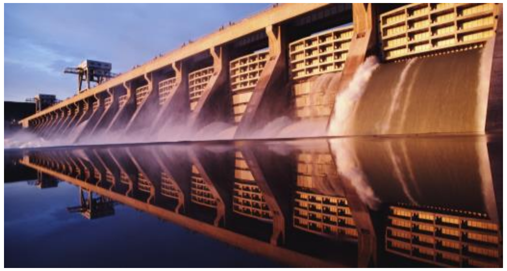  

Study assessment of aFRR products

For Balancing Stakeholders Group workshop 15 January 2016

Version 1.1 (update for 15 January 2016 meeting of presentation for 27 November 2015 that was cancelled)

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Objective of this meeting

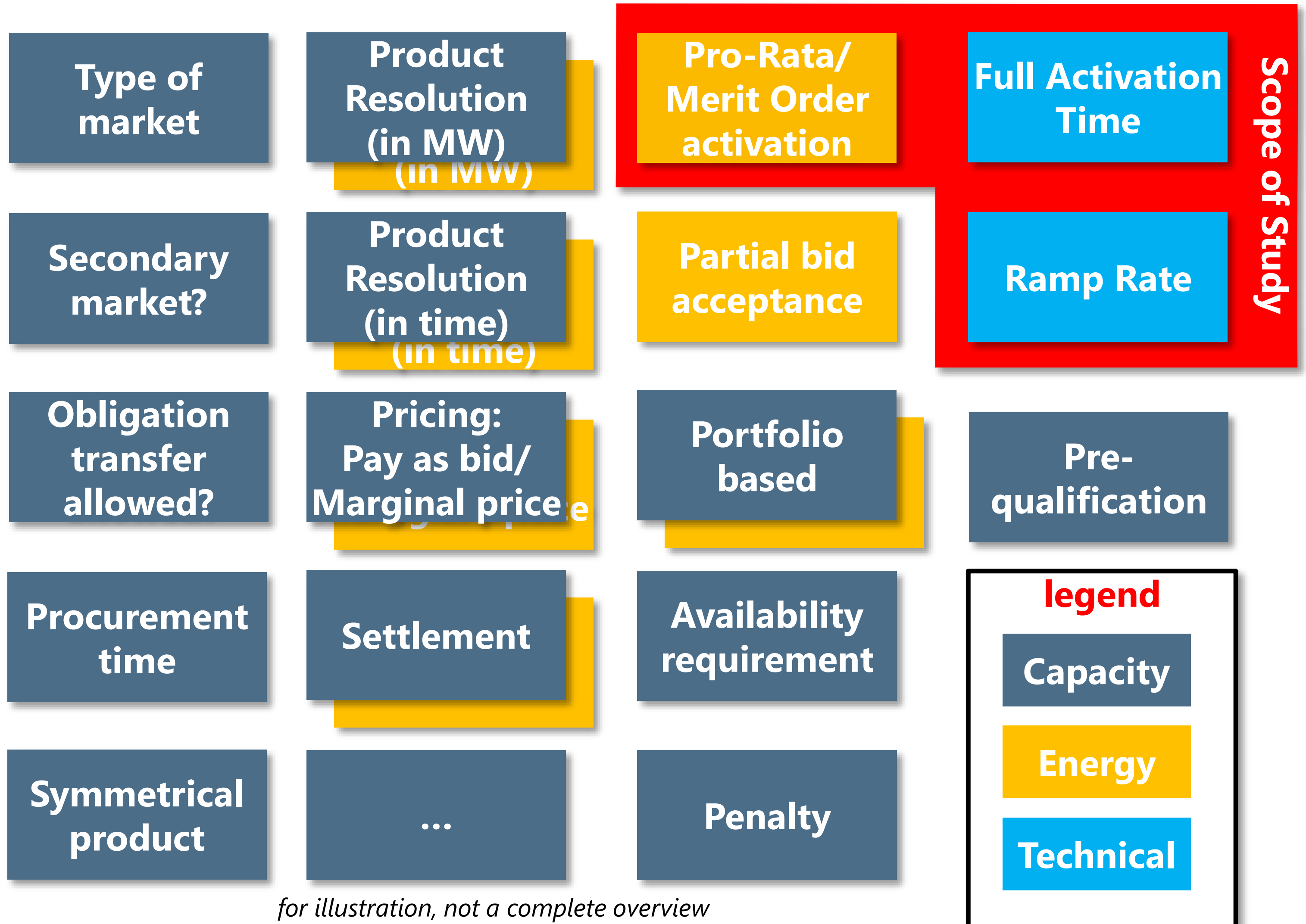
- To provide ‘balancing stakeholders group’ (BSG) an introduction to the aFRR study
- To present and discuss project results with BSG

This presentation

Objective of the study

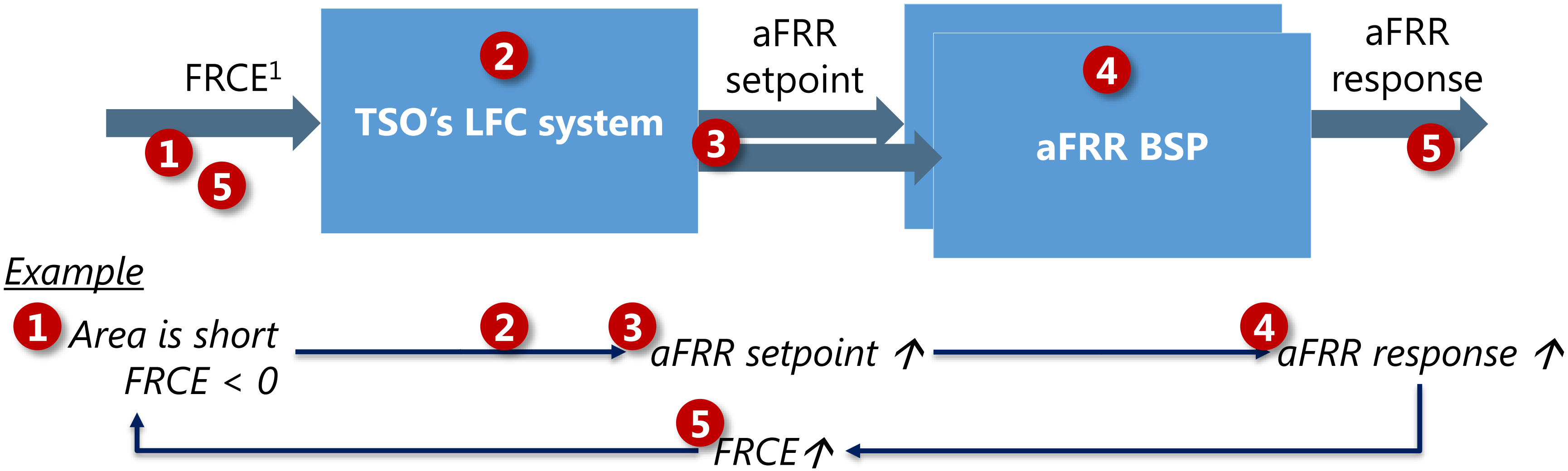
- *Background:*
  - ENTSO-E's working group Ancillary Services (and more specifically ENTSO-E WG AS SG5) is working on the definition of standard products for automatic Frequency Restoration Reserves (aFRR).
- *Objective*: ENTSO-E wants to:
  - receive an overview of the *technical differences* between the aFRR products (including *activation times, ramp rates*) and *aFRR activation schemes* throughout Europe
  - understand the *impact* of a *change in Full Activation Time (FAT) and ramp rates requirements* for aFRR products on frequency/regulation quality and aFRR markets
  - understand the impact of a transition from *pro-rata activation* to *merit order activation* for aFRR on frequency/regulation quality and aFRR markets
- *Limitation of the study:*
  - Technical aFRR capability and regulation quality will be assessed quantitatively
  - The impact on aFRR energy and capacity markets will be discussed qualitatively

Scope or our study is limited to *selected design criteria* and *their influence on regulation quality of TSO* → focus is *technical*



for illustration, not a complete overview

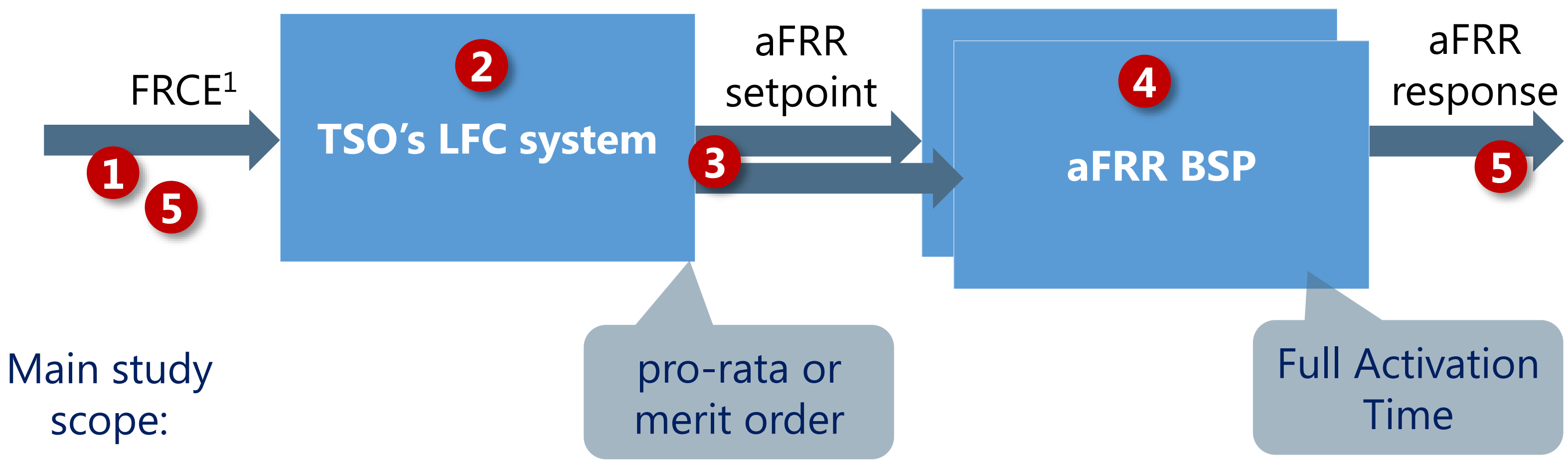
The study mainly focuses on the *technical aFRR* systems



1. The input of systems is the Frequency Restoration Control Error[1] (FRCE) of the LFC Block
2. The Load Frequency Controller (LFC) calculates continuously (every 3-10s) the required automatic Frequency Restoration Reserves (aFRR)
3. The LFC distributes the required aFRR over the aFRR Balance Service Providers (BSPs) and sends them aFRR setpoints
4. The BSP automatically activates their related aFRR reserves, typically with spinning units
5. The aFRR response of the unit will reduce the absolute FRCE of the LFC Block

[1] *ENTSO-E definition:* The control error for the FRP which is equal to the ACE of a LFC Area or is equal to the Frequency Deviation where the LFC Area geographically corresponds to the Synchronous Area.

The study focuses on the *technical aFRR* systems at TSO and BSP



1. The input of systems is the Frequency Restoration Control Error[1] (FRCE) of the LFC Block
2. The Load Frequency Controller (LF Controller) calculates continuously (every 3-10s) the required automatic Frequency Restoration Reserves (aFRR)
3. The LF Controller distributes the required aFRR over the aFRR Balance Service Providers (BSPs) and sends them aFRR setpoints
4. The BSP automatically activates their related aFRR reserves, typically with spinning units
5. The aFRR response of the unit will reduce the absolute FRCE of the LFC Block

[1] *ENTSO-E definition:* The control error for the FRP which is equal to the ACE of a LFC Area or is equal to the Frequency Deviation where the LFC Area geographically corresponds to the Synchronous Area.

This presentation

Focus of this study

Continental European and Nordic countries use automatic Frequency Restoration Reserves (aFRR)

- aFRR is used in the country (red)
- aFRR is *not* used in the country (green)

The focus of this overview is:

- ENTSO-E members
- Synchronous areas that apply aFRR

Continental Europe (CE)	Nordic
many LFC blocks	one LFC block
Each LFC block has one or more LFCs	only one LFC for entire area
LFC on 'Tie-line Bias control'	LFC on 'frequency control'

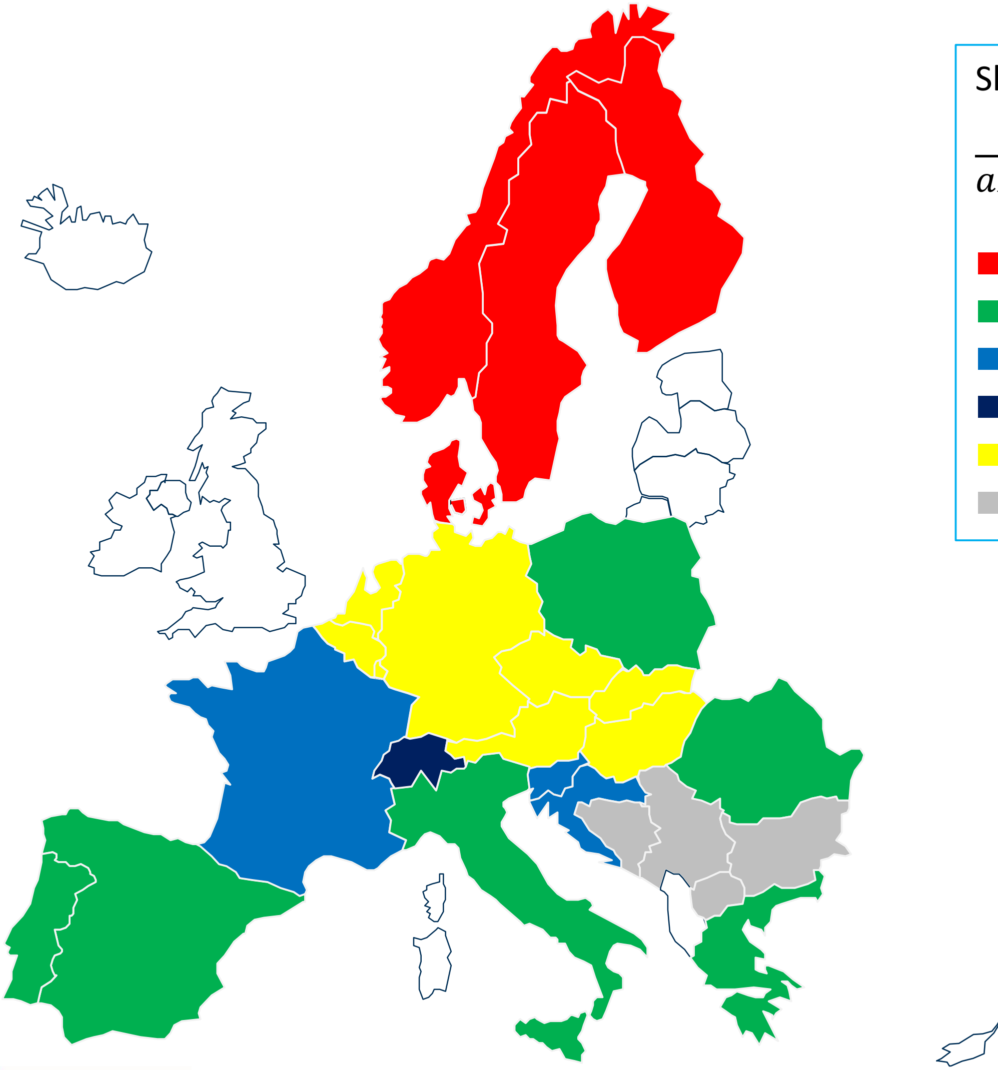
Each TSO controls own Frequency Restoration Control Error (FRCE)

Nordic TSOs directly control frequency

and indirectly CE frequency

Share of aFRR in total balancing energy

Some TSOs balance their system almost exclusively with aFRR, other TSOs apply a lot of manual reserves



Share of activated aFRR balancing energy

$$\frac{aFRR}{aFRR + mFRR + RR} \cdot 100\%$$

- < 20%
- 20 – 40%
- 40 – 60%
- 60 – 80%
- > 80%
- *No information*

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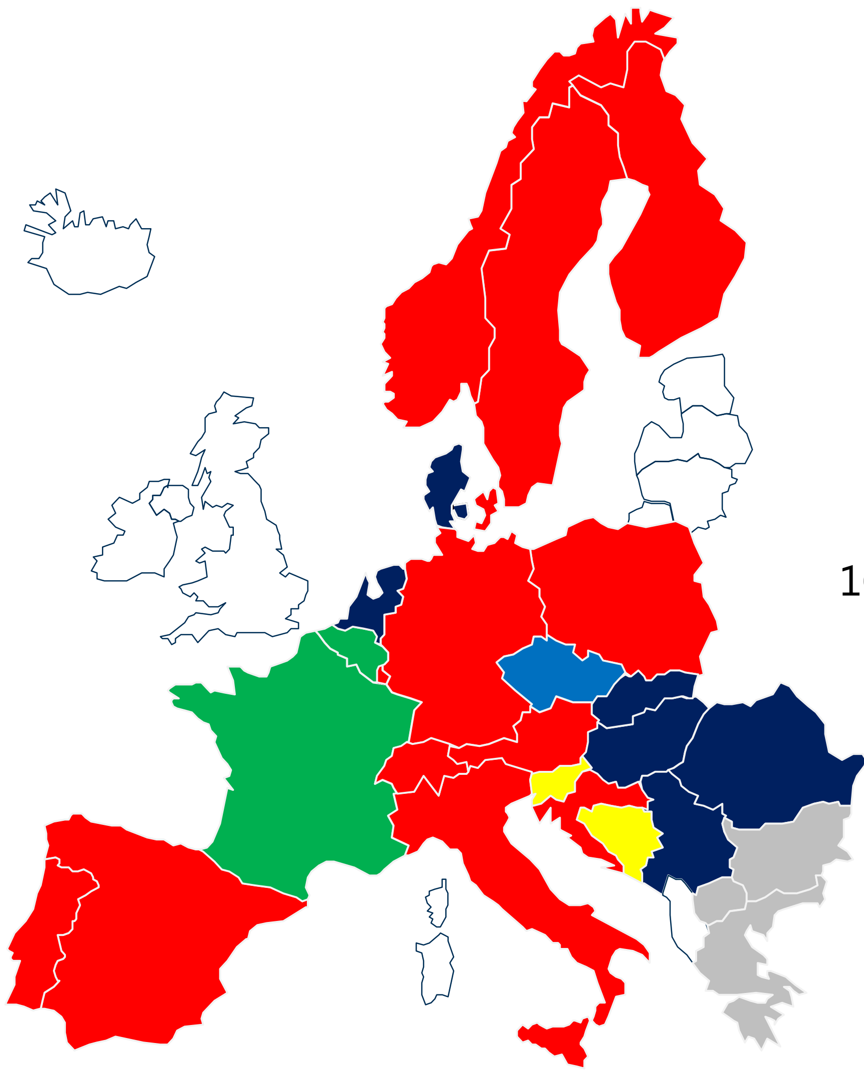
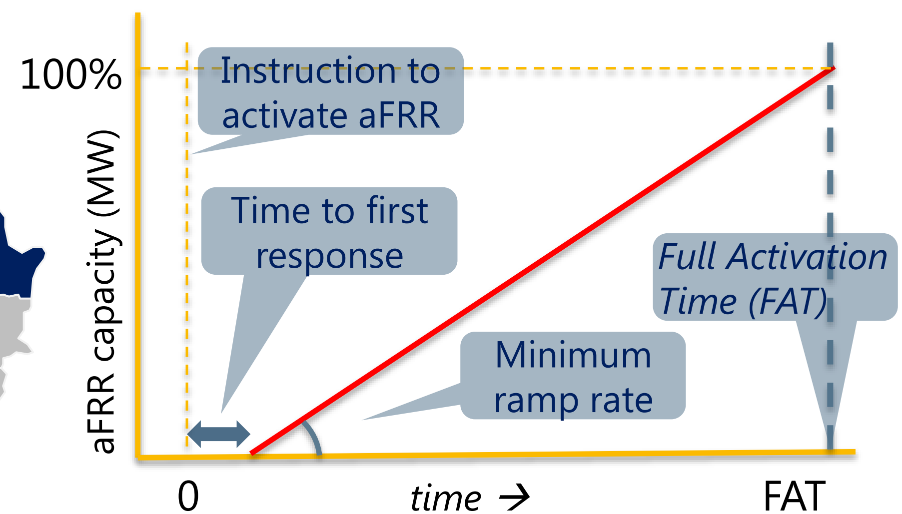
aFRR product: minimum response

Minimum response requirements for activating full aFRR capacity ranges from 2 minutes to 15 minutes



Full Activation Time (FAT)[1]:

- < 6 minutes *(typically 5 minutes)*
- 6 - 9 minutes
- 9 – 12 minutes
- > 12 minutes *(typically 15 minutes)*
- No generic minimum requirements, minimal ramp rate for each power plant agreed individually
- *No information*



1. as specified by TSO or as sum of specified 'first response time' + 1/'minimum ramp rate'

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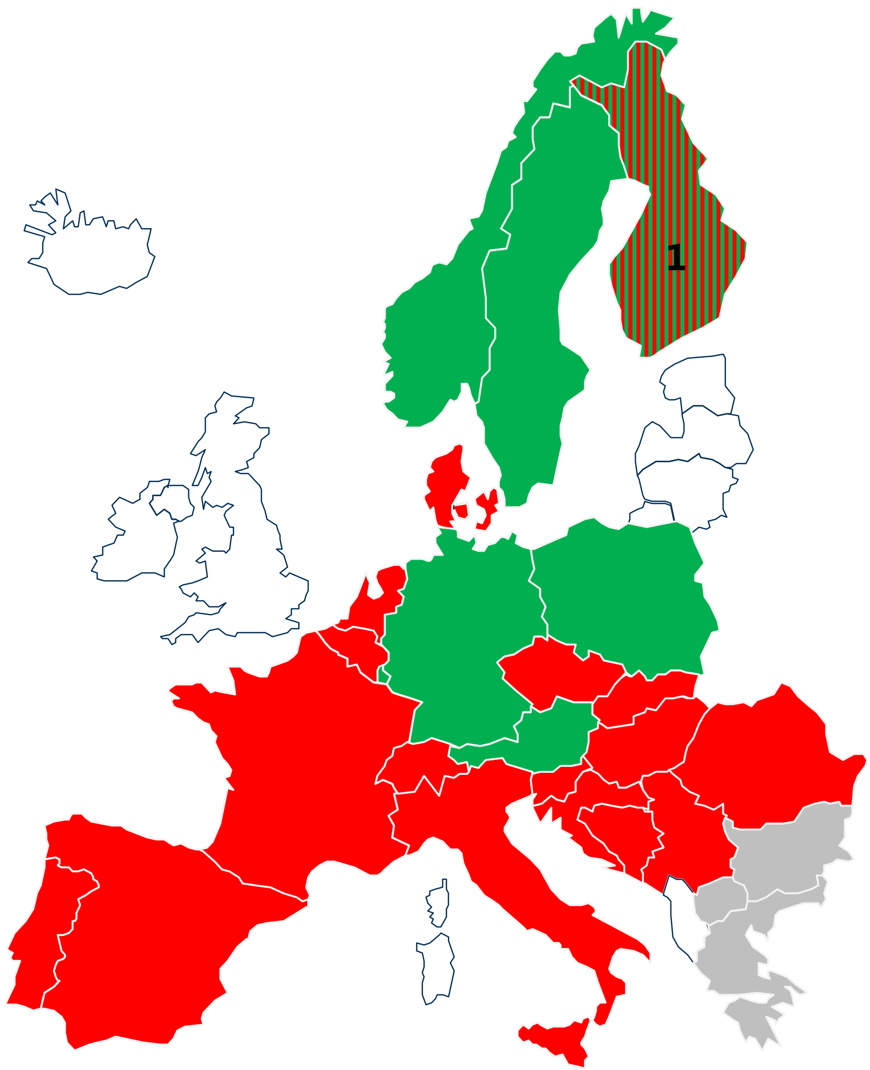
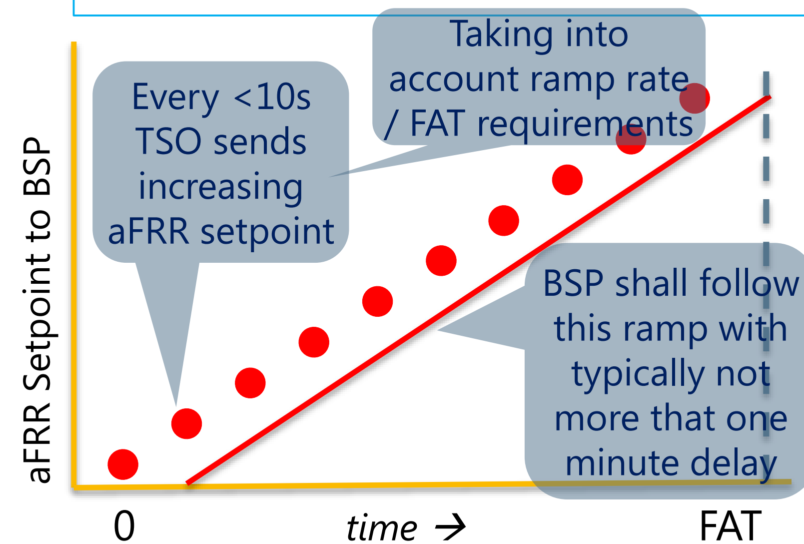
aFRR activation: Continuous or Stepwise

Most TSOs prescribe aFRR response by sending *continuous* ramping setpoints every <10s…



- TSO LFC's *continuous* ramp signal (sent every ≤ 10s) shall be followed by BSP
- TSO LFC's *stepwise* aFRR activation shall be activated by BSP within *Full Activation Time with at least a linear ramp to 100%*
- *Other*
- *No information*



1. *Nordics:* hydro units receive 'step-wise' setpoints that shall be realised within the Full Activation Time. Thermal units receive a 'continuous' ramp signal

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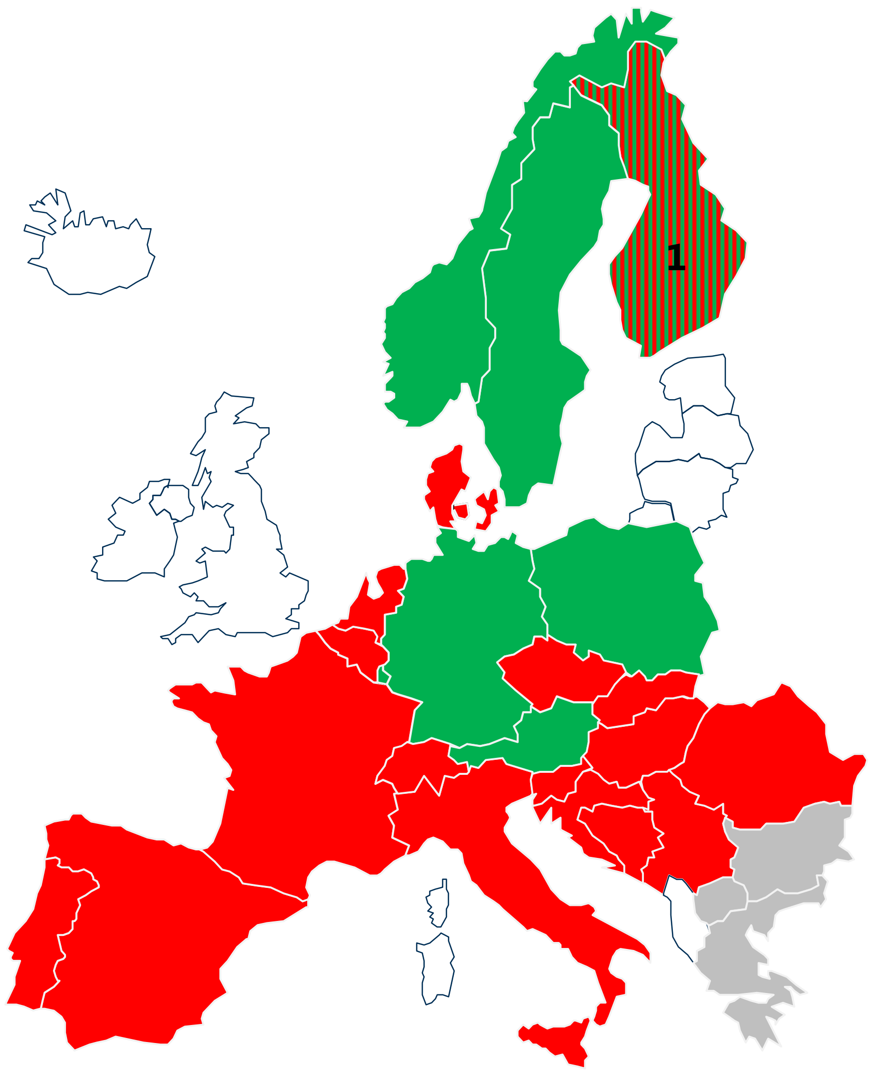
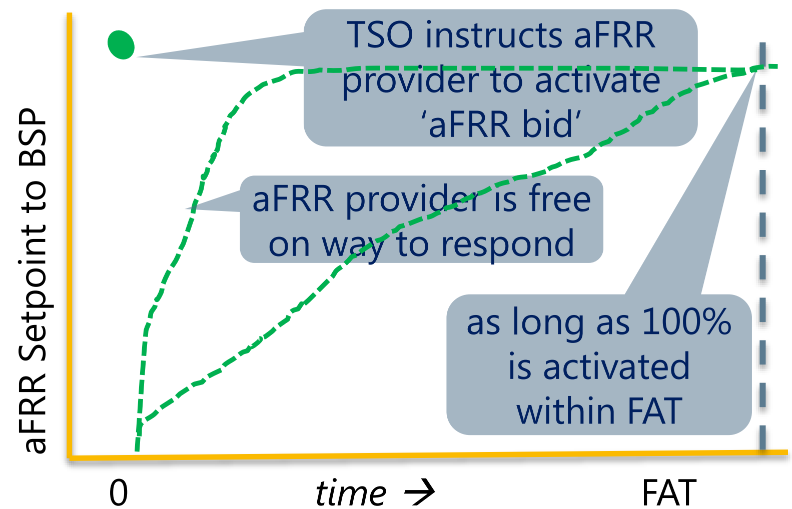
aFRR activation: Continuous or Stepwise

…Some TSOs activate aFRR *stepwise* and are only interested in that aFRR is activated after FAT





1. *Nordics:* hydro units receive 'step-wise' setpoints that shall be realised within the Full Activation Time. Thermal units receive a 'continuous' ramp signal

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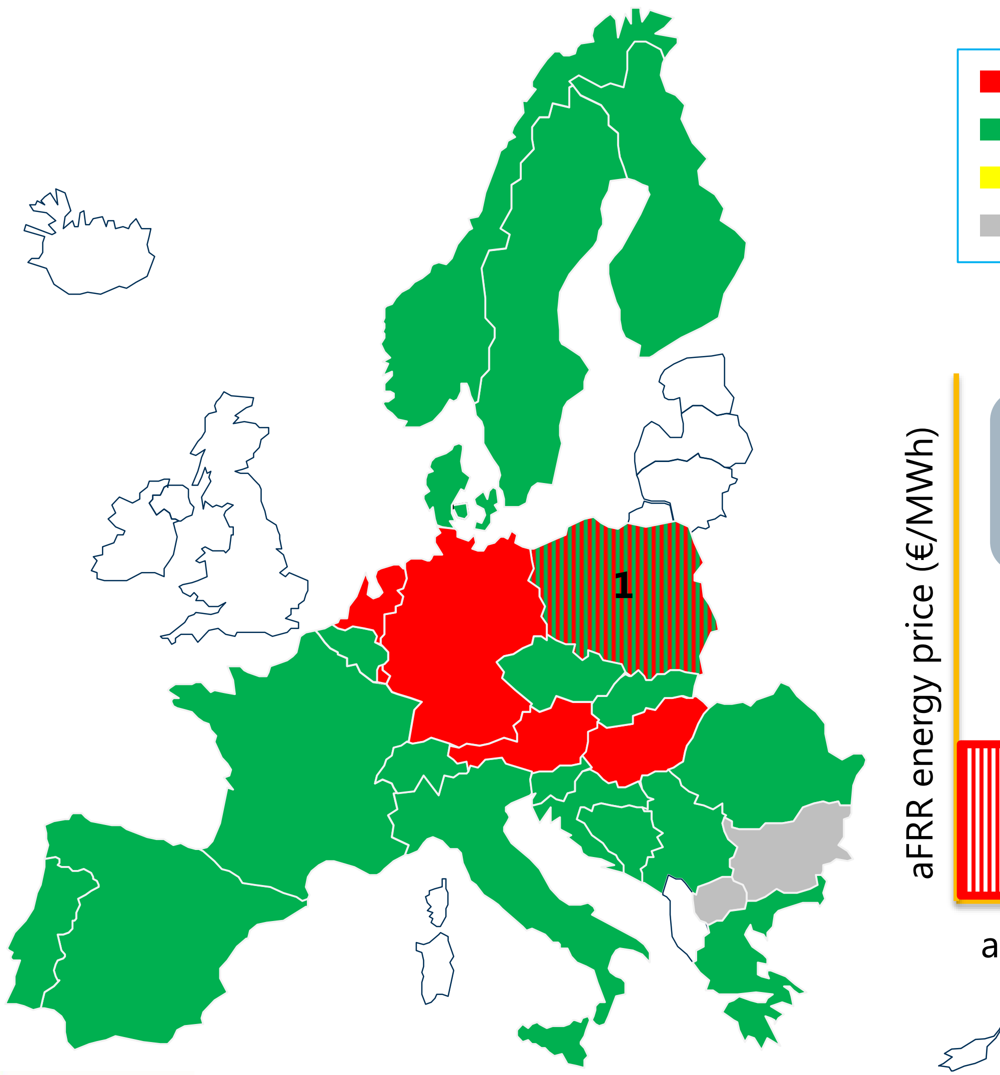
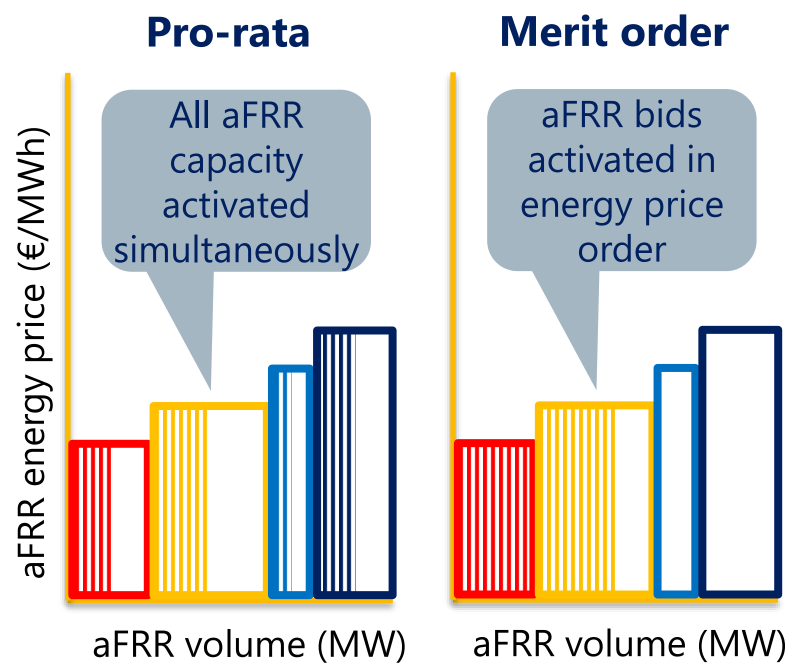
aFRR activation: Pro-Rata or Merit Order

Five countries apply merit order activation, other TSOs apply pro-rata activation





1. *PL:* aFRR activation is a combination of pro-rata and merit order activation

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This presentation

Impact of a change in Full Activation Time (FAT) on aFRR markets and aFRR procurement costs

- One of the objectives of the aFRR study is to understand the *impact* of a *change in Full Activation Time (FAT) requirements* on aFRR markets and aFRR procurement costs
- Our approach takes the following steps:

1. Assess the technical aFRR Capability for each LFC block:
   - Determine the 'total maximum generation capacity per LFC block that could be provided for aFRR' (= aFRR Capability) as a function of FAT
   - Units that are not yet connected to the LFC are in principle *included*
   - We only exclude units that are technically not capable to provide aFRR or reduce/exclude capability of Nuclear units for which safety regulations apply
2. Calculate the relative *increase/decrease in aFRR capability* per LFC block if the FAT in this block is changed to 5, 7.5, 10 or 15 minutes. This relative *increase/decrease in aFRR capability* will be considered as proxy for the available volume and resulting liquidity in case of changing FAT
3. Calculate the influence of FAT on the frequency quality → Section 4
4. These values calculated under 2 and 3 will be used to qualitatively assess the impact of change in FAT on liquidity in aFRR capacity and energy markets

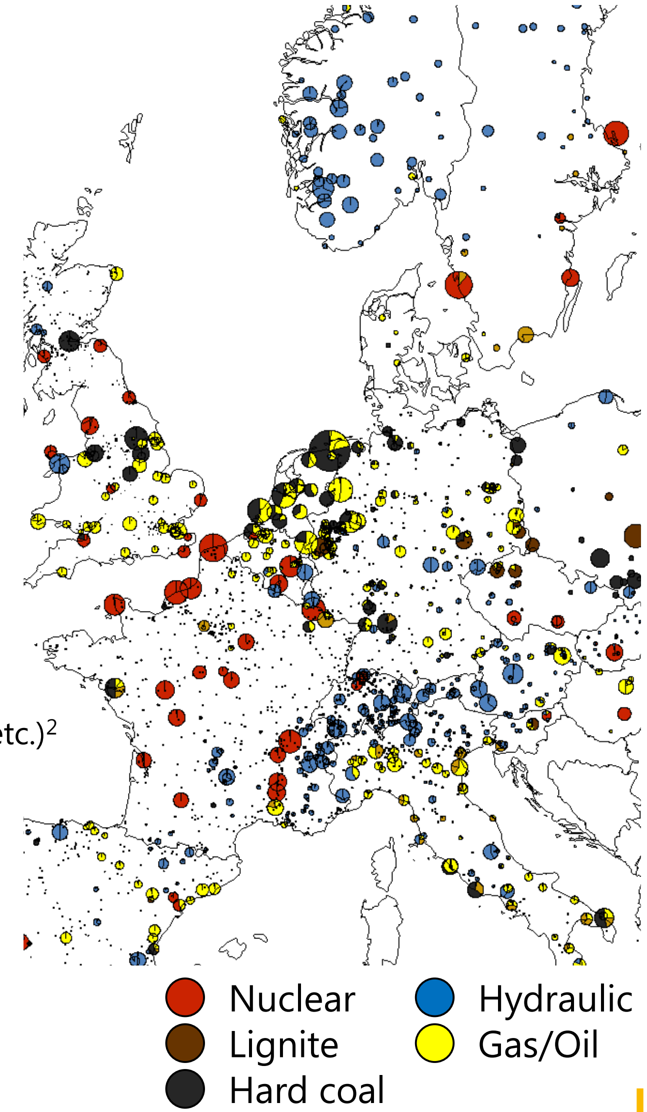
aFRR Capability in European LFC Blocks as function of FAT

European Electricity System 2014

- Over 2,500 generation units in Europe
- Hydraulic and thermal power plants
- Photovoltaic, wind and other RES
- Power plant data based on ENTSO-E and national publications
- Installed capacities according to ENTSO-E factsheet 2014

Technical parameters

- Minimum and maximum power output
- Power-dependent efficiencies
- Technical non-availability (revisions, power plant outages)
  - Thermal power plants in Germany: Based on VGB-statistics[1]
  - Other: Published availabilities on different platforms (e.g. EEX, Elia, etc.)[2]
- Minimum operating hours/minimum downtime
- Reserve (ramping) gradients



[1] The power plant information system KISSY of VGB contains availability data and performance indicators from international power plant providers of a total capacity (gross) of approx. 270 GW. Evaluated period from 2002 to 2011.

[2] Public data on power plant availability according to EU regulation nr. 1227/2011 for different time periods between 2005 and 2014.

Clarification of terms

Real/Actual

aFRR capacity ≠

Technical/Theoretical

aFRR capability

Could be understand as:

- Prequalified aFRR volume
- aFRR capacity that is or will be offered to the market

Is meant as total maximum capability per unit, i.e.:

- Not necessarily economical
- Not necessarily equipped with a LF controller yet
- No consideration of FCR
- Optimal operation point of each unit for providing aFRR

➡ Relative change of aFRR capability (depending on FAT) as an indicator for change of liquidity

General Assumptions for aFRR Capability

Assumptions and generation class parameters

- Given aFRR capabilities do not take into account existing FCR requirements, hence no simultaneous delivery of FCR on the unit is assumed
- Reserve (ramping) gradient in $\frac{\%}{min}$ (referred to P_{max}) is dependent on generation class and commissioning year
- Power plants have to be in operation and spinning: *Maximum aFRR capability* $\Delta P_{aFRR,max}$ *determined through* $P_{max} - P_{min}$

Additional constraints to apply

- Technical availability rates based on historic statistical data dependent on generation class and country
- Ability/condition for load-following operation: No units with commissioning date (and without revision) before: 1985[1]

[1] Not applied for Hydro, Biomass and oil-/natural gas-fired gas turbines due to flexibility

→ ***Technical aFRR capability per LFC-Block equals the sum of capability per unit***

aFRR capability overviews

General Remarks

- Determined capabilities are determined for units in operation in 2014
- Capability of CCGT and biomass assume that the underlying process allows for it

Nuclear Power Plants

- We include aFRR capability of NPP as far as this capability is not subject to safety, environmental, nuclear authority or other non-technical regulation/legislation that likely prevents for NPP to provide aFRR

even if:

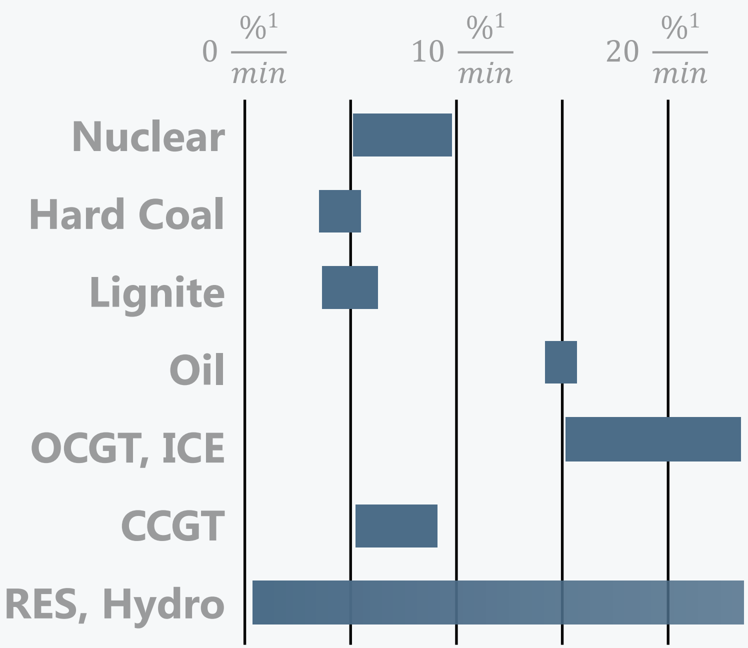
  - NPP is currently not equipped with control systems or other systems that prevent for providing aFRR, but can be equipped with the missing systems
  - NPP units need to go through the TSO's prequalification process for providing aFRR or more aFRR than prequalified today
  - Market considerations make it unlikely that NPP will provide aFRR in the country

however:

  - technical restrictions that prevent for NPP providing aFRR shall be taken into account in the aFRR capability

Assumptions – Parameters

Ramping gradients per technology



OCGT: Open Cycle Gas Turbine
ICE: Internal Combustion Engines
CCGT: Combined Cycle Gas Turbine

[1] $\frac{\%}{min}$ referred to $P_{\max}$

Average[2] availability in %

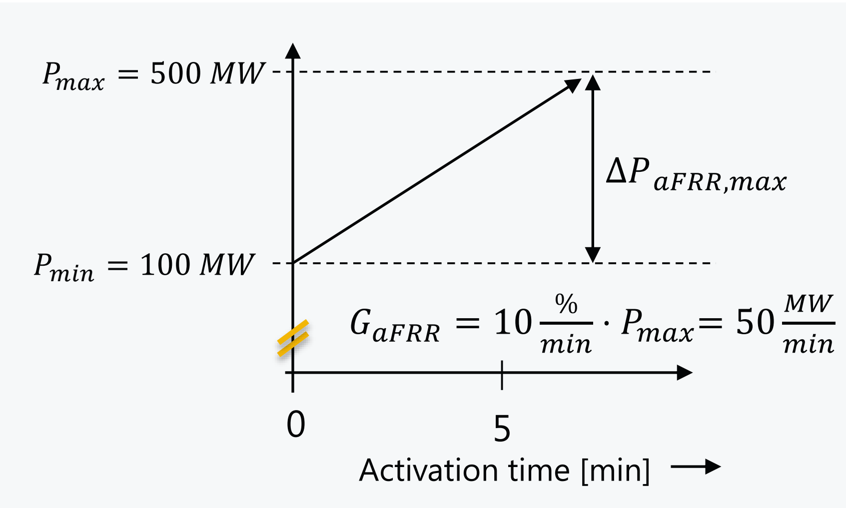
	Average[2] availability	Average P_{min}
Nuclear	81 %	40 %
Hard Coal	86 %	40 %
Lignite	89 %	75 %
Oil	92 %	40 %
OCGT, ICE	90 %	40 %
CCGT	93 %	20 %
Hydro	95 %[3]	20 %

[2] For calculation, individual availability dependent on country.
[3] Assumption due to missing statistical data.

Methodology – Example Calculation

Maximum technical capability for one unit to provide aFRR

- Power plant with $P_{max} = 500\ MW\ and\ P_{min} = 100\ MW$ and a ramping gradient of $10\frac{\%}{min}$
- Operated on either the rated capacity P_{max} or their minimum stable capacity P_{min}



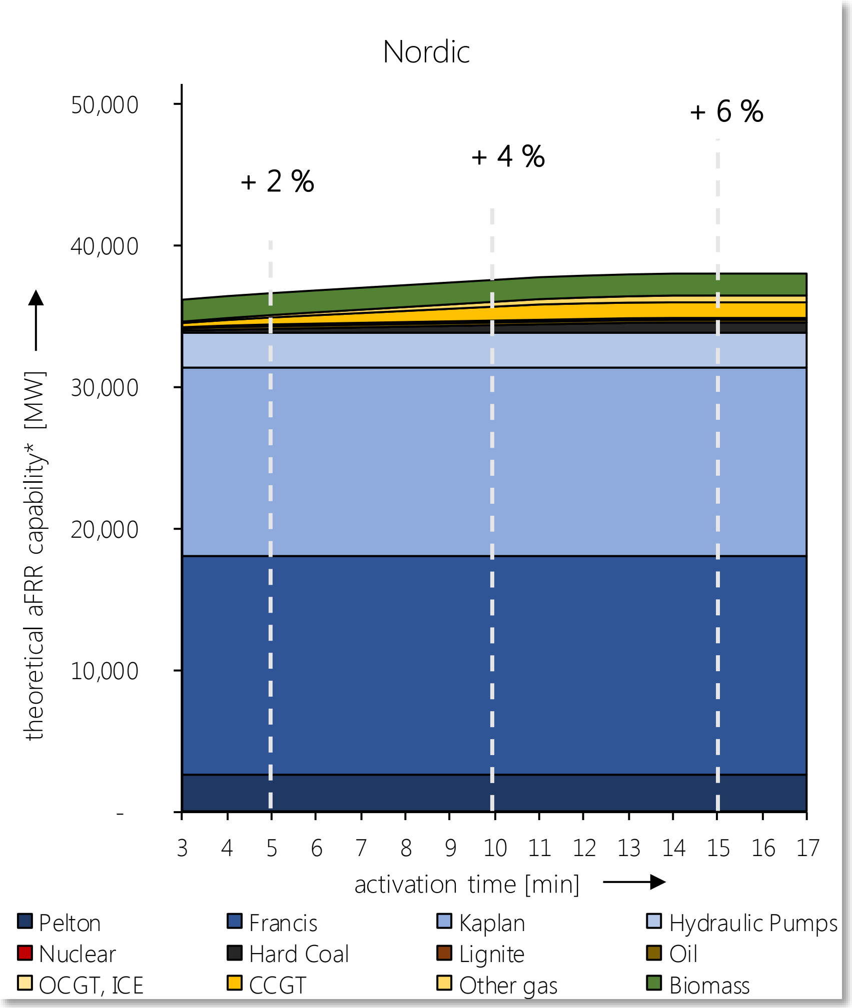
FAT	aFRR capability
5 min	250 MW
10 min	400 MW
15 min	400 MW

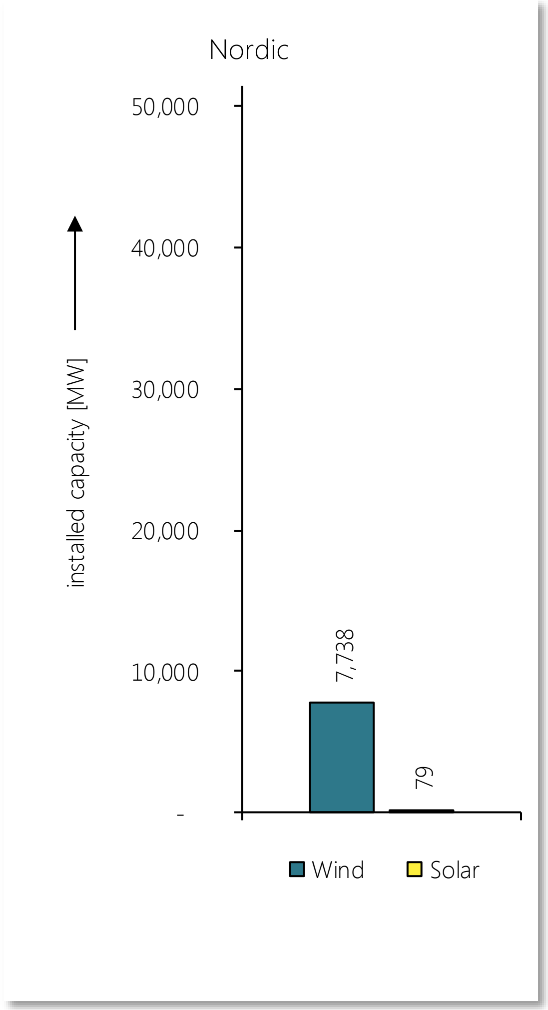
$\Delta P_{aFRR,max}$ is reached 10 minutes after receiving the LFC signal.

- Resulting technical aFRR capability does not necessarily match prequalified volume and is dependent on the operation point of the unit

→ But: Result is maximum technical capability of a unit to provide upward aFRR at operating point P_{min} or downward aFRR at operating point P_{max}

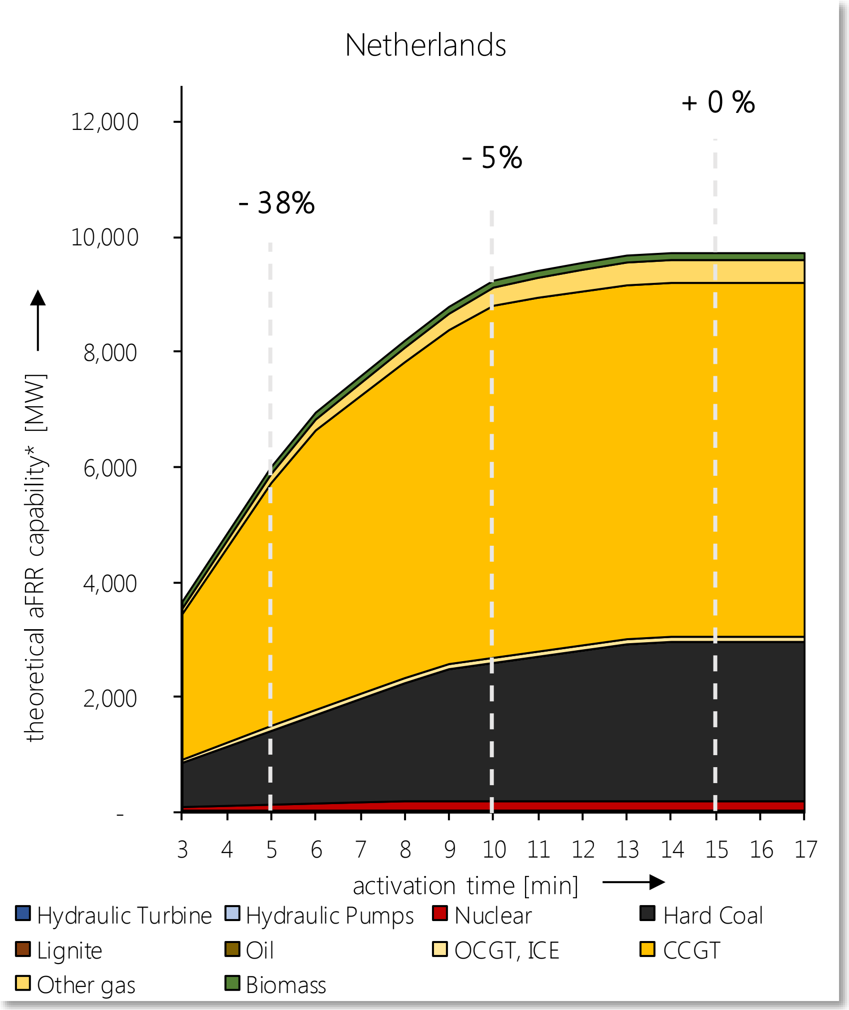
Theoretical aFRR capability – Nordic

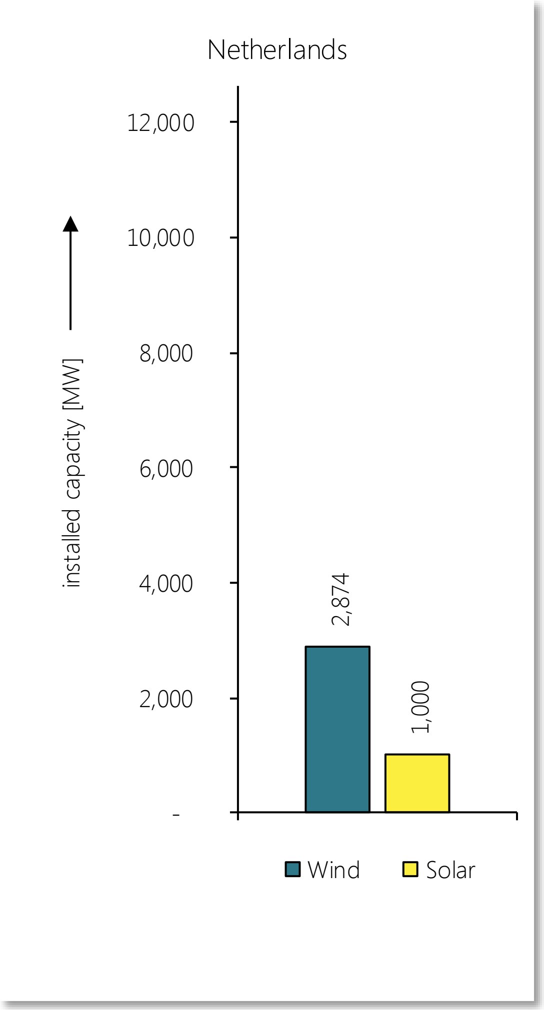




*upward or/and downward, not symmetric

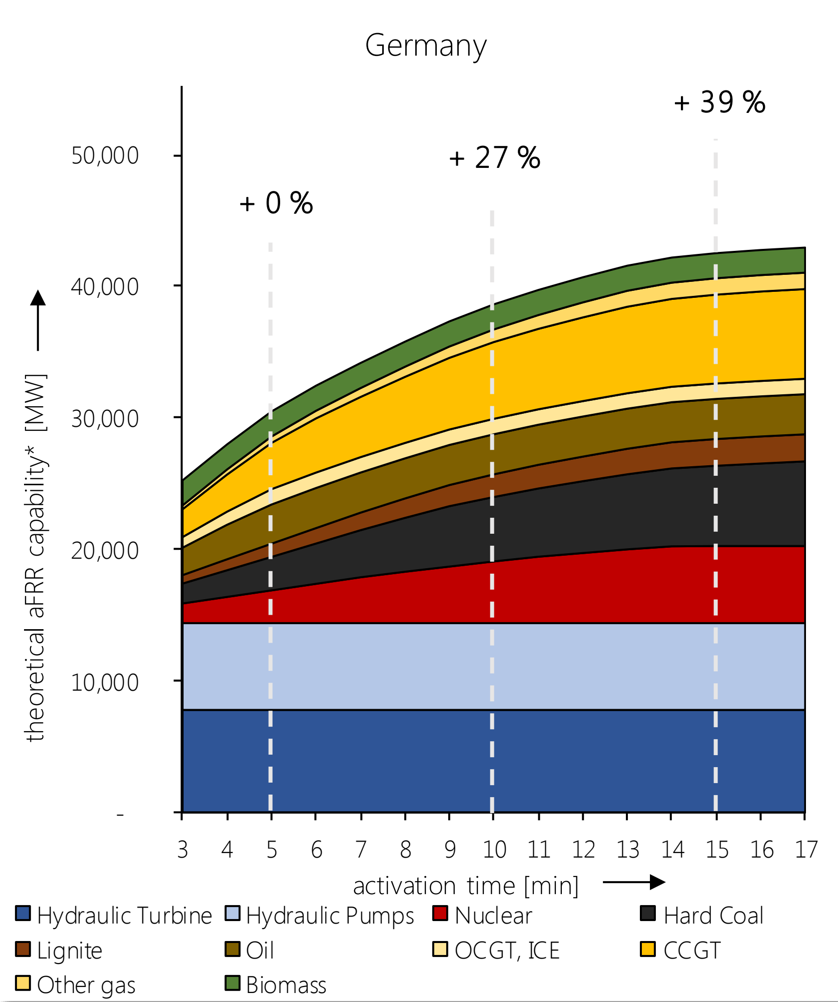
Theoretical aFRR capability – The Netherlands

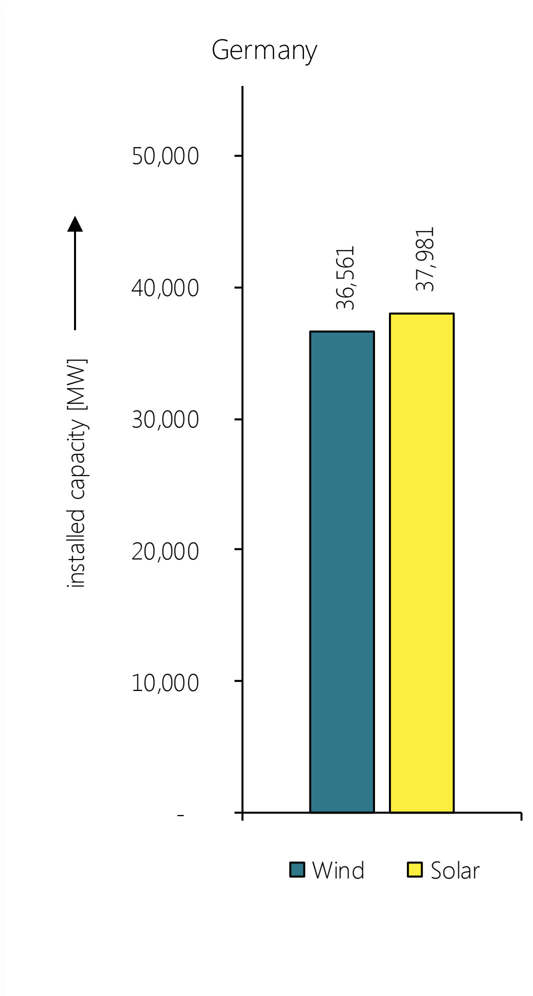




*upward or/and downward, not symmetric

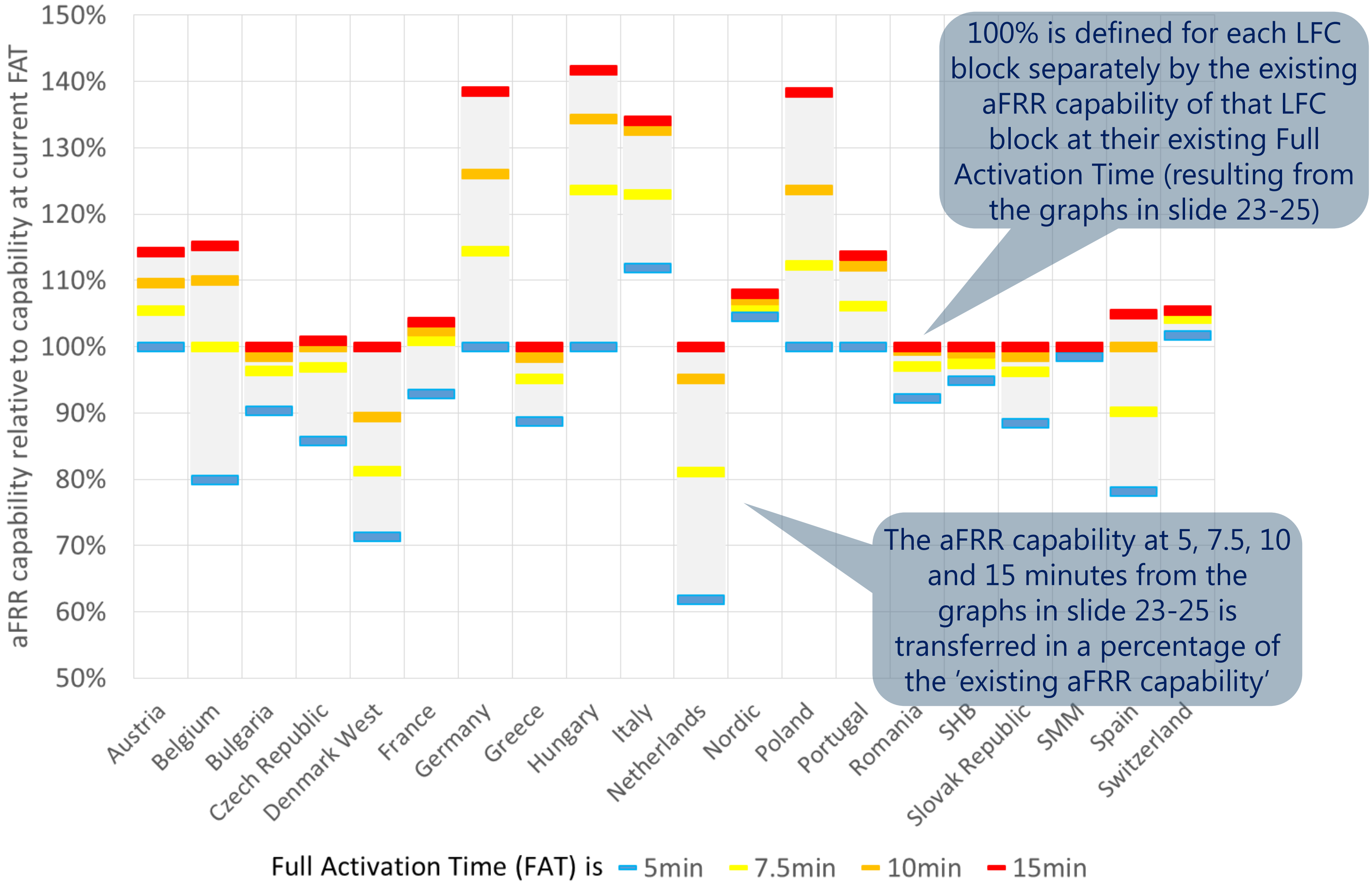
Theoretical aFRR capability – Germany





*upward or/and downward, not symmetric

aFRR Capability in European LFC blocks as function of FAT



aFRR provision by wind and photovoltaic power plants

- No known units which provide aFRR *at the moment* (except from field tests)
- From technical perspective most RES can provide aFRR with sufficient ramping gradients (e.g. wind turbines up to 20% per second)
- aFRR capabilities are not permanently available but dependent on availability of sun or wind
- Making aFRR from RES available requires connecting the control systems to the TSO's LFC
- Providing downward aFRR seems to be most efficient, but technically also upward regulation is possible

aFRR provision by demand

- Besides electrical boilers with power to heat (e.g. in Denmark), no customers which provide aFRR *at the moment* are known.
- From technical perspective - suitable demand for aFRR shall be able to continuously ramp up/or down within the FAT
- Capabilities are not permanently available but dependent on load profile
- Requires IT implementation that may be supported in near future by increasingly "smart" demand appliances', e.g. for smart electrical vehicle charging, electrical heating or cooling
- It is important to avoid that aFRR activation (e.g. reduced cooling load) results in compensation by the customer in the other direction immediately after the activation (e.g. increased cooling load)
- Large technical potential in future for aggregators of small demand units up to large industries and for storage
- For most demand, providing upward aFRR seems to be most efficient, but for some demand upward regulation may be possible

This presentation

Simulations of LFCs in Nordic and Continental LFC blocks with different *Full Activation Time* and *Merit Order Activation*

The objective of the simulations in this project is to quantify the influence of

- a transition from existing situation to *merit order activation*
- a change of *Full Activation Time (FAT)* to *5, 7.5, 10 and 15 minutes*

on:

- *FRCE quality*
- both for *small deviations* and *large deviations*

We will simulate for most European LFC blocks individually and use as input:

- ACE (FRCE) and aFRR activation (< 10s values) for February and June 2015
- Existing available aFRR capacity for February and June 2015
- Current settings of the Load Frequency Controller (LFC) of the LFC block

We calculate results per LFC block:

- Change of *FRCE quality*, expressed in standard deviation (of 1min and 15min results)[1]
- Change of *response (time) to a large deviation*

We will also study mitigation measures to reduced FRCE quality

[1] for Nordic area, we also calculate 'minutes outside 49.9-50.1Hz band;

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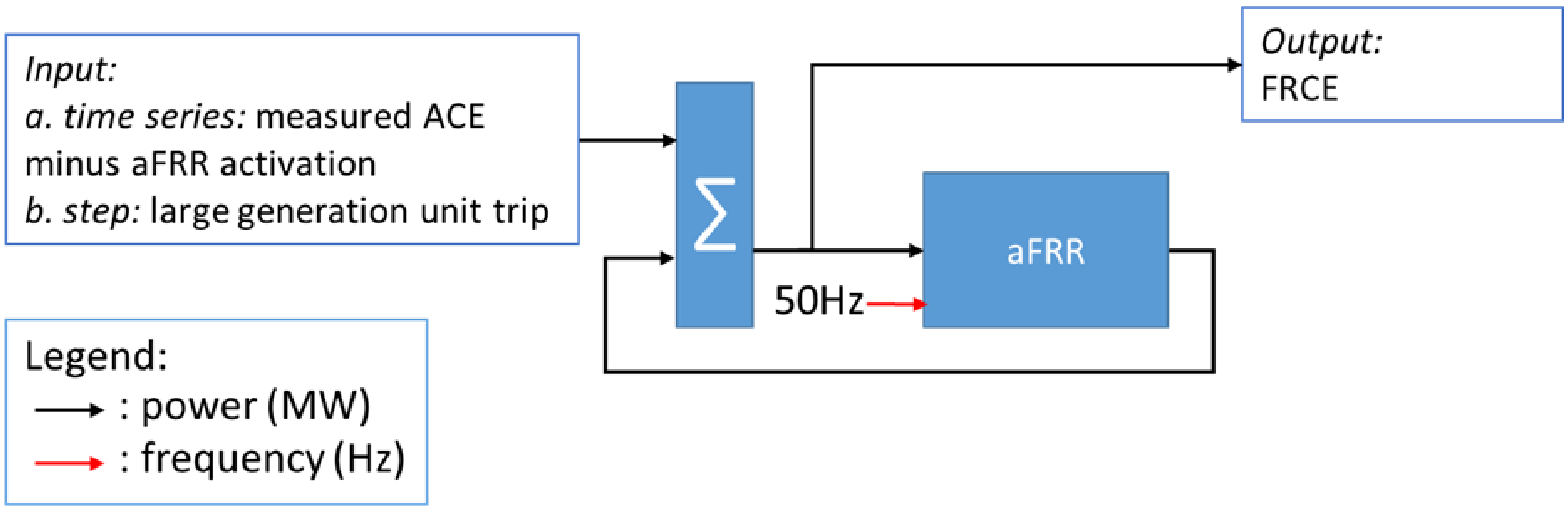
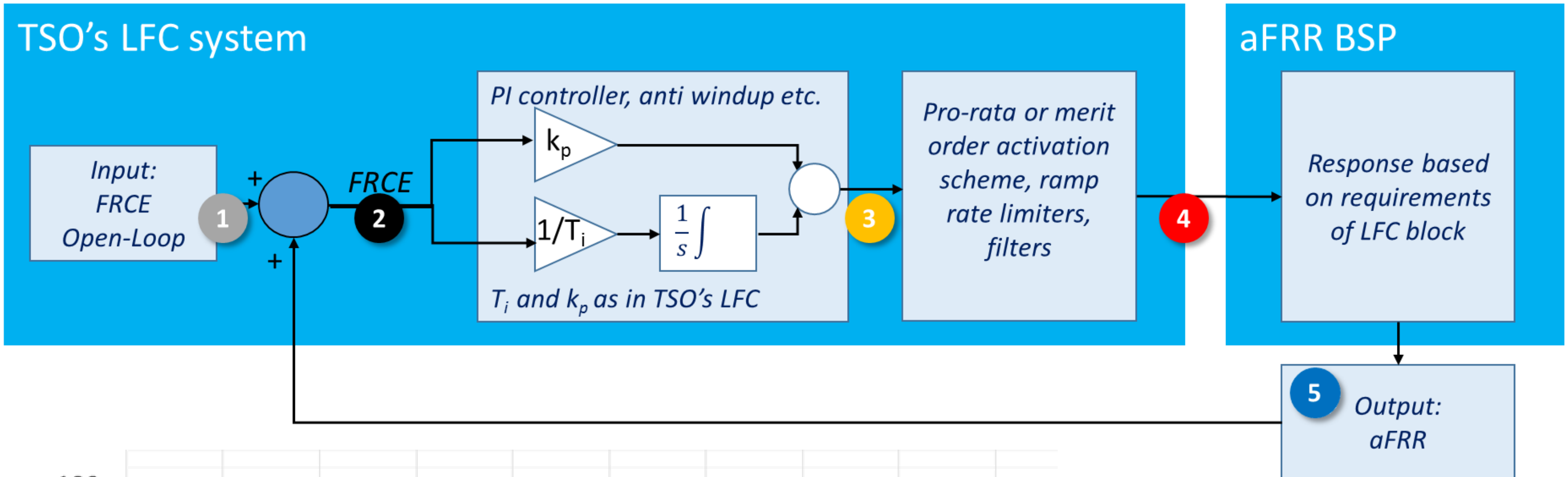
Simulations of LFCs in Nordic and Continental LFC blocks with different *Full Activation Time* and *Merit Order Activation*

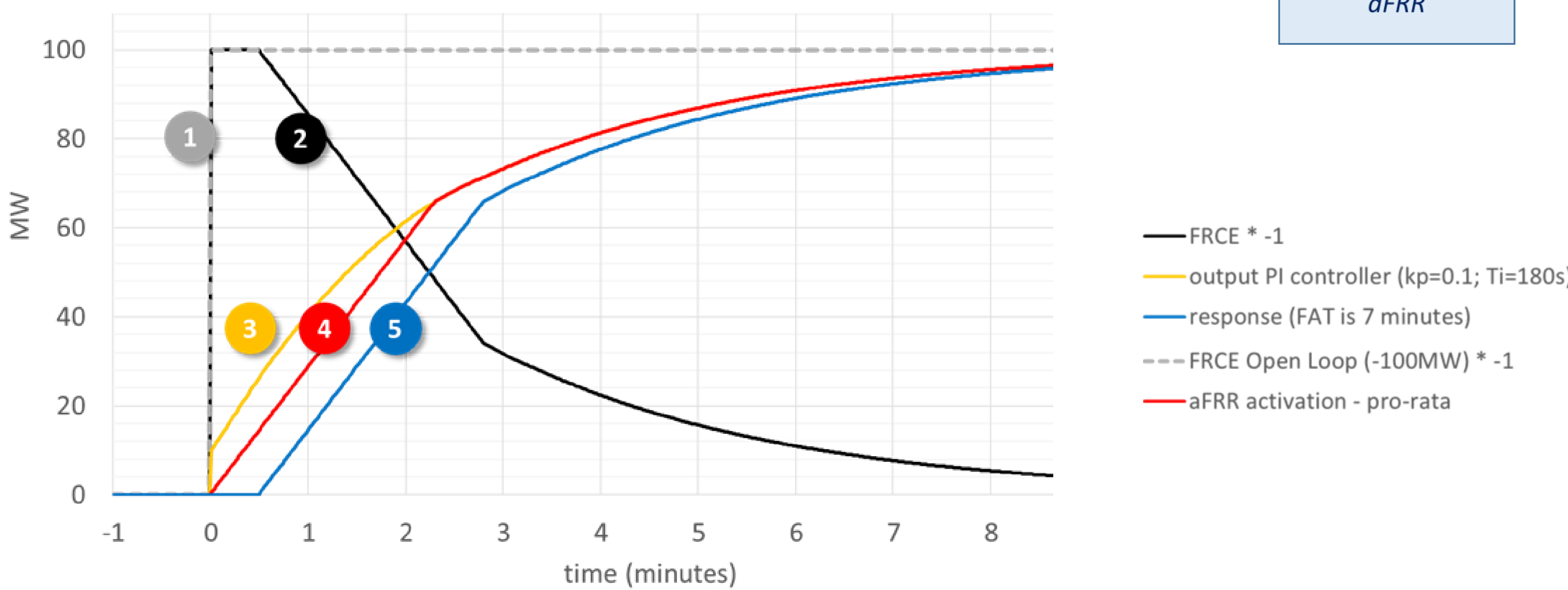


High level Matlab/Simulink model for individual LFC blocks in CE system

Note: in order to focus on aFRR we assume 50Hz for Continental European LFC Blocks. For Nordic block, the model also includes FCR

Response time dependent on both TSO's LFC and BSP response





This presentation

Document control

Version	Description	Date	By
0	Skeleton	4-11-2015	E-Bridge
0.1	Internal draft	9-11-2015	E-Bridge/IAEW
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0.3	Internal draft after review by ENTSO-E	19-11-2015	E-Bridge/IAEW
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