Optimal Activation of Standard Products for Balancing as Required by Draft ENTSO-E Network Codes

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Main interest: Electricity Balancing

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Integration of Balancing Markets

Standard Products

Activation Optimization Function

Modeling the Problem

Case Study

Simulation Results

Ongoing Work

Questions

- **Integration of Balancing Markets**
- Standard Products
- Activation Optimization Function
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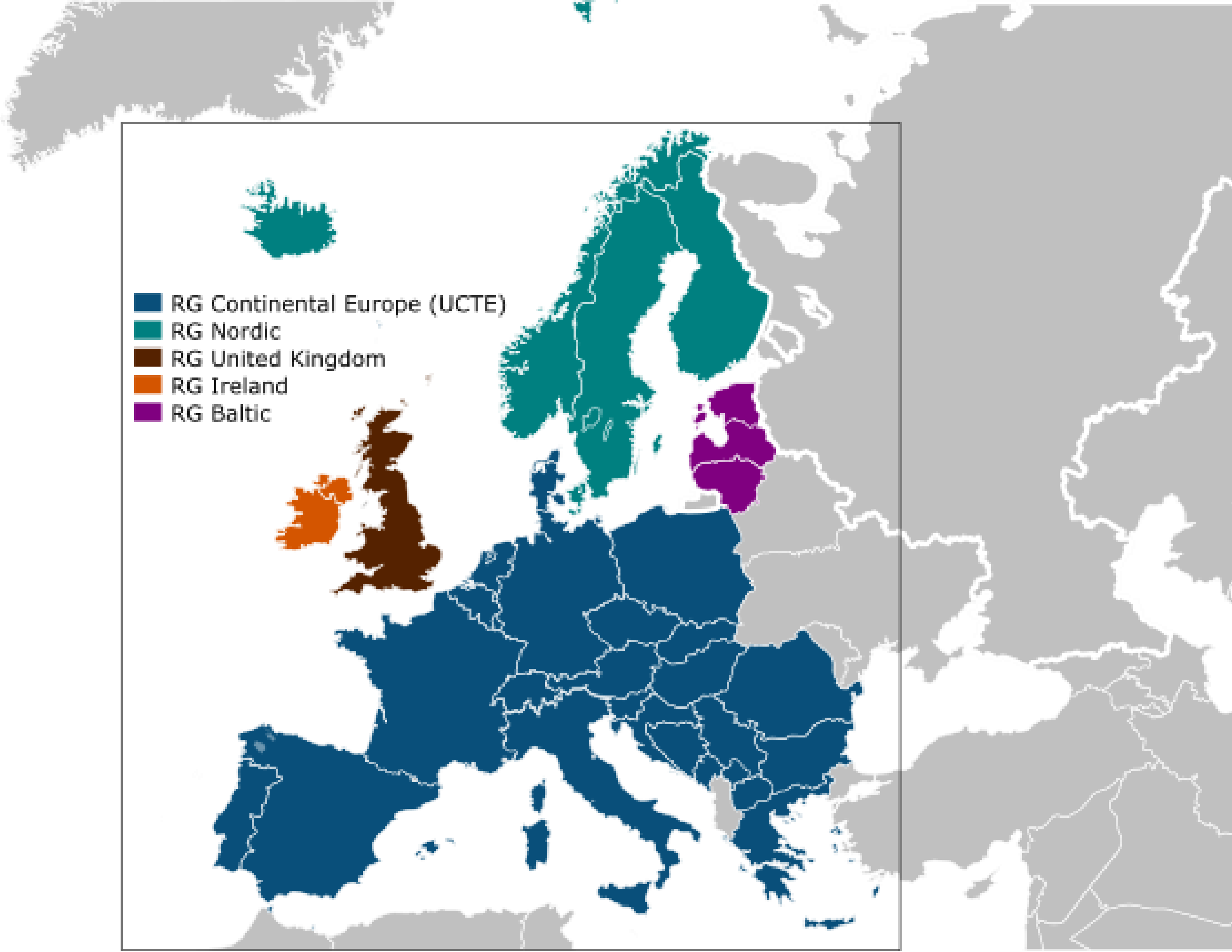
- Ongoing Work
- Questions

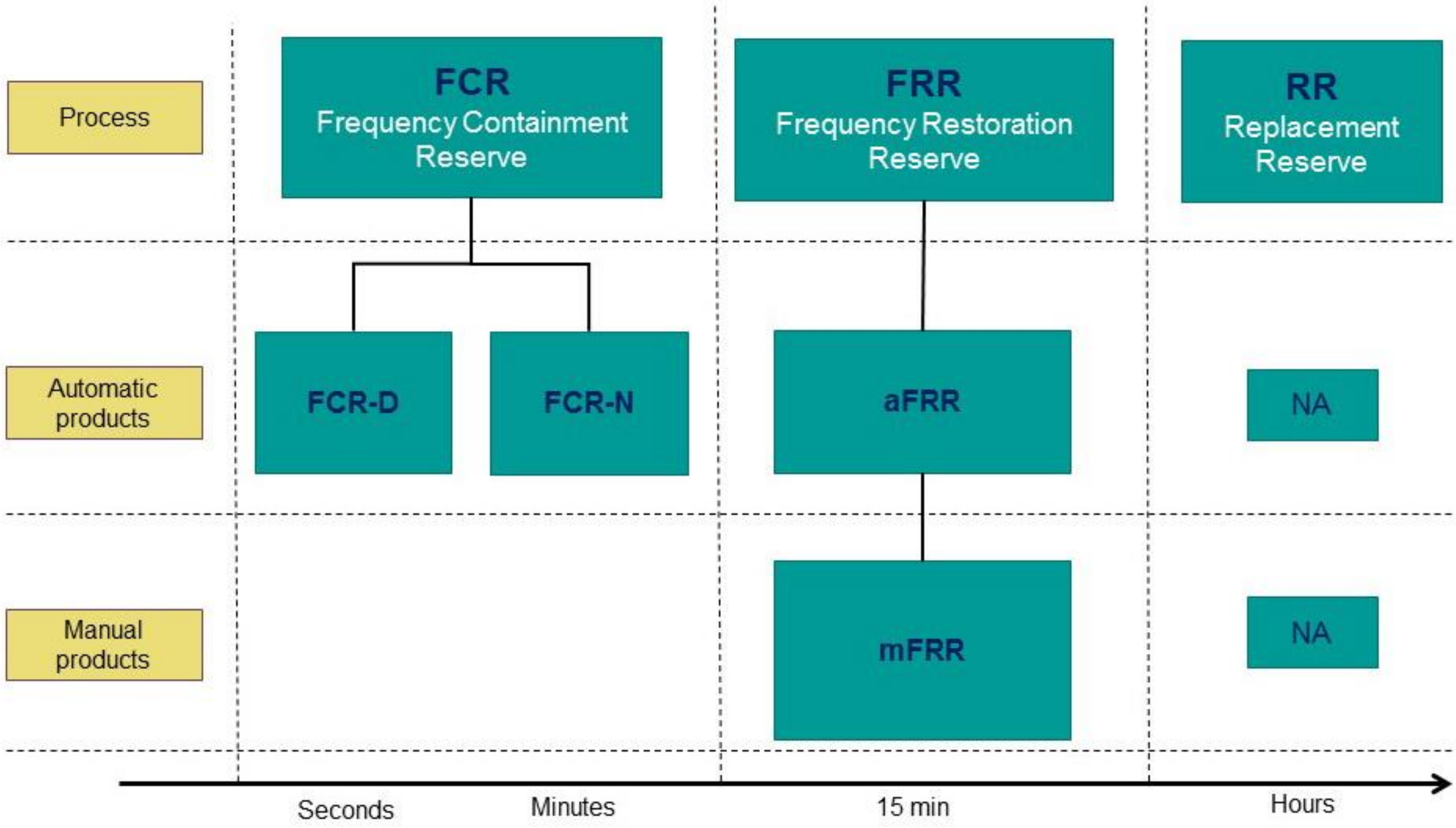
Network Codes

- Electricity Balancing

- Emergency and Restoration
- Demand Connection
- HVDC
- Forward Capacity Allocation
- System Operation

- Capacity Allocation and Congestion Management
- Requirements for Generators


RG Continental Europe (UCTE)
RG Nordic
RG United Kingdom
RG Ireland
RG Baltic



Process
FCR
Frequency Containment Reserve
FRR
Frequency Restoration Reserve
RR
Replacement Reserve
Automatic products
FCR-D
FCR-N
aFRR
NA
Manual products
mFRR
NA
Seconds
Minutes
15 min
Hours

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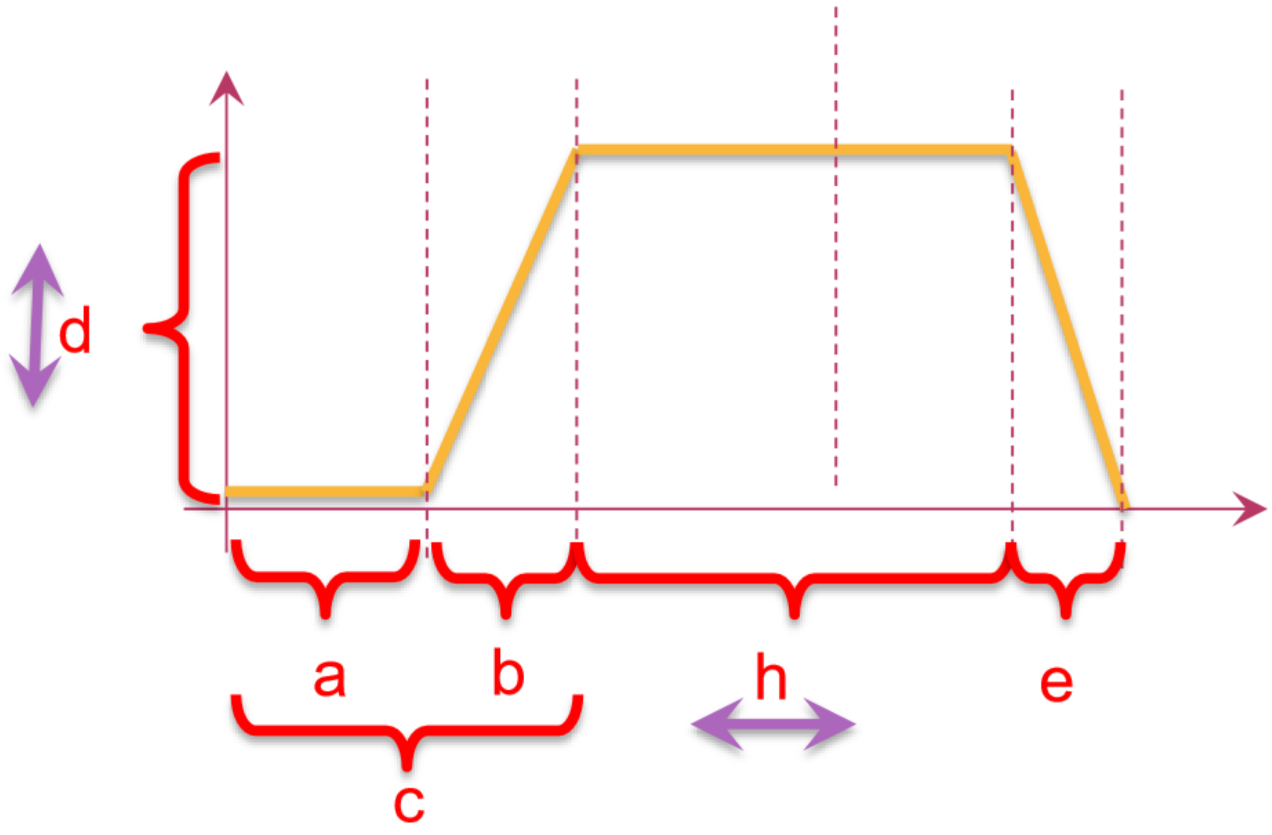

Characteristics

(a) Preparation time
(b) Ramping period
(c) Full activation time
(d) Minimum/maxiumum quantity
(e) Deactivation period
(f) Divisibility
(g) Validity period
(h) Min/max **delivery period**
(i) Mode of activation

Product proposals

2014	2015	2016	?
4 aFRR	? aFRR	1 aFRR	1 aFRR?
6 mFRR	4 mFRR	3 mFRR	1 mFRR?
2 RR	2 RR	1 RR	1 RR?

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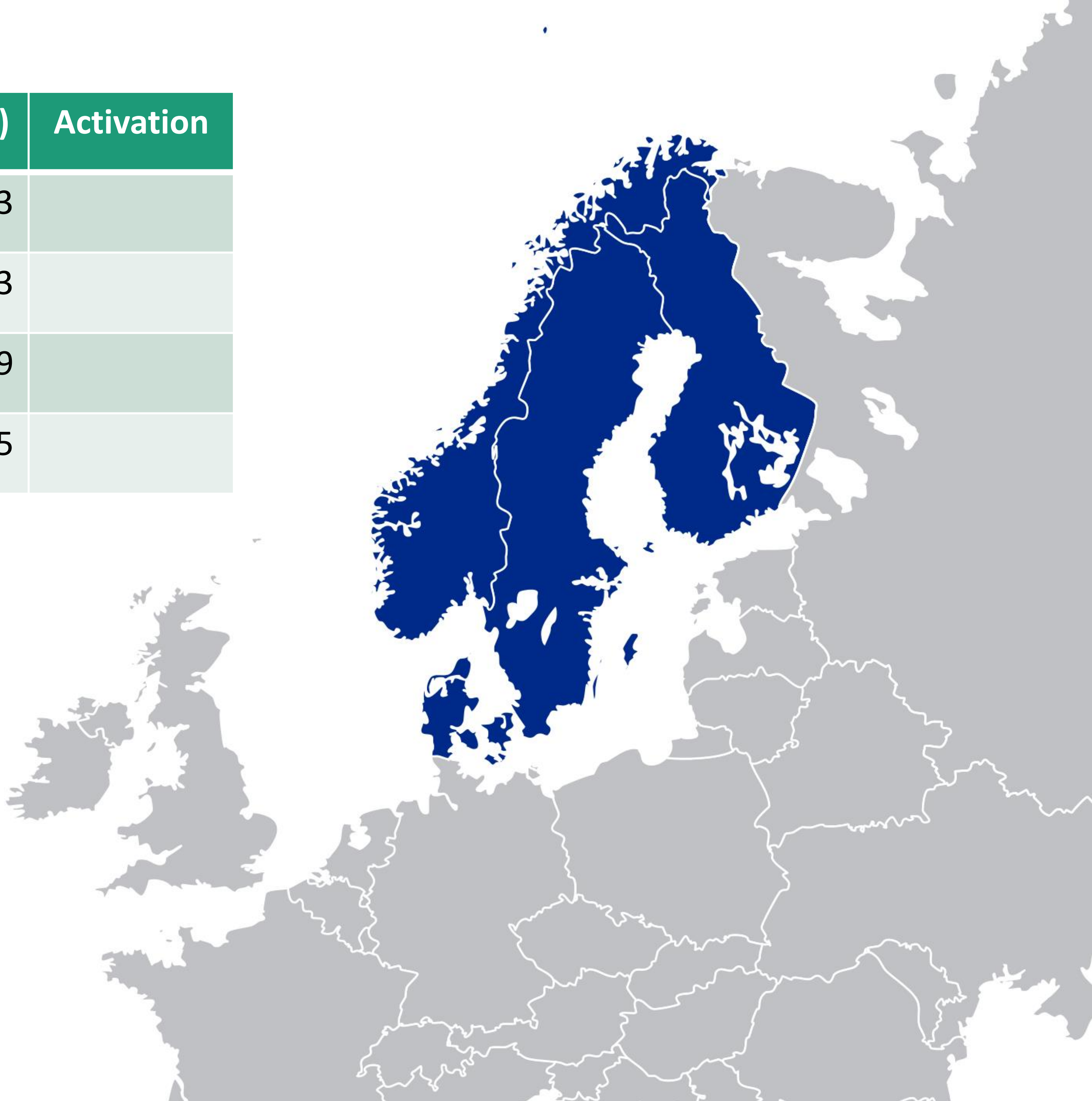
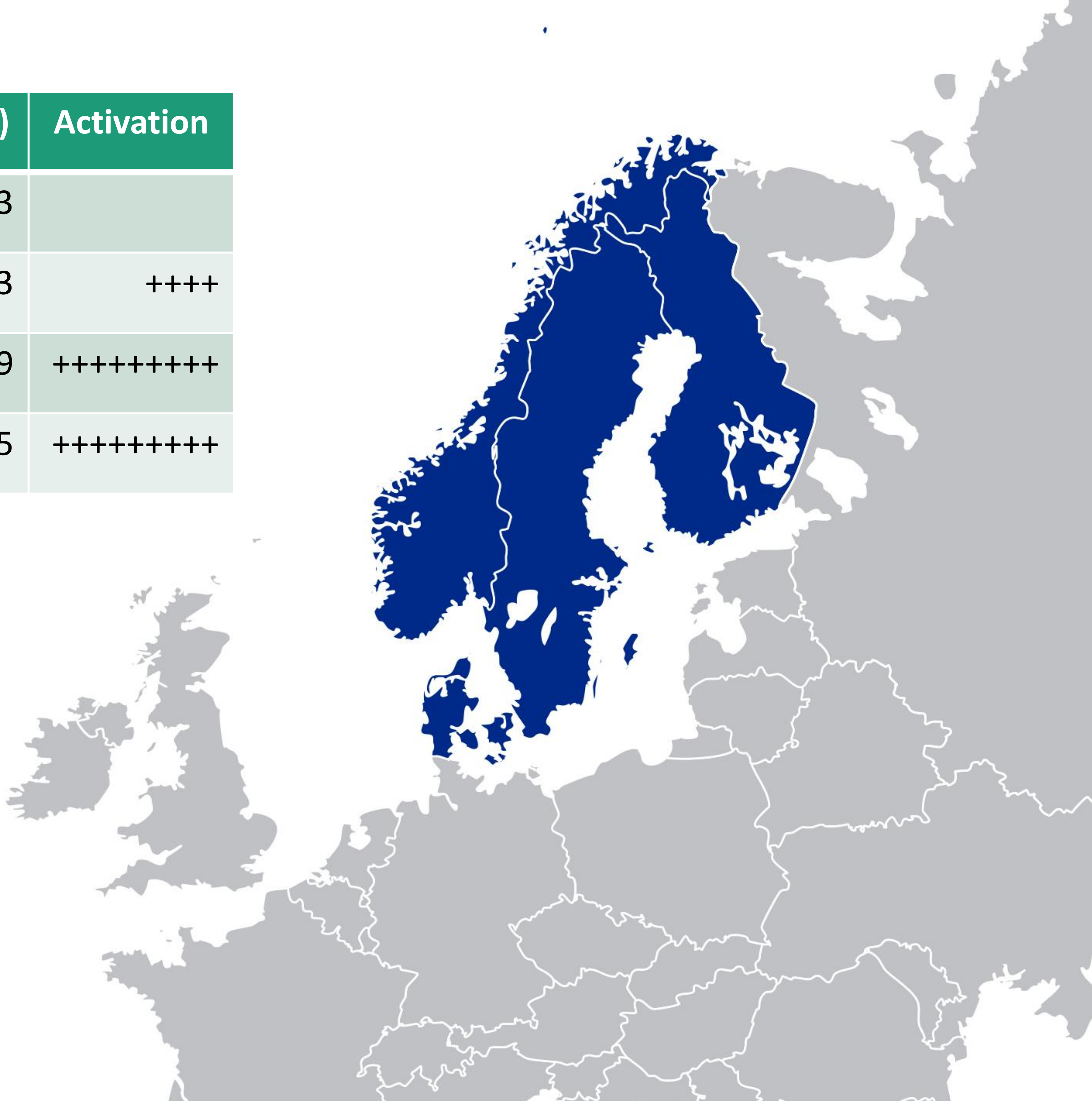
Bid provider	Price (€)	Quantity (MW)	Activation
Oslo Hydro Heroes	46	43	
Copenhagen Useful Utility	44	13	
Helsinki Superpower	39	39	
Stockholm Power	36	25	

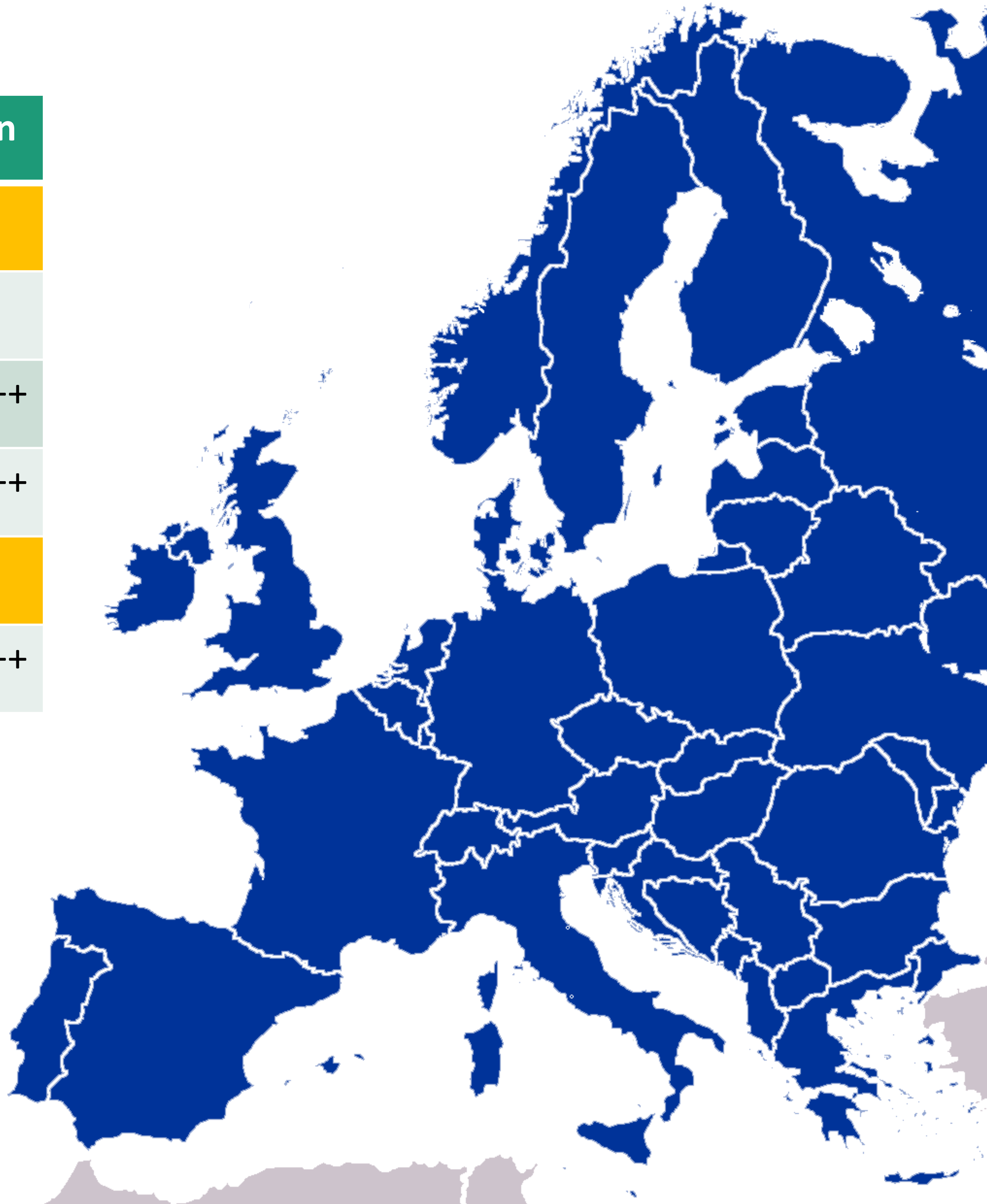
Need 70 MW



Bid provider	Price (€)	Quantity (MW)	Activation
Oslo Hydro Heroes	46	43	
Copenhagen Useful Utility	44	13	++++
Helsinki Superpower	39	39	+++++++++
Stockholm Power	36	25	+++++++++



Bid provider	Price (€)	Quantity (MW)	Activation
Lisbon Electric	89	4	
Oslo Hydro Heroes	46	43	
Copenhagen Useful Utility	44	13	++++
Helsinki Superpower	39	39	+++++++++
Berlin Intense Solar	37	30	
Stockholm Power	36	25	+++++++++



Bid provider	Price (€)	Quantity (MW)	Activation
Lisbon Electric	89	4	
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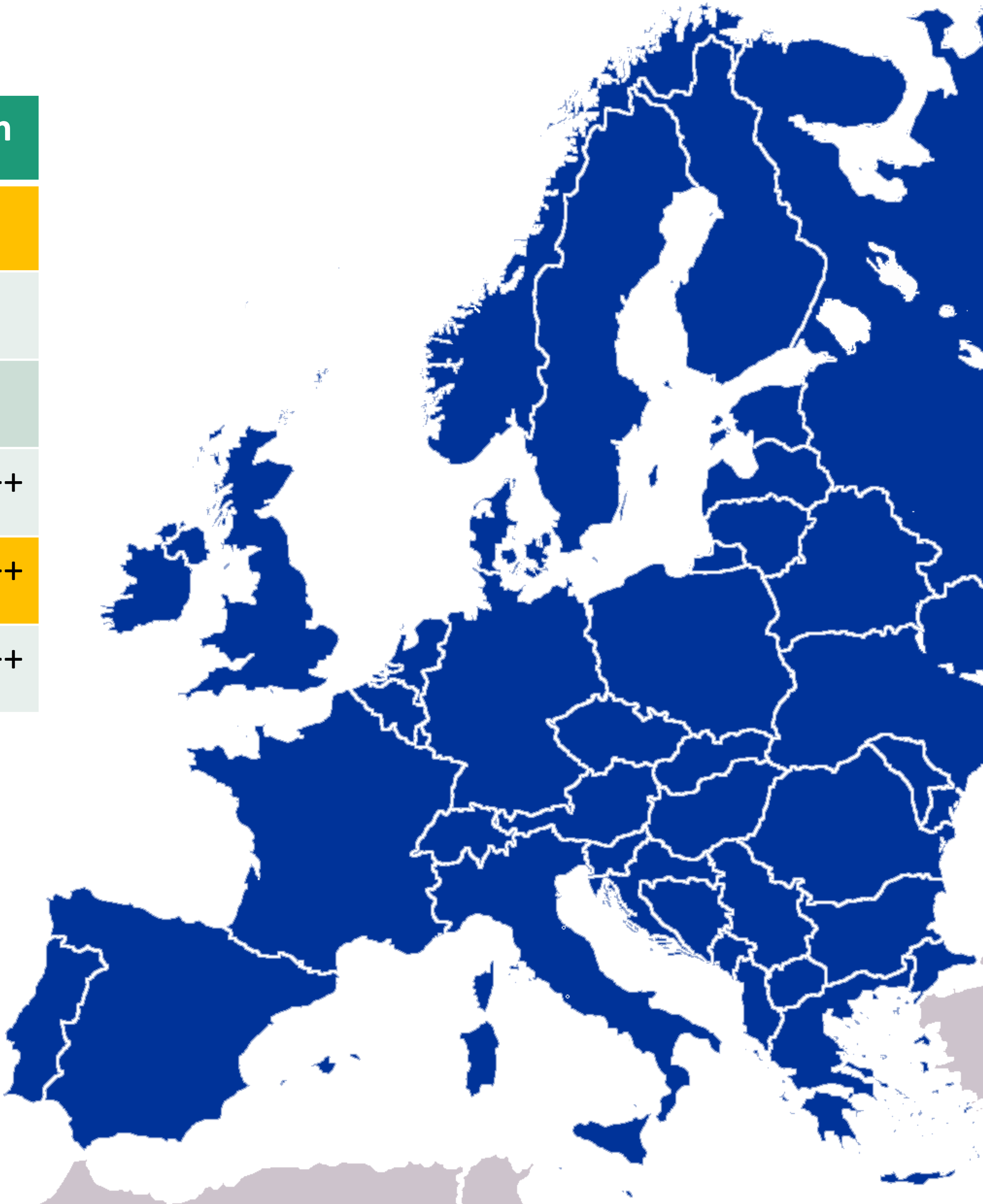
Copenhagen Useful Utility	44	13	
Helsinki Superpower	39	39	++++
Berlin Intense Solar	37	30	+++++++++
Stockholm Power	36	25	+++++++++



Bid provider	Product	Price (€)	Quantity (MW)	Activation
Lisbon Electric	aFRR	89	4	
Oslo Hydro Heroes	mFRR-5	46	43	
Copenhagen Useful Utility	mFRR-15	44	13	
Helsinki Superpower	RR	39	39	
Berlin Intense Solar	mFRR-15	37	30	
Stockholm Power	mFRR-10	36	25	

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Cost minimization

$$C^a = \sum_{t\in T}\left(\sum_{b\in B_u} c_b y_{b,t} + \sum_{b\in B_d}(p^{DA} - c_b)y_{b,t}\right)$$

Activation cost

Upward activations

Downward activations

$$C^p = \sum_{t\in T}\sum_{k\in K} p_k\left(f_t^{ok} + f_t^{uk}\right)$$

$$\min C = C^a + C^p$$

Cost minimization

$$C^a = \sum_{t \in T} \left(\sum_{b \in B_u} c_b y_{b,t} + \sum_{b \in B_d} (p^{DA} - c_b) y_{b,t} \right)$$

$$C^p = \sum_{t \in T} \sum_{k \in K} p_k \left(f_t^{ok} + f_t^{uk} \right)$$

Penalty cost

Penalty param.

Over freq.

Under freq.

$$\min C = C^a + C^p$$

Cost minimization

$$C^a = \sum_{t \in T} \left(\sum_{b \in B_u} c_b y_{b,t} + \sum_{b \in B_d} (p^{DA} - c_b) y_{b,t} \right)$$

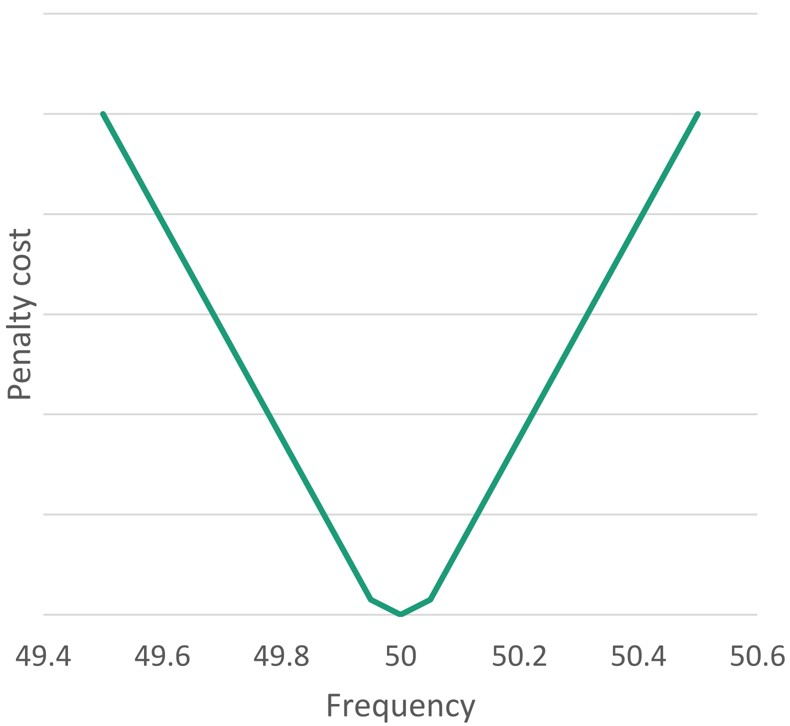
$$C^p = \sum_{t \in T} \sum_{k \in K} p_k \left(f_t^{ok} + f_t^{uk} \right)$$

$$\boldsymbol{\min C = C^a + C^p}$$

Total cost

Frequency Deviations

Penalty function



Frequency estimation

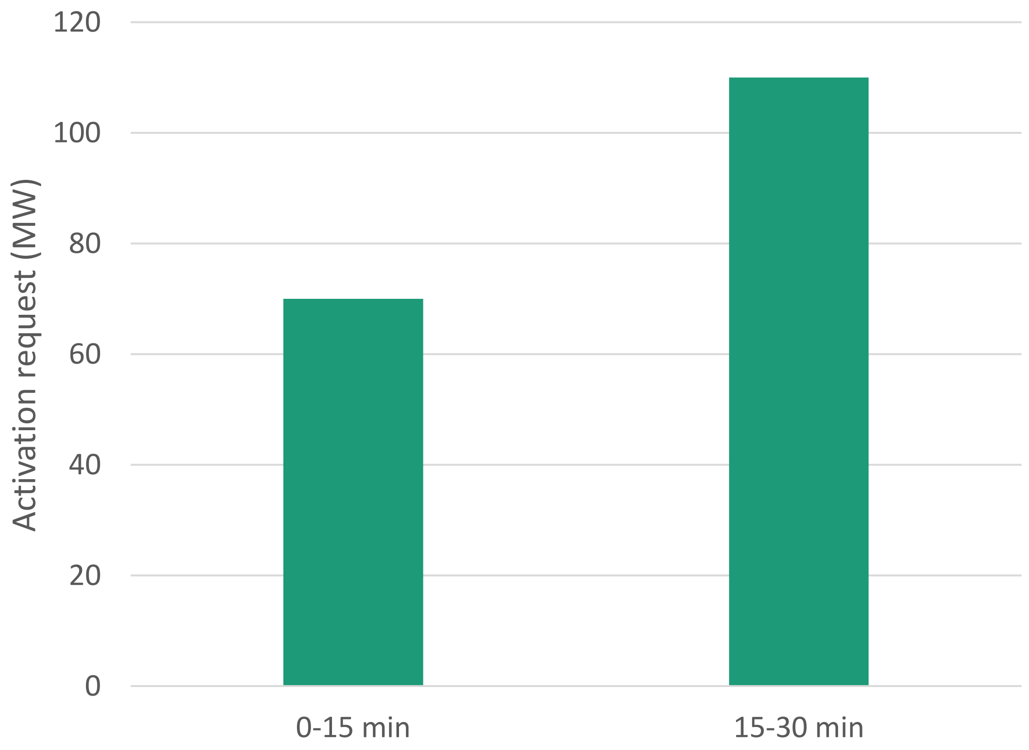
$$f_t = f_N + \frac{1}{\lambda} \sum_{t \in T} \left(\sum_{b \in B_u} y_{b,t} - \sum_{b \in B_d} y_{b,t} + \omega_t \right)$$

Freq. bias

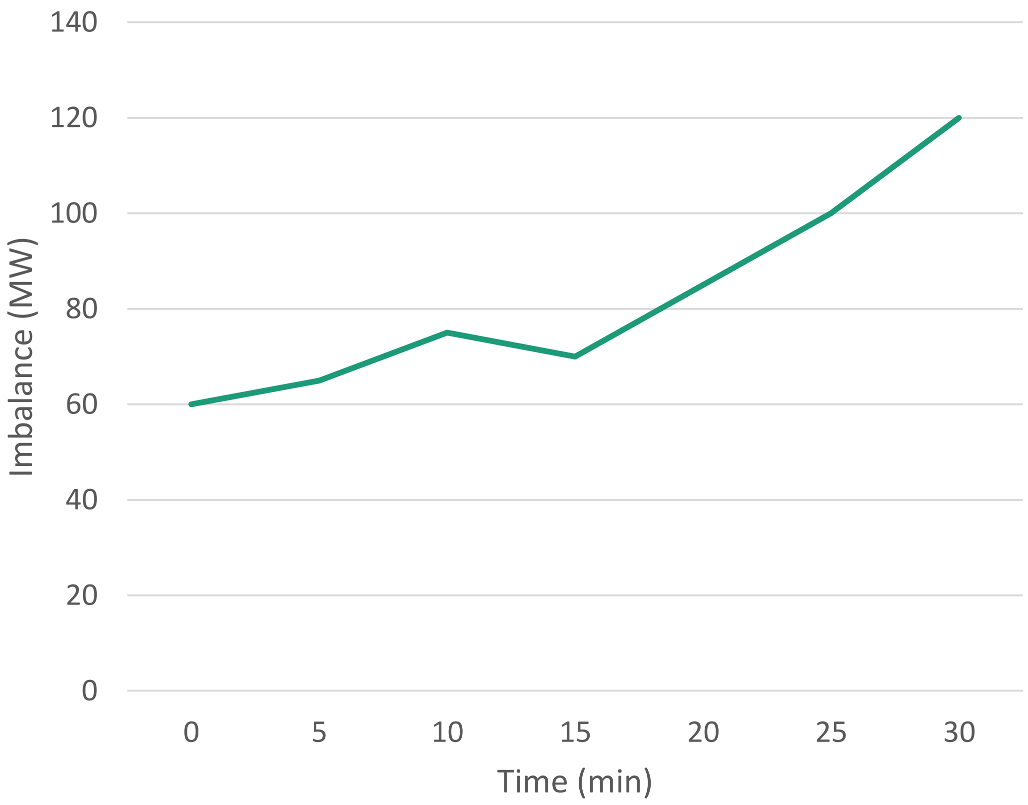
Imbalance

Imbalance forecasts

We need 70 MW, then 110 MW in the next period

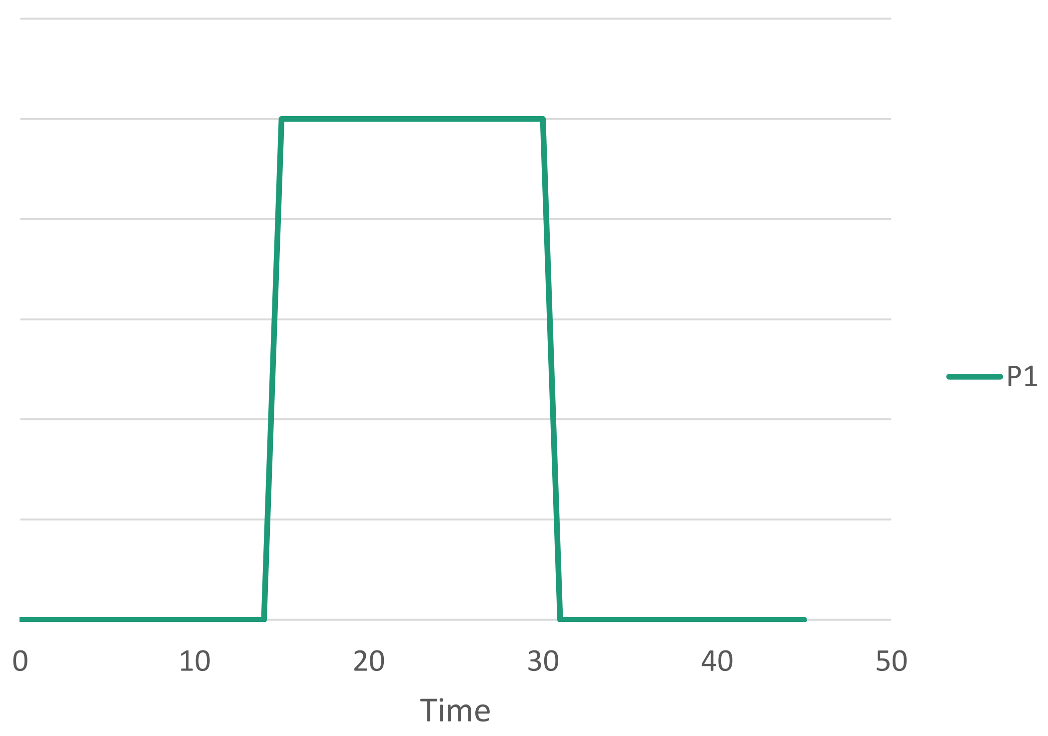


Or: this is our expected imbalance, please cover it

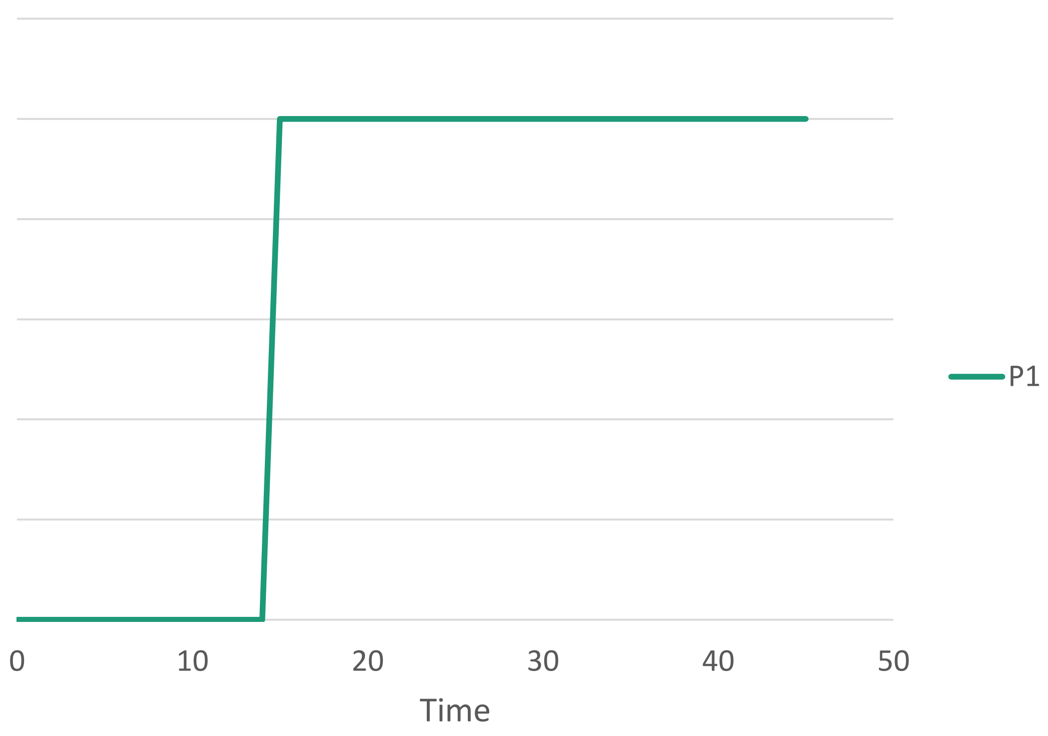


Standard Products

Minimum duration

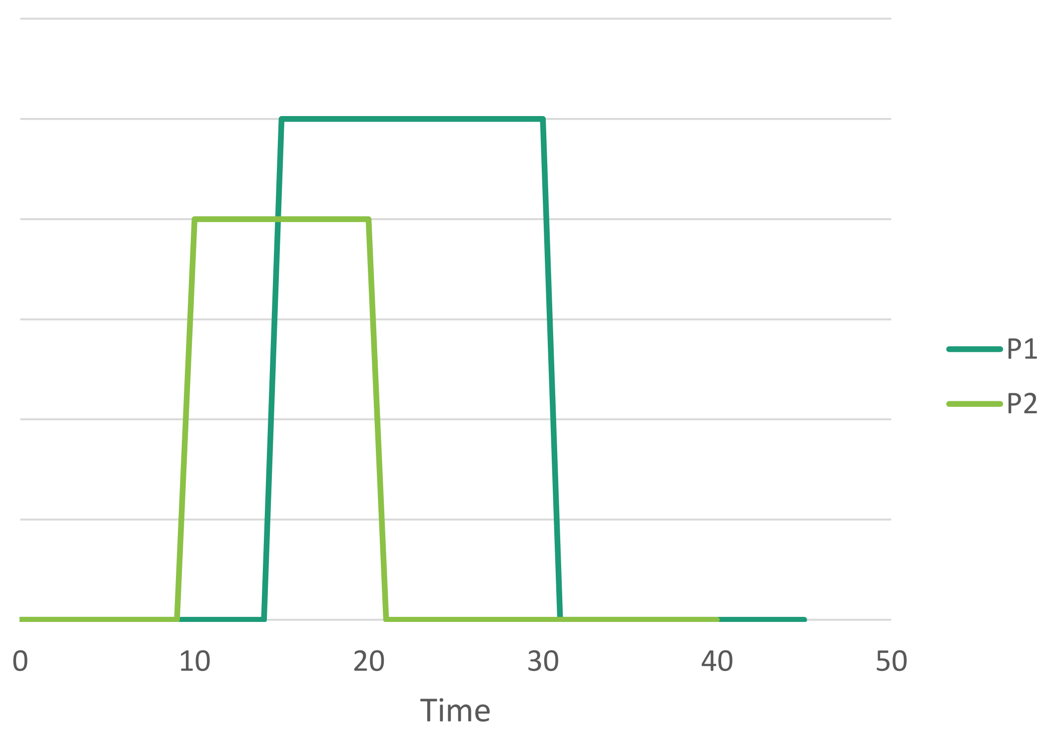


Potential duration

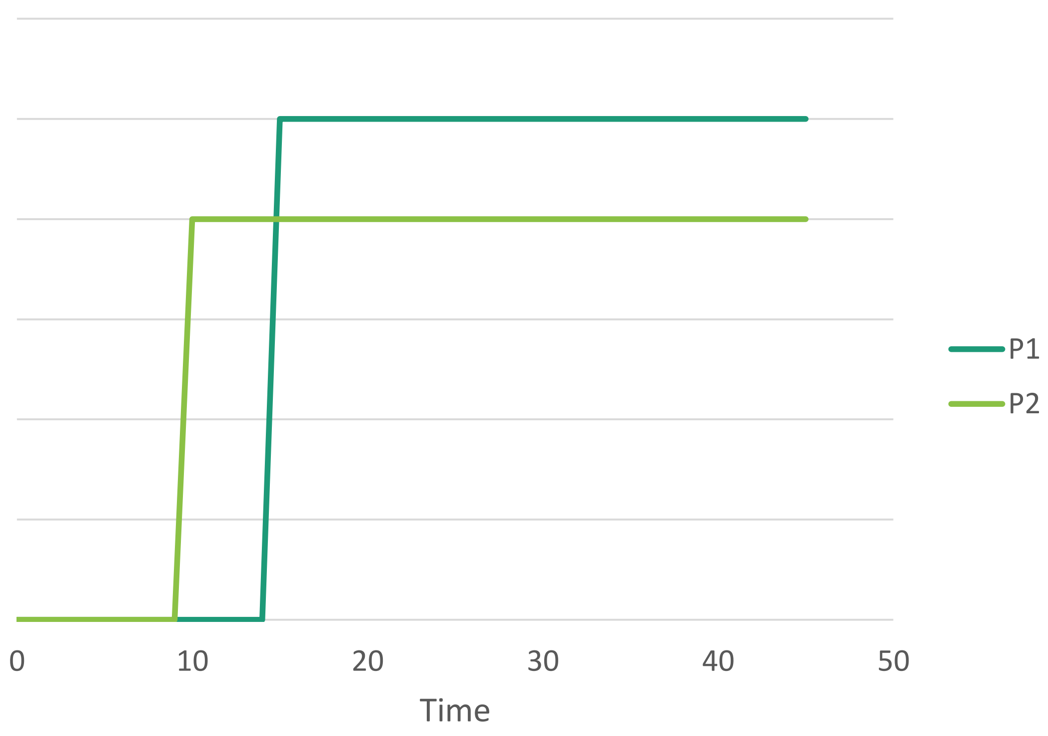


Standard Products

Minimum duration

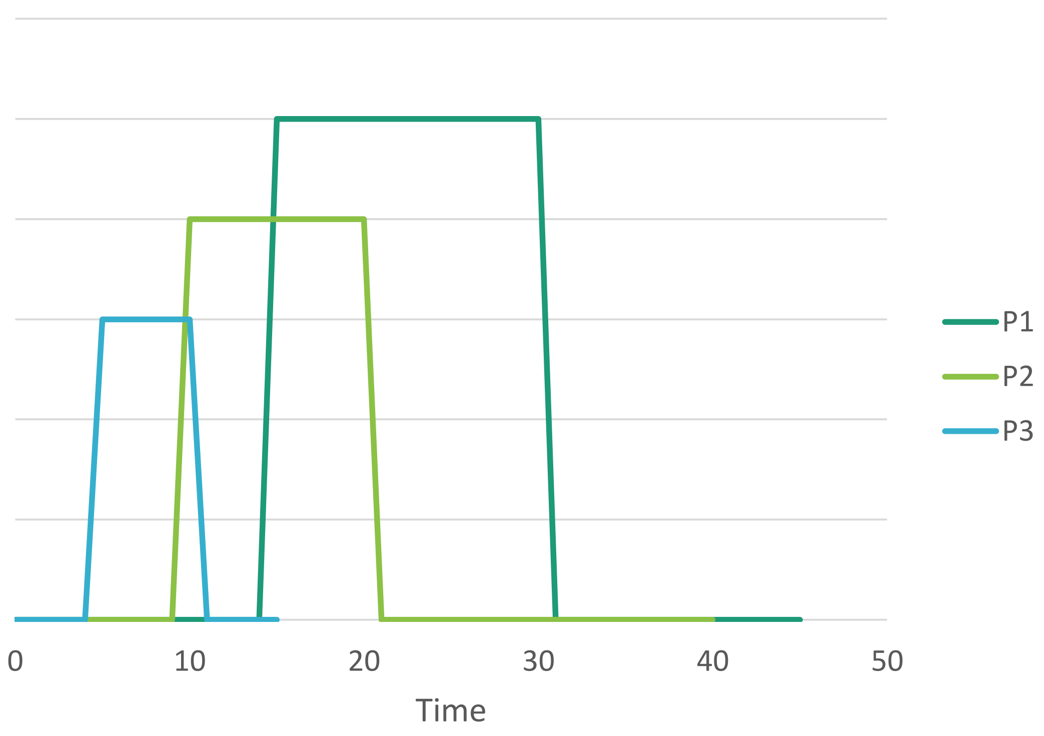


Potential duration

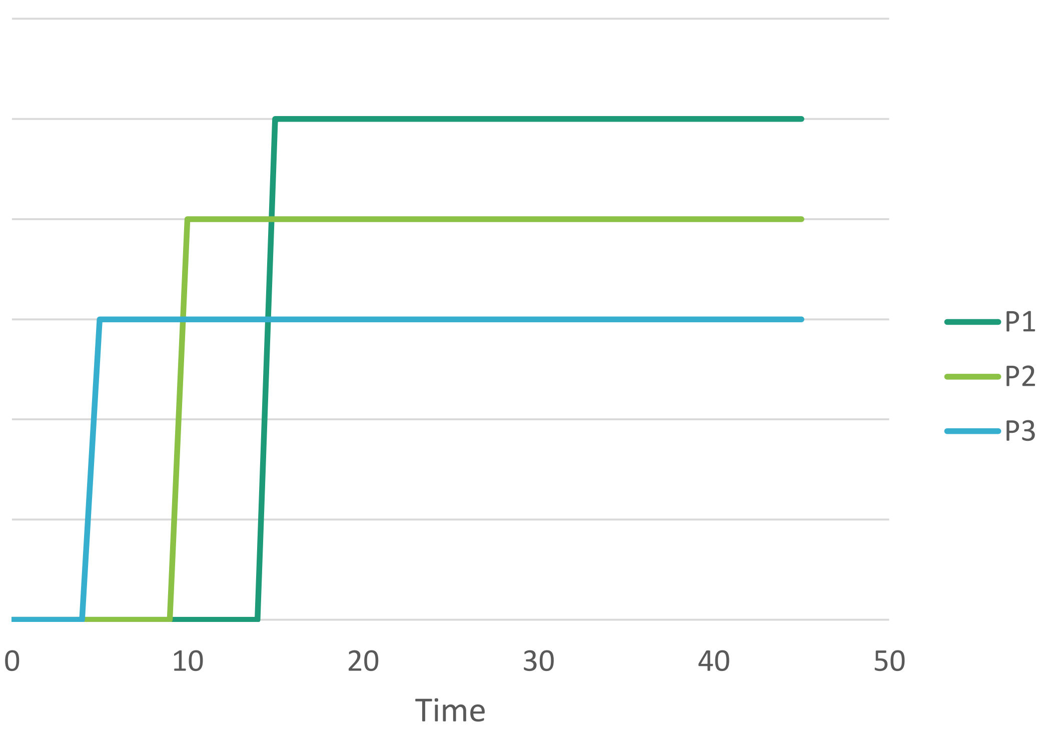


Standard Products

Minimum duration



Potential duration



Standard Products: Behind the scenes

Ramping restrictions

$$y_{b,t} \leq \overline{y}_b u_{b,t}$$
$$y_{b,t} \geq \underline{y}_b u_{b,t}$$
$$y_{b,t} \leq y_{b,t-1} + \overline{y}_b x_{b,t}$$
$$y_{b,t} \geq y_{b,t-1} - \overline{y}_b x_{b,t}$$

Minimum duration

$$\sum_{t=1}^{L_b} u_{b,t} = L_b \quad \forall b$$

$$\sum_{t=s}^{s+\underline{DP}_p-1} u_{b,t} \geq \underline{DP}_p \left(u_{b,s} - u_{b,s-1}\right) \quad \forall b, s \in \left\{1 + L_b + 1, \dots, |T| - \underline{DP}_p + 1\right\}$$

$$\sum_{t=s}^{|T|} u_{b,t} \geq \sum_{t=s}^{|T|} \left(u_{b,s} - u_{b,s-1}\right) \quad \forall b, s \in \left\{|T| - \underline{DP}_p + 2, \dots, |T|\right\}$$

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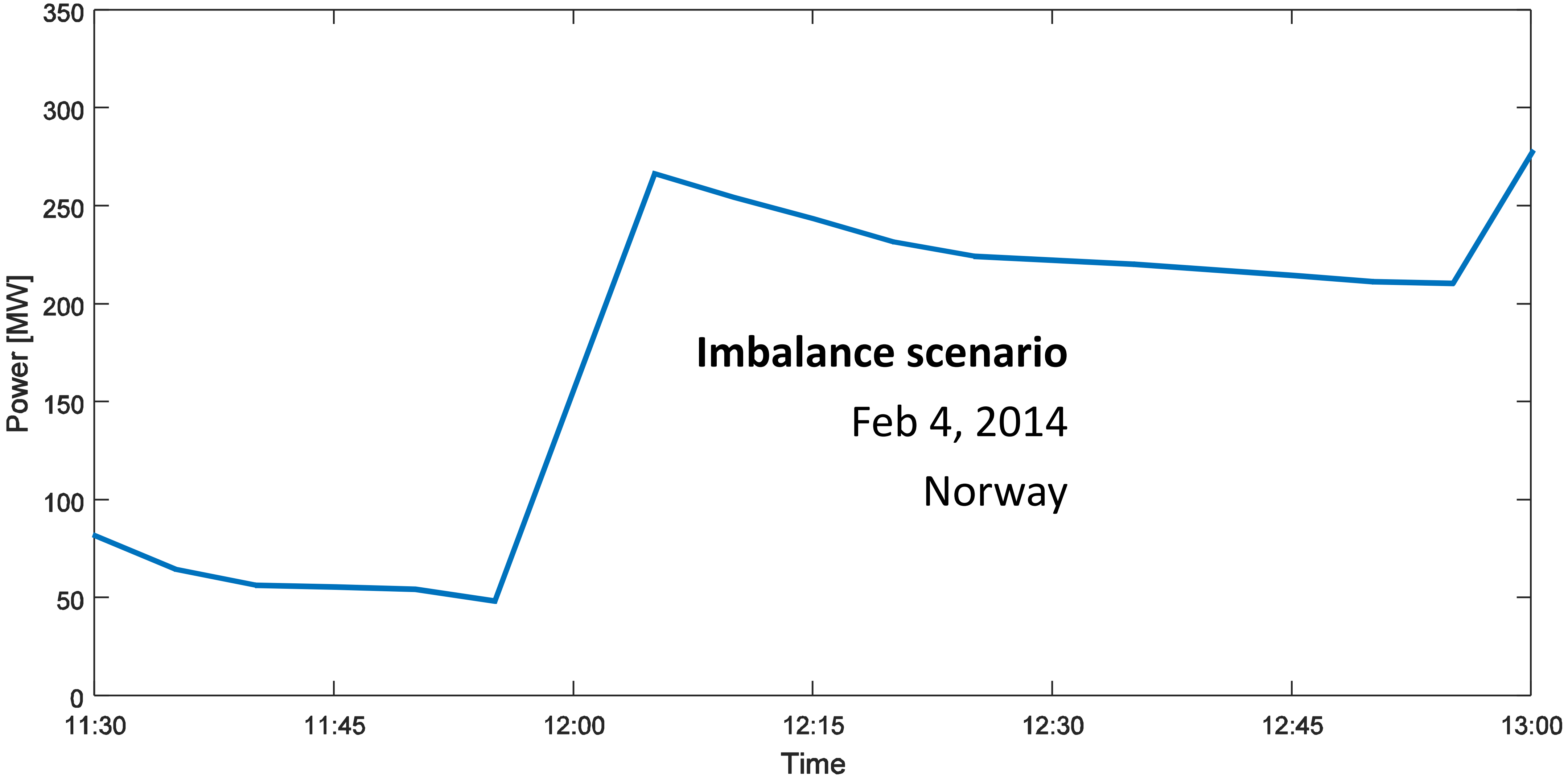


Imbalance scenario
Feb 4, 2014
Norway
Power [MW]
350
300
250
200
150
100
50
0
11:30
11:45
12:00
12:15
12:30
12:45
13:00
Time

Case study

Fictive activation market

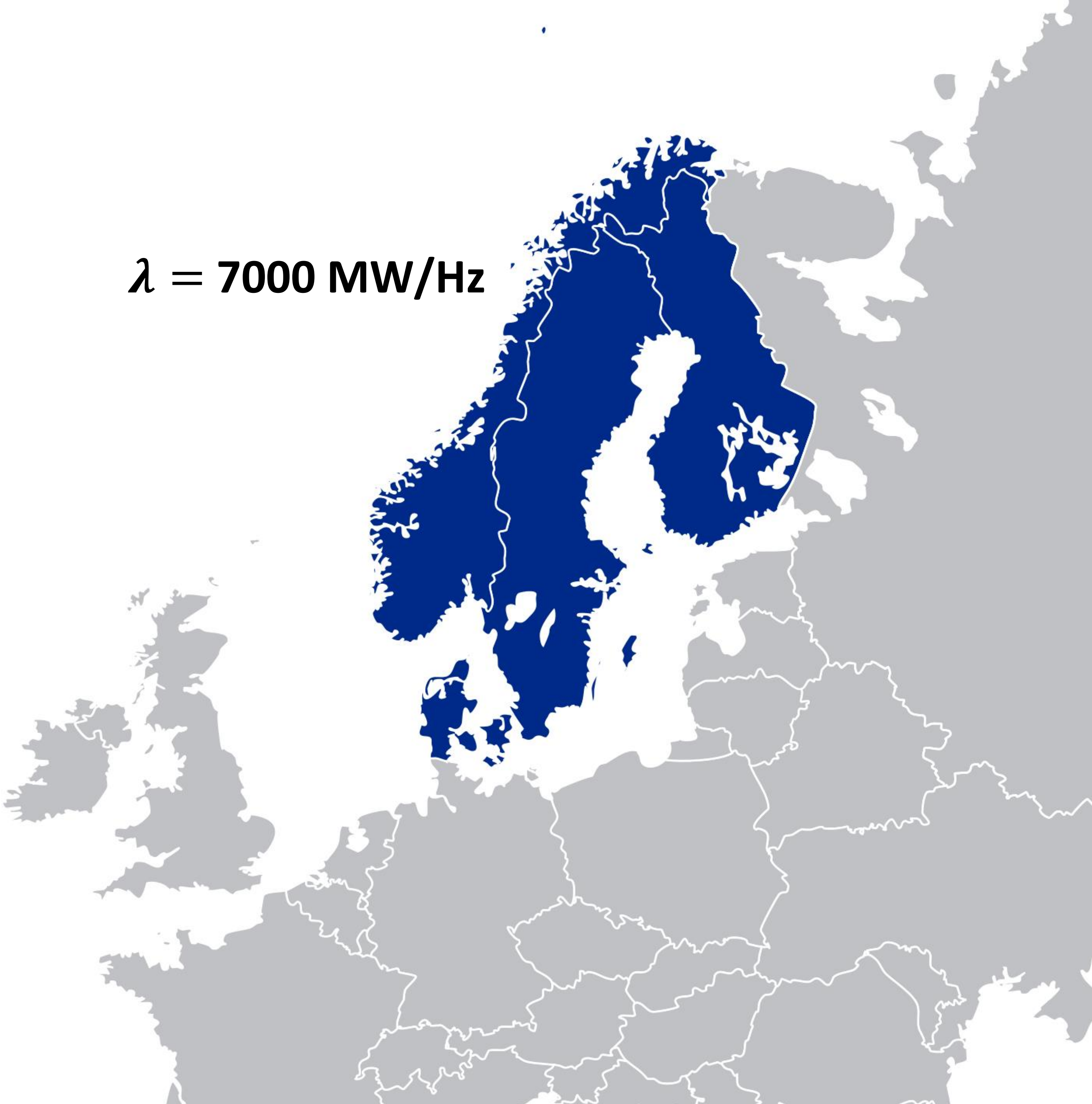
50 bids

3 products

Tønsberg	[illegible]	24.4	120	NO1	P2
Molde	72	24.7	120	NO3	P4
Uppsala	51	25.4	120	SE3	P2
Stockholm	89	26.1	120	SE3	P5
Porsgrunn	130	26.6	120	NO2	P2
Bodø	55	26.7	120	NO4	P4
Oslo	38	27.5	120	NO1	P4
Horten	68	27.9	120	NO1	P1
Trondheim	73	28.2	120	NO3	P5
Göteborg	83	28.9	120	SE3	P1
Ålesund	45	29.4	120	NO3	P2
Drammen	71	29.6	120	NO1	P1
Linköping	109	29.8	120	SE3	P2
Gjøvik	85	31.4	120	NO1	P1
Västerås	22	31.7	120	SE3	P1
Askøy	60	32.1	120	NO5	P2
Malmö	83	32.2	120	SE4	P1
Örebro	63	32.4	120	SE3	P5
Lillehammer	95	33.4	120	NO1	P5
Fredrikstad	39	34.5	120	NO1	P5
Moss	78	35.8	120	NO1	P1
Helsingborg	140	35.9	120	SE4	P4
Tromsø	36	36.4	120	NO4	P1
Kristiansand	145	36.9	120	NO2	P5

Case study

Planning up to 90 mins ahead



$\lambda = $ **7000 MW/Hz**

Case study

What if we …

Only use P1 product	Activate strictly in price order	Only plan 15 minutes ahead

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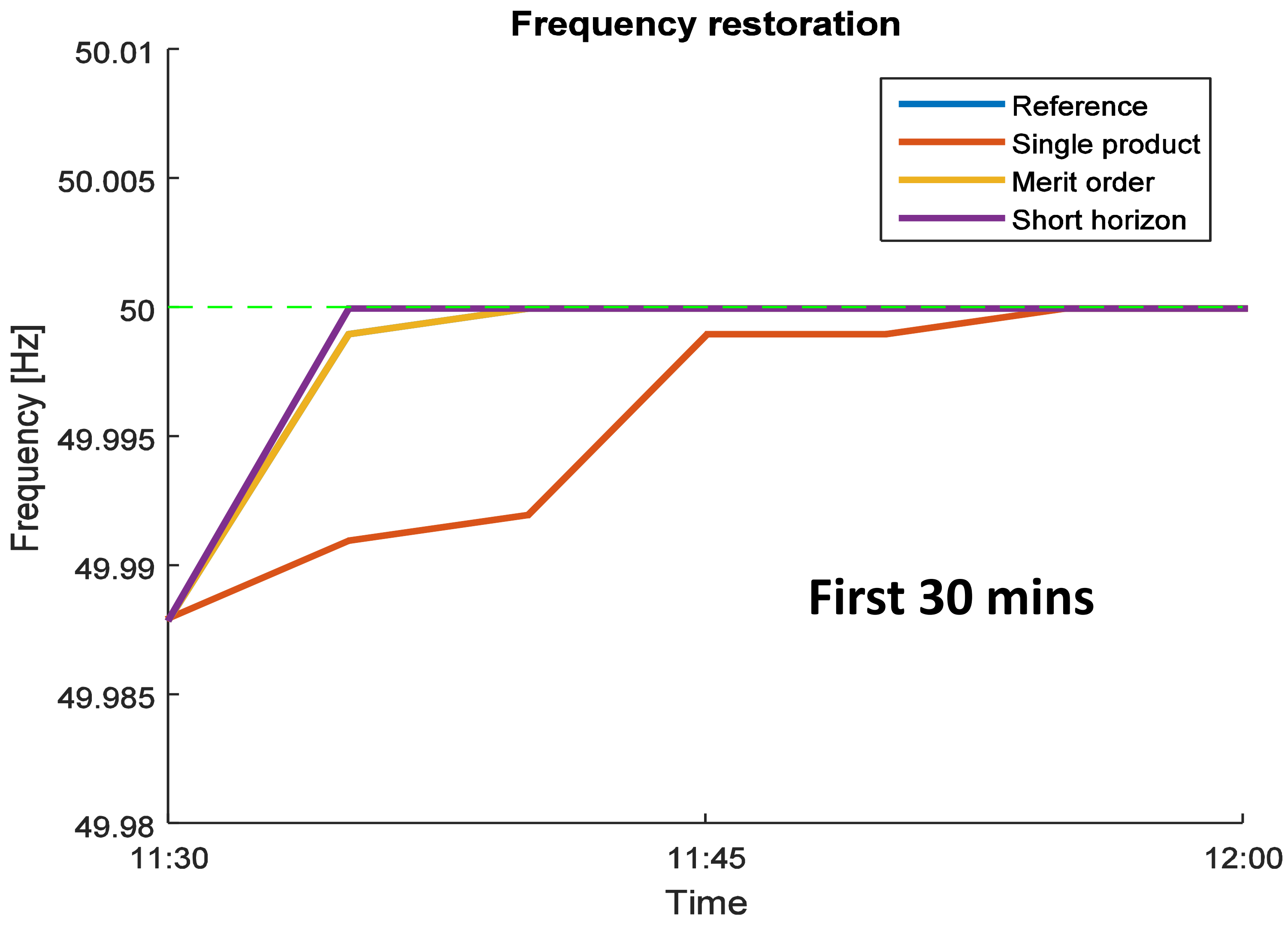
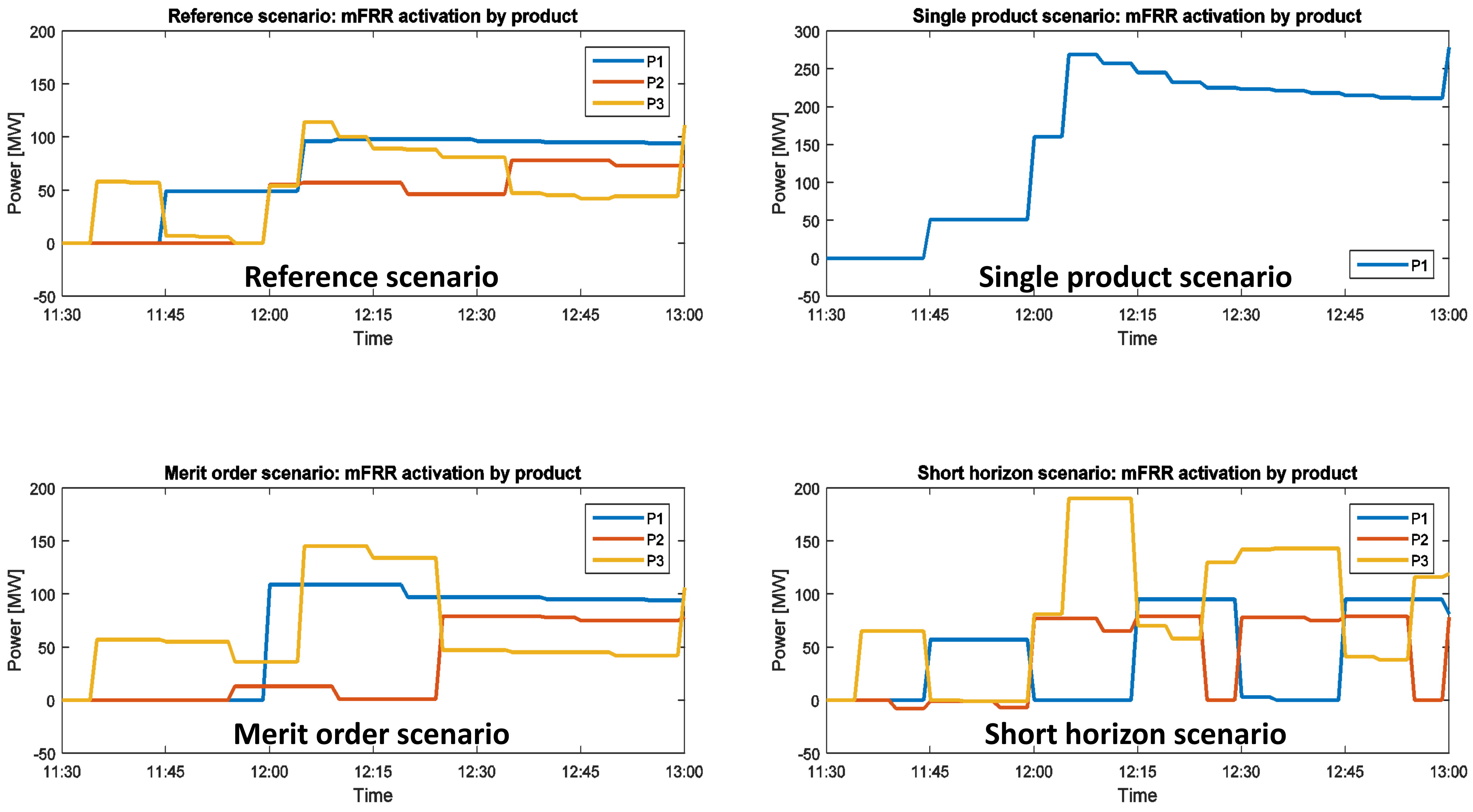
Simulation results: frequency



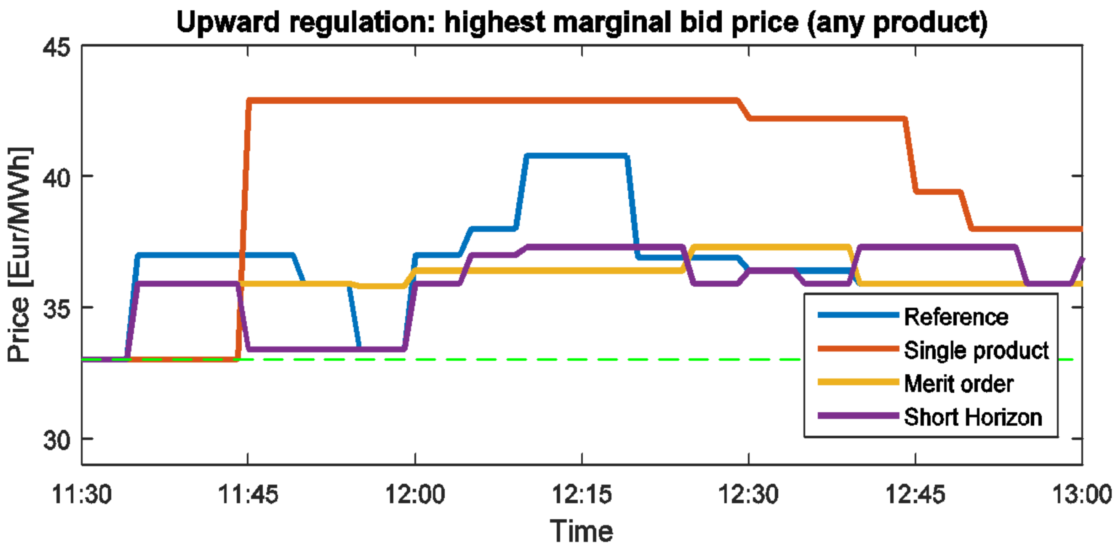
Simulation results: costs

SCENARIO	ACTIVATION	PENALTY	TOTAL
REFERENCE	9 323	722	10 045
SINGLE PRODUCT	8 979	1 642	10 621
MERIT ORDER	9 324	743	10 068
SHORT HORIZON	9 552	687	10 239


Reference scenario: mFRR activation by product
Power [MW]
Time
P1
P2
P3
Reference scenario
Single product scenario: mFRR activation by product
Power [MW]
Time
P1
Single product scenario
Merit order scenario: mFRR activation by product
Power [MW]
Time
P1
P2
P3
Merit order scenario
Short horizon scenario: mFRR activation by product
Power [MW]
Time
P1
P2
P3
Short horizon scenario
11:30
11:45
12:00
12:15
12:30
12:45
13:00

Simulation results: prices

Highest upward price



Main findings

- Using only P1 gives slow response
- Short horizons possible, but suboptimal
- Merit order stabilizes prices in this case

Main shortcomings

- Imbalance forecasts are deterministic
- No transmission network
- No aFRR
- What is the correct penalty?

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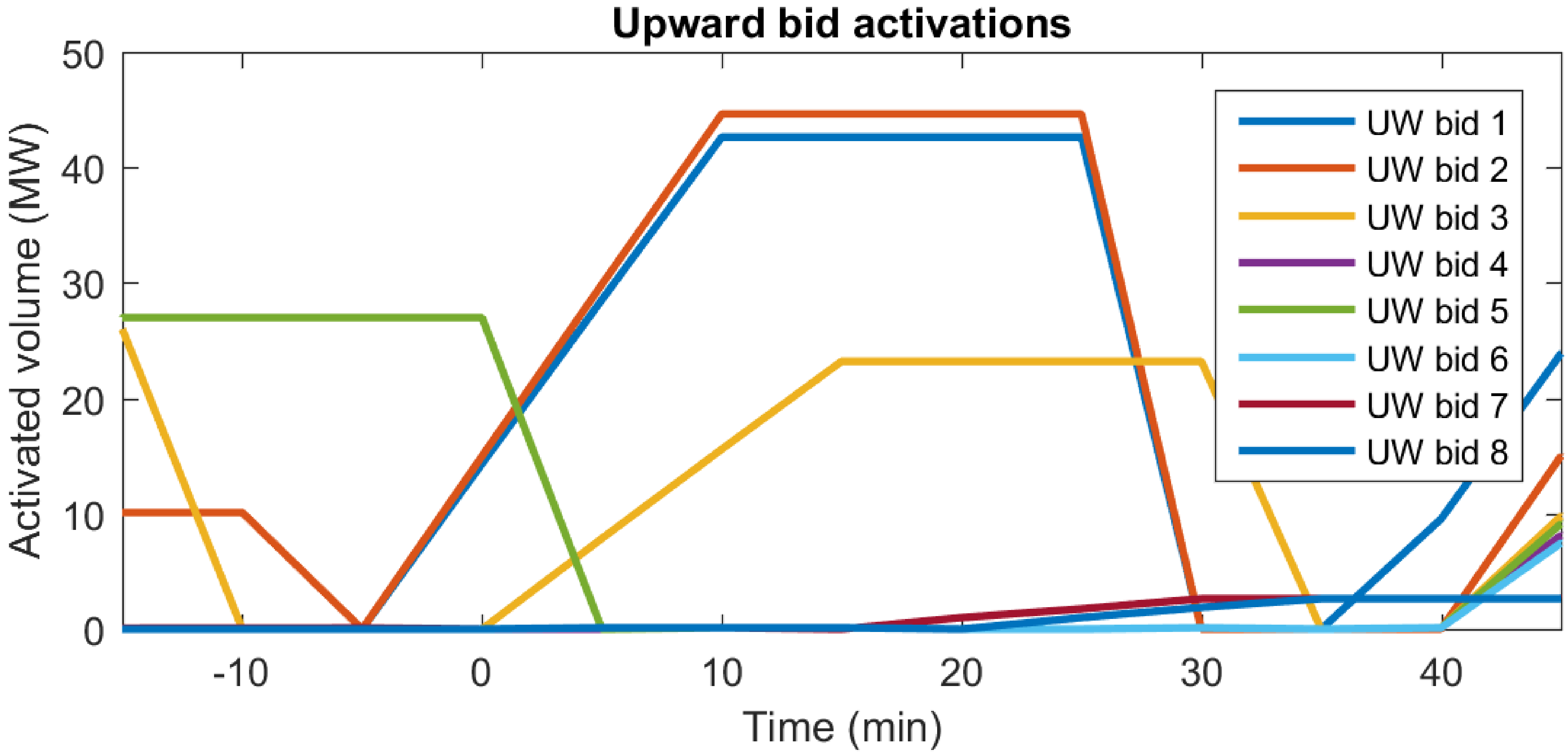
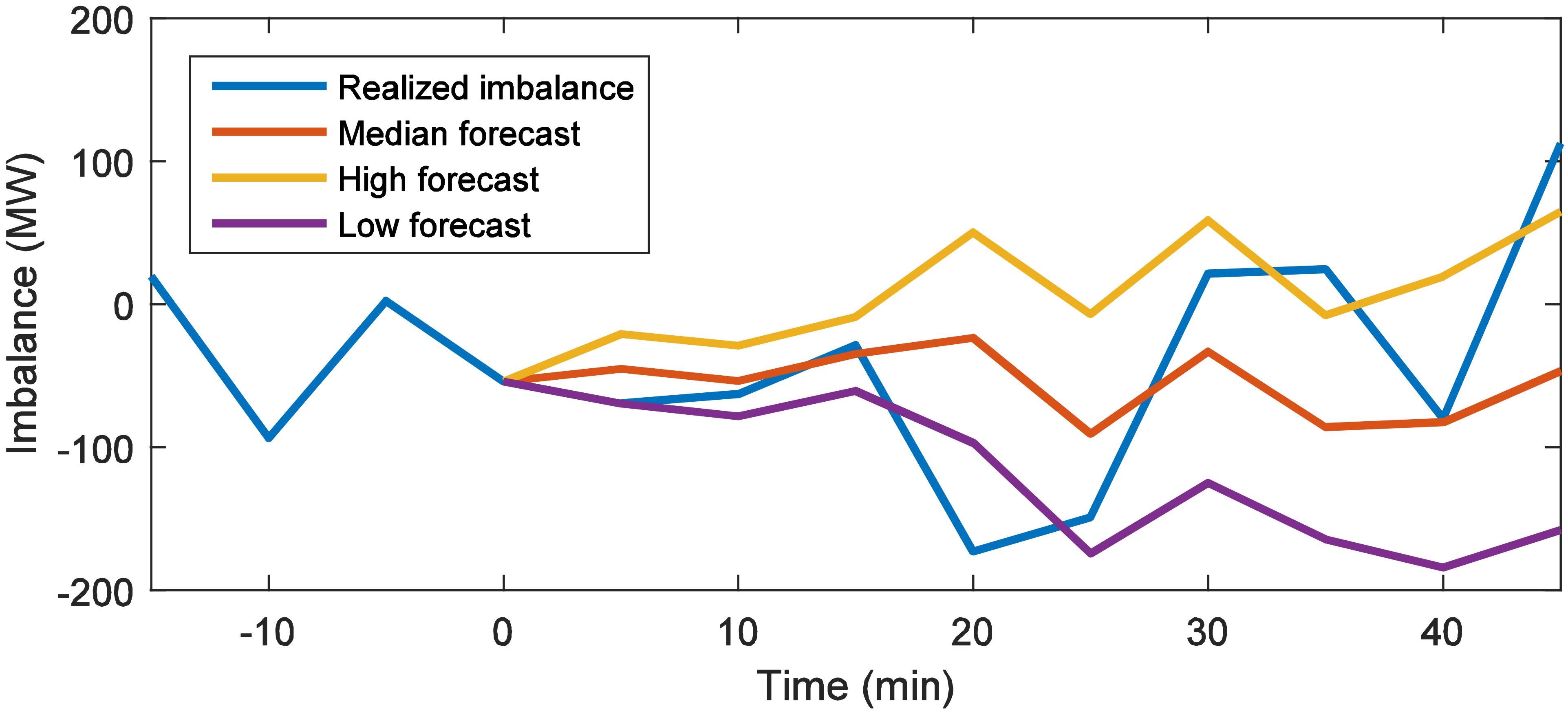
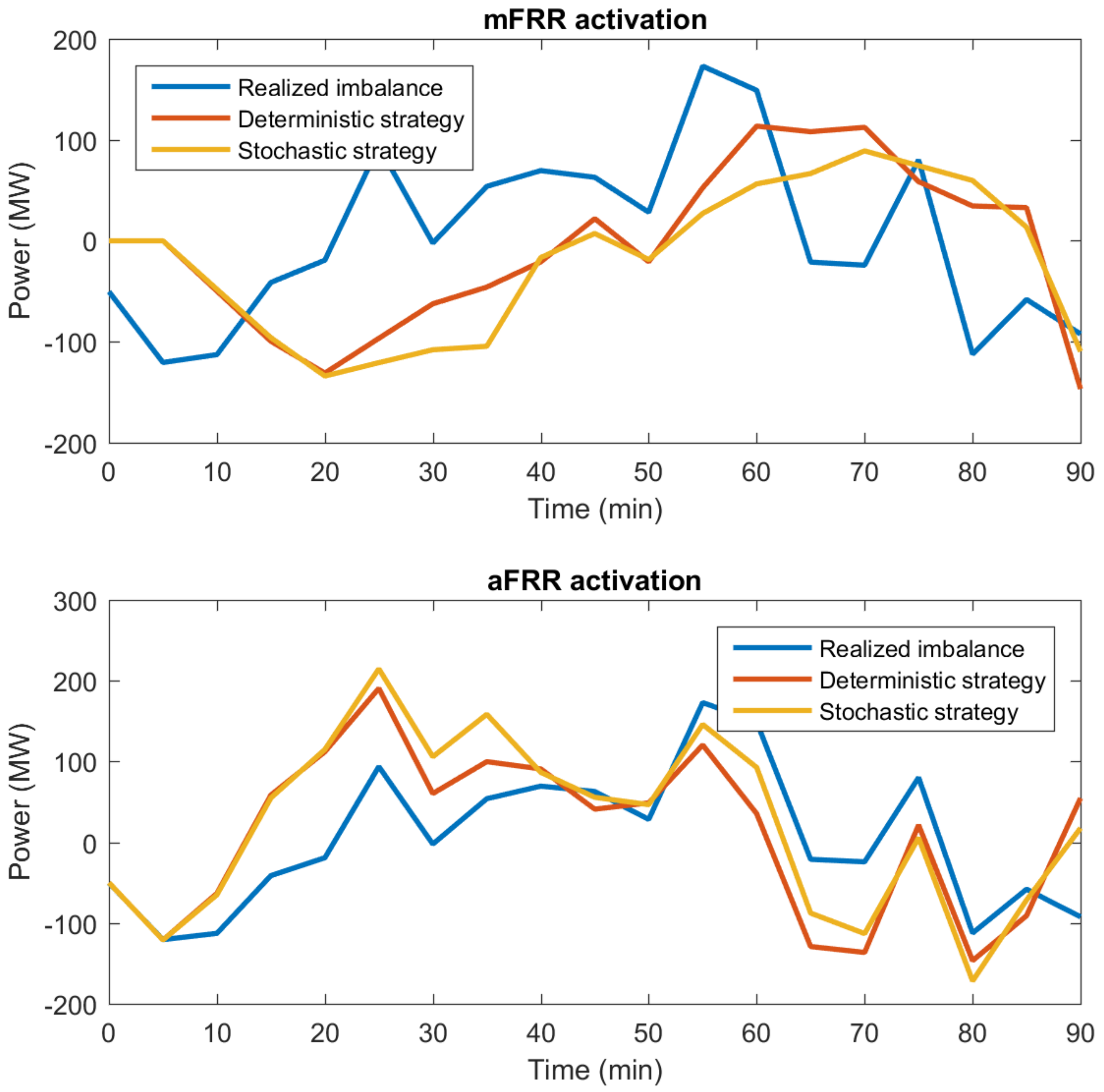
Detailed mFRR product model



Imbalance forecasts based on historical data

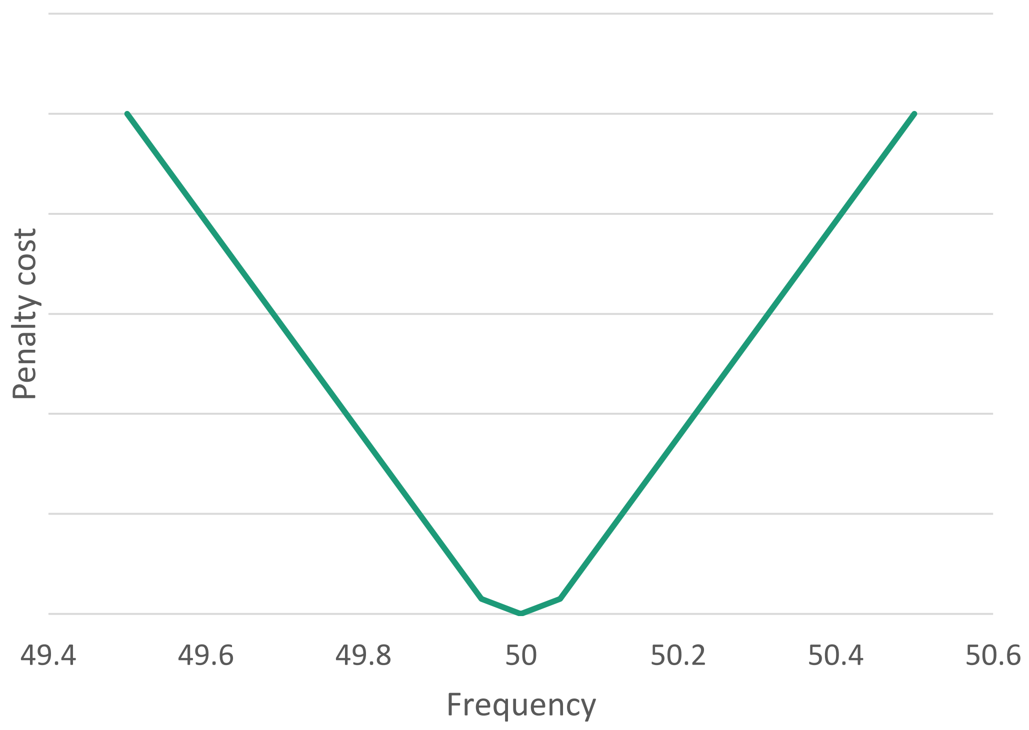


Stochastic strategy

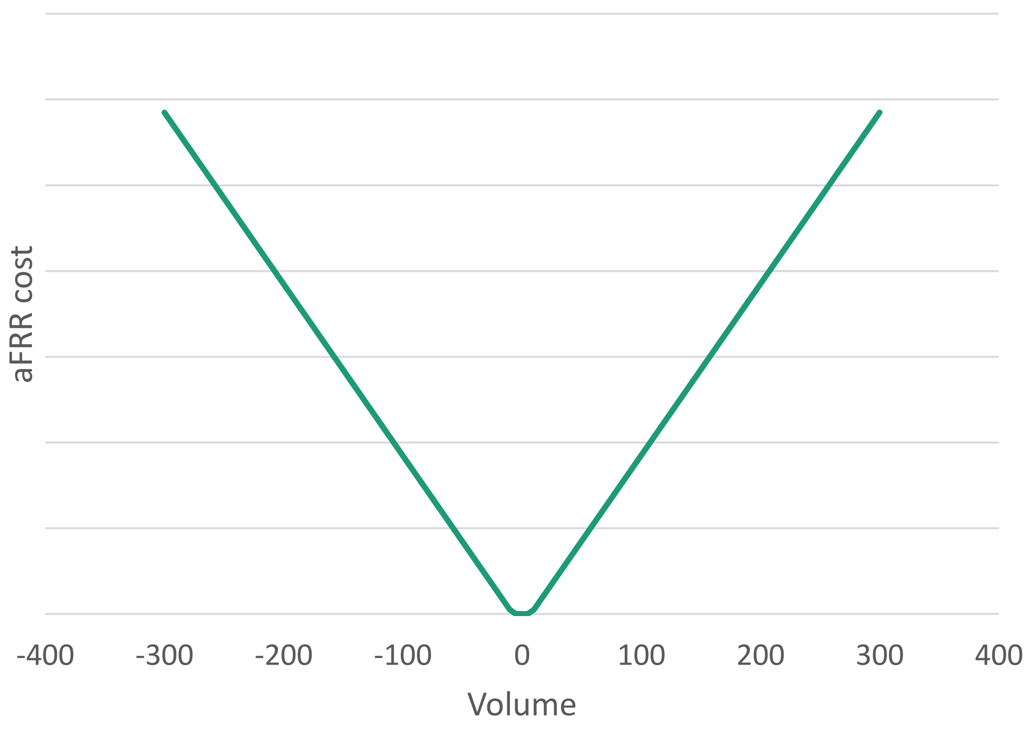


aFRR in stead of penalties

Penalty function



Leave it to aFRR: cost function



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Thank you