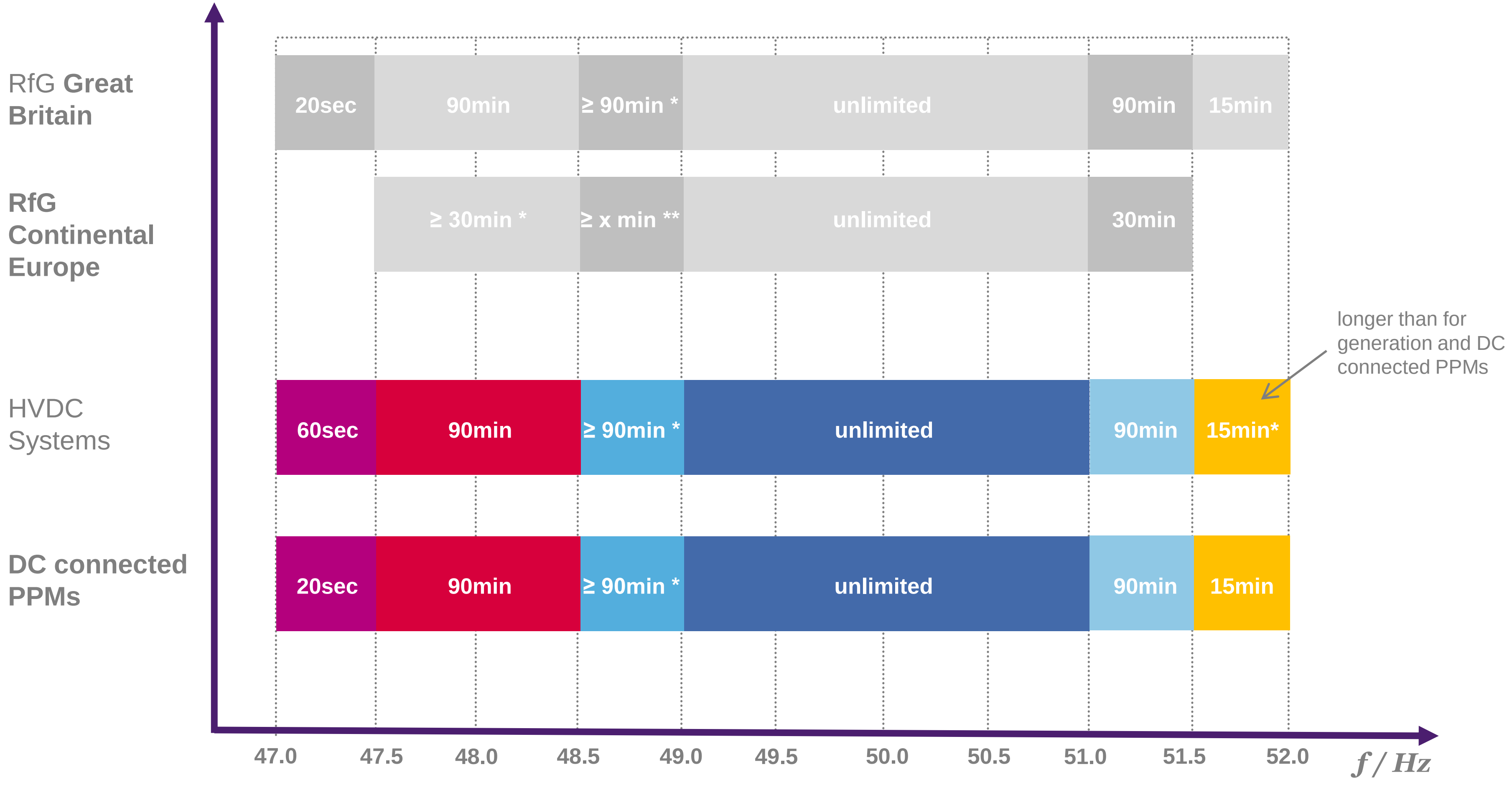
Demand Side Response System Frequency Control

- **Frequency and Voltage requirements met by all SFC demand units**

- **Below 110kV connection point voltage requirements specified by system operator**

- **All demand units providing system frequency control primarily must:**
  - Respond to changes in frequency proportionally with an increase or reduction in demand
  - Be able to detect and respond to a +/-0.01Hz change in frequency refreshed at least every 200mS
  - Have a 5 minute random timer on return to service
  - Meet TSO specified dead-band around 50Hz and frequency where it provides its maximum response

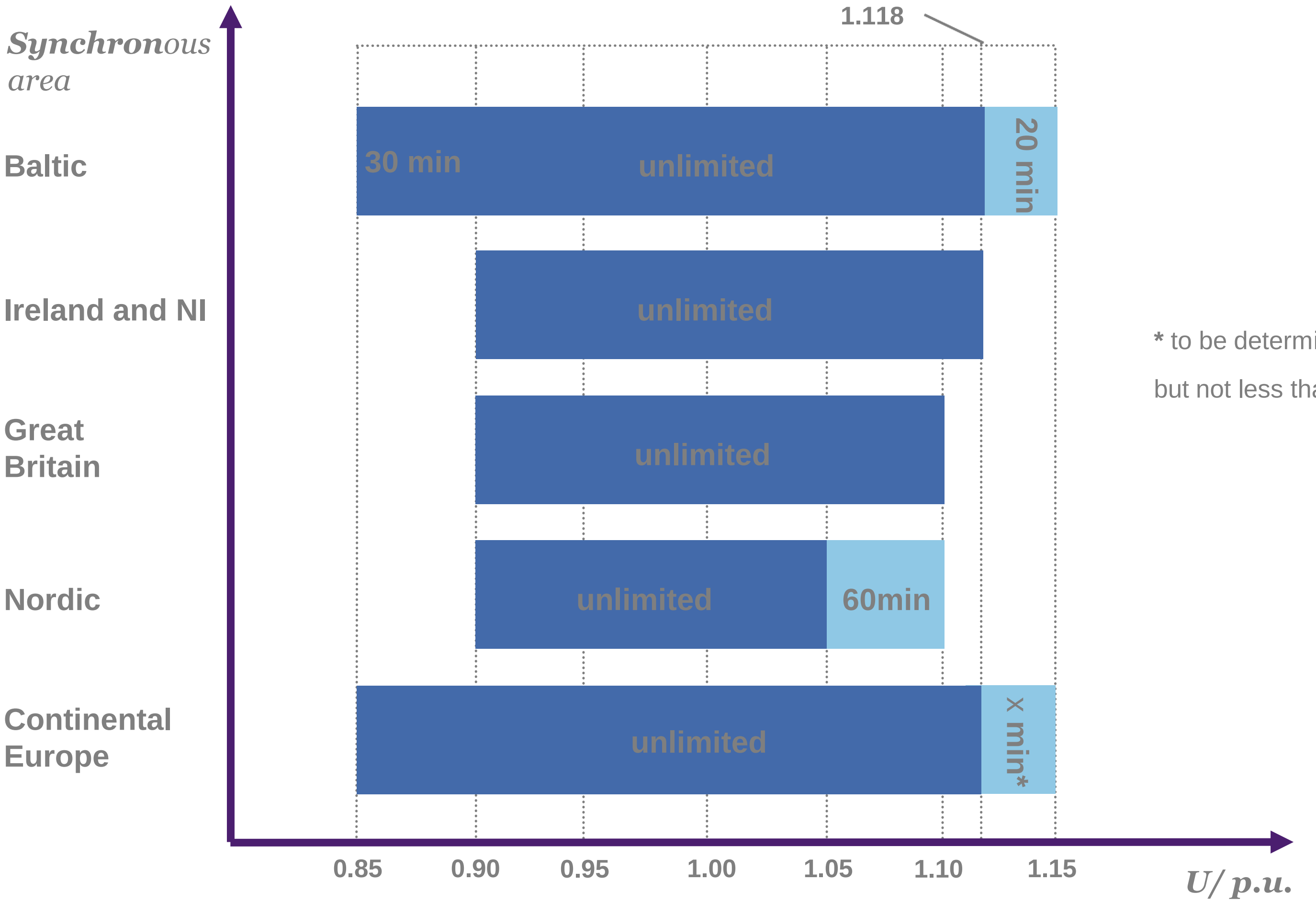
HVDC Frequency Ranges



* to be determined by the relevant TSO

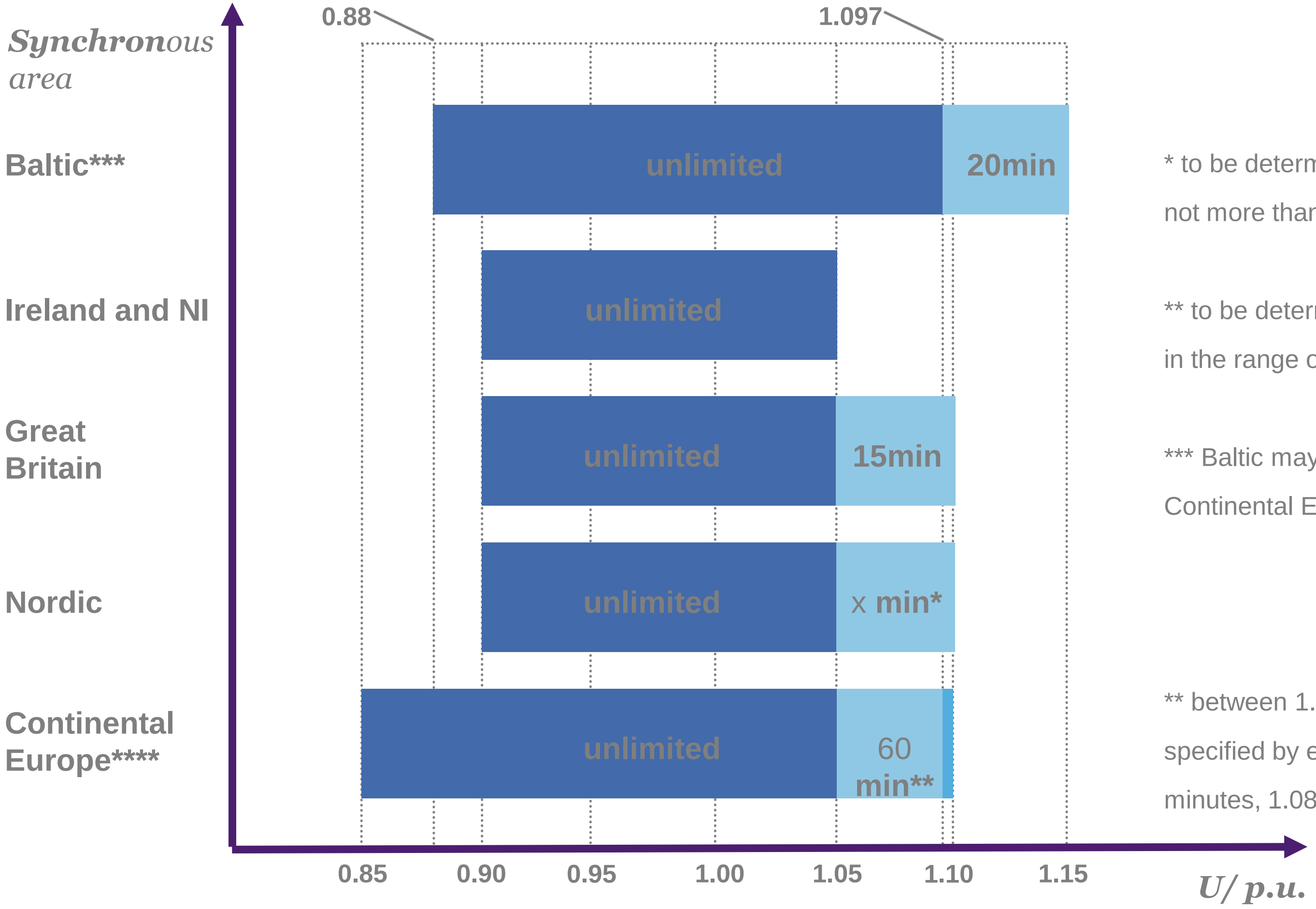
** to be determined by the relevant TSO; ≥ time of **47.5 - 48.5 Hz**

Voltage Ranges for HVDC systems (Voltage levels 110 kV ≤ U < 300 kV)



* to be determined by the relevant TSO but not less than 20 minutes

Voltage Ranges for HVDC systems (Voltage levels 300 kV ≤ U ≤ 400 kV)



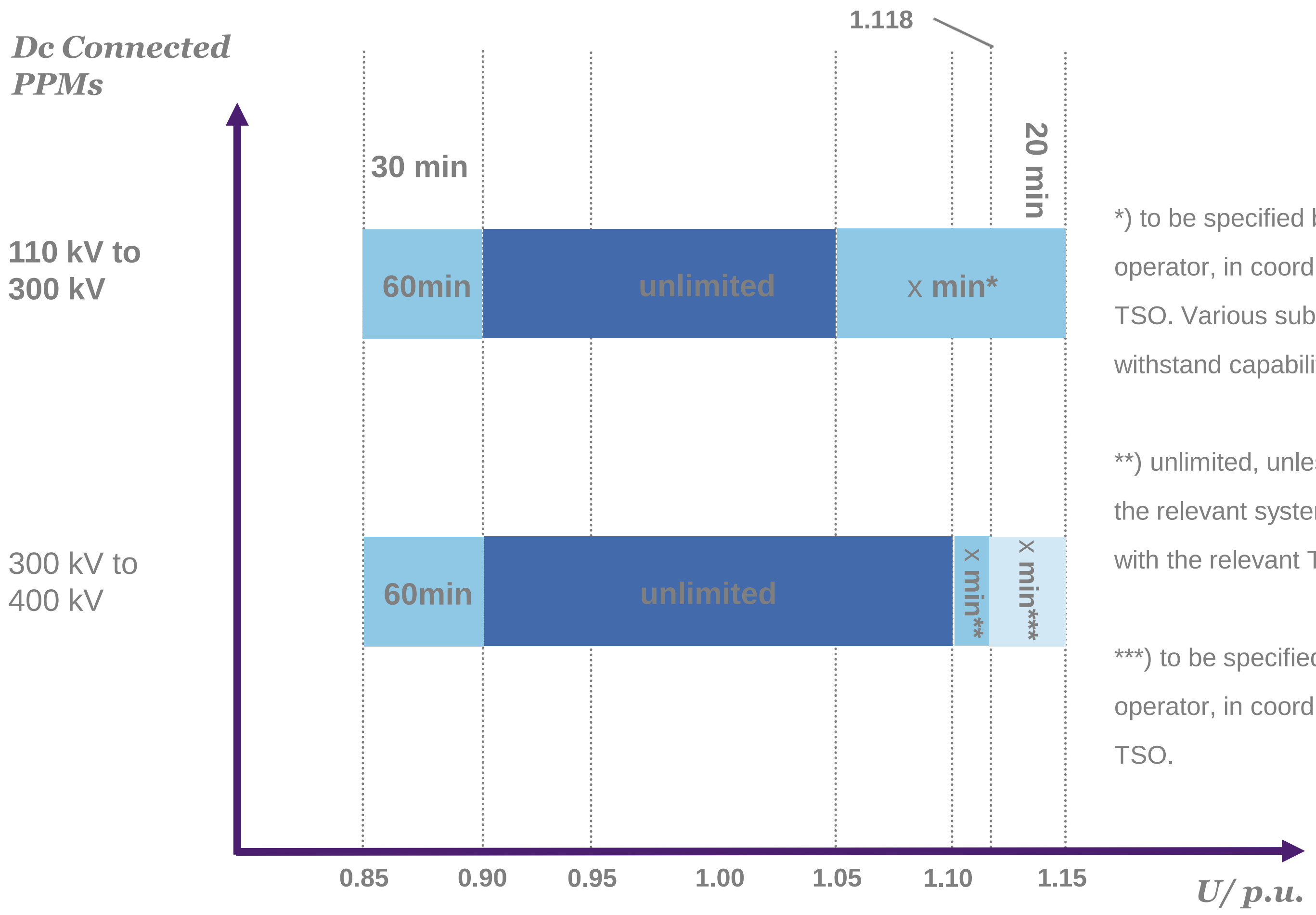
* to be determined by the relevant TSO, but not more than 60 minutes

** to be determined by the relevant TSO in the range of 20 – 60 minutes

*** Baltic may require capabilities as of Continental Europe for the 400 kV level

** between 1.05 pu and 1.0875 pu to be specified by each TSO, but not less than 60 minutes, 1.0875 pu to 1.1 pu 60 min.

Voltage Ranges for DC connected PPMs

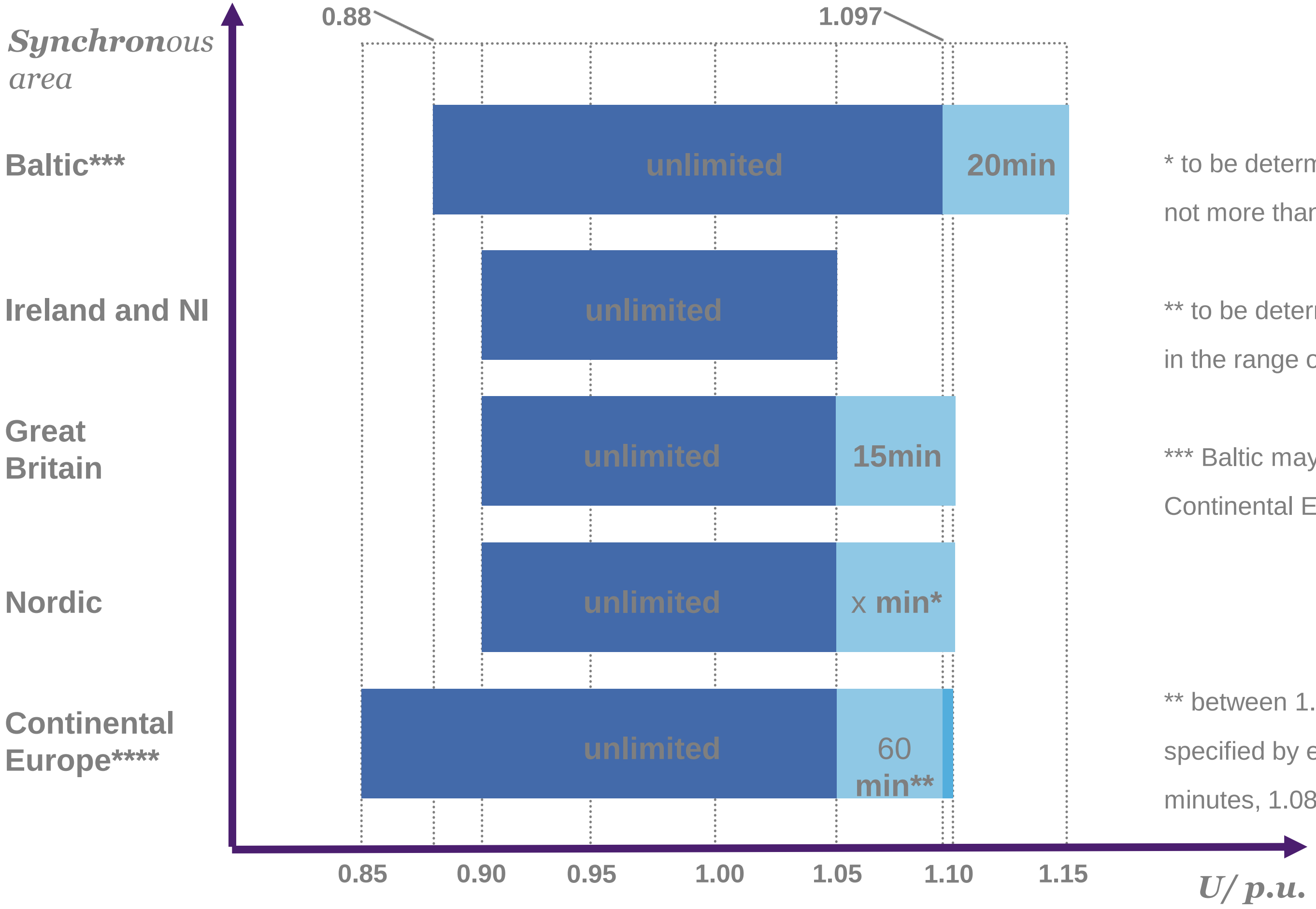


*) to be specified by the relevant system operator, in coordination with the relevant TSO. Various sub-ranges of voltage withstand capability can be specified.

**) unlimited, unless specified otherwise by the relevant system operator, in coordination with the relevant TSO.

***) to be specified by the relevant system operator, in coordination with the relevant TSO.

Voltage Ranges for DC connected PPMs (Voltage levels 300 kV ≤ U ≤ 400 kV)



* to be determined by the relevant TSO, but not more than 60 minutes

** to be determined by the relevant TSO in the range of 20 – 60 minutes

*** Baltic may require capabilities as of Continental Europe for the 400 kV level

** between 1.05 pu and 1.0875 pu to be specified by each TSO, but not less than 60 minutes, 1.0875 pu to 1.1 pu 60 min.