Part 2: Technical FB for beginners

- Introduction to capacity calculation
  - Power system operation and market operations basics
  - Today: NTC (Explain basic concept of NTC, i.e. what we do today)
  - Tomorrow: FB (Explain basic concept function of FB and focus on PTDF and RAM)
- Introduction to market coupling and capacity allocation
  - Today: NTC
  - Tomorrow: FB
- Results of FB EPR: What stakeholders need to know
- Where to find more information

Flow Based Market Coupling

…for beginners…

Nordic CCM Stakeholder Meeting

13.03.2024

Trond Jensen

trond.jensen@statnett.no

ENERGINET SVENSKA KRAFTNÄT FINGRID Statnett

Table of content

- CC elaboration
- Calculation Process
- MC elaboration
- EPR

ENERGINET SVENSKA KRAFTNÄT FINGRID Statnett

Capacity Calculation: From complexity to simplicity

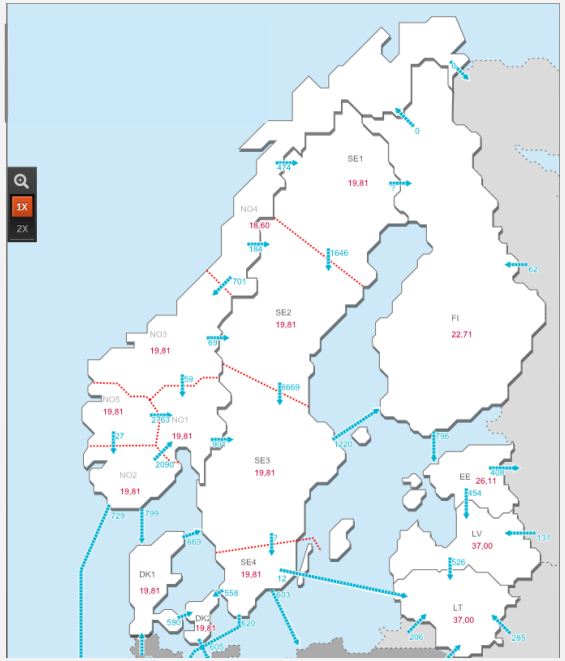
The physical world

Detailed grid model (CGM) → Nodal pricing → FB → NTC

Capacity calculation is the process of translating the complex physical grid into a simplified form that can be understood and applied by the power exchange

- **Providing grid constraints to the market platforms**

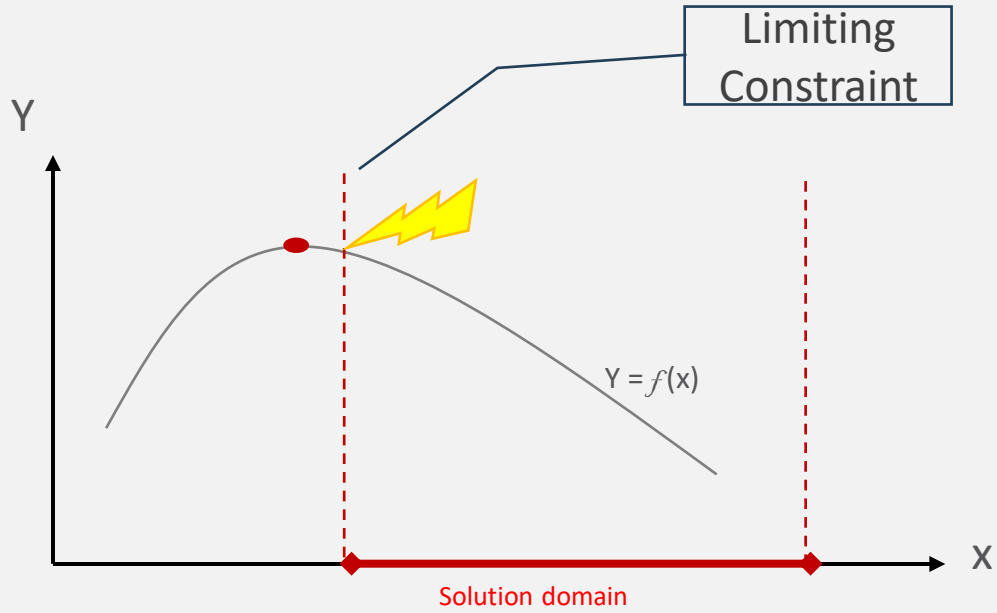
The power market



ENERGINET SVENSKA KRAFTNÄT FINGRID Statnett

The objective of the market algorithm

- Find a market equilibrium for the European electricity market (Prices and Net Positions)
- By maximizing the welfare economic surplus in the electricity market within the boundaries of grid constraints and global energy balance

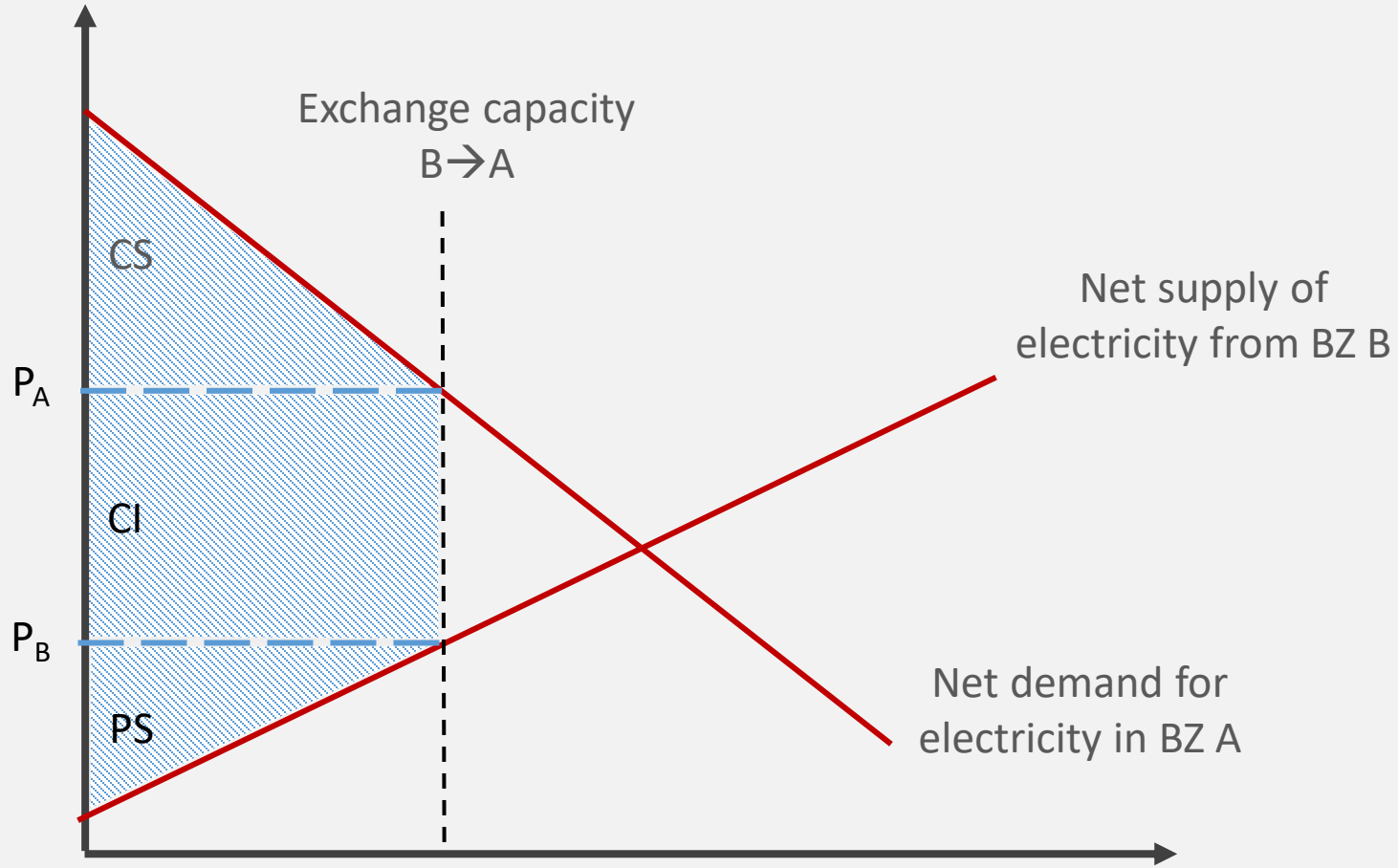


- $f(x)$ = Welfare economic surplus
- x = Net position (Supply - Demand)
- Solution domain = All valid net positions
  ⇒ Fowbased Domain
  ⇒ NTC-domain

ENERGINET SVENSKA KRAFTNÄT FINGRID Statnett

Calculation of welfare economic surplus

- **Total welfare** is the sum of individual utility minus the sum of generation
- **Demand functions** reflects the consumers valuation of electricity
- **Supply functions** reflects the firms cost of delivering electricity



ENERGINET SVENSKA KRAFTNÄT FINGRID Statnett

Single Day-Ahead Coupling

Capacity calculation

- Individual Grid Model (IGM) from each TSO containing grid topology, production and consumption forecasts
- Realiability Margins (RM)
- Critical Network Elements (CNE)

Input to the capacity calculation (TSOs)

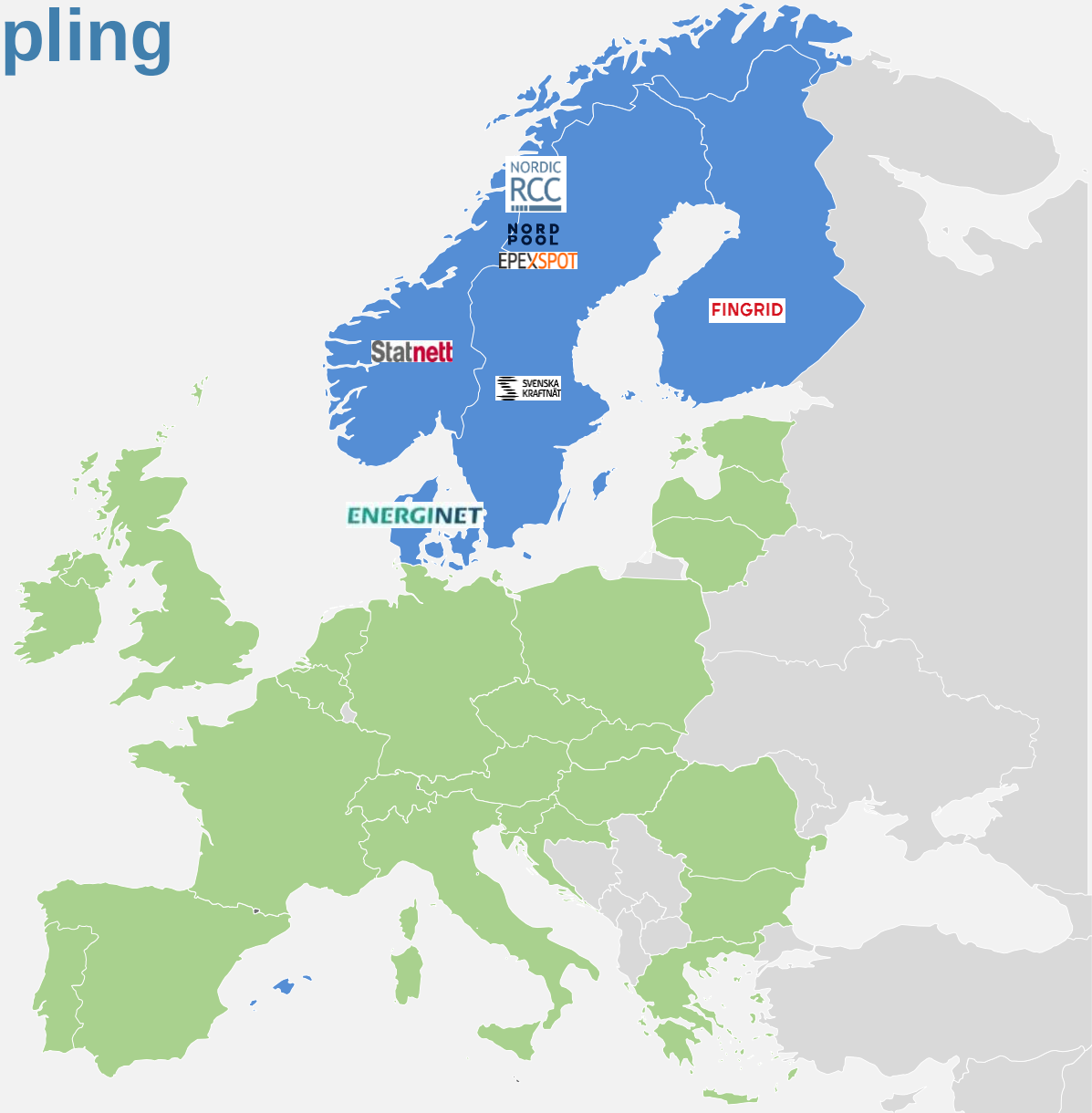
Results of the capacity calculation (RCC)

- Merge IGMs to Nordic CGM (Common Grid Model)
- Compute flow-based domain (including PTDFs and RAMs)

Market Coupling

- Prices
- Dispatch
- Commersial transfers
- Limiting network elements

Results of the market coupling (NEMO)



ENERGINET SVENSKA KRAFTNÄT FINGRID Statnett

Important expressions

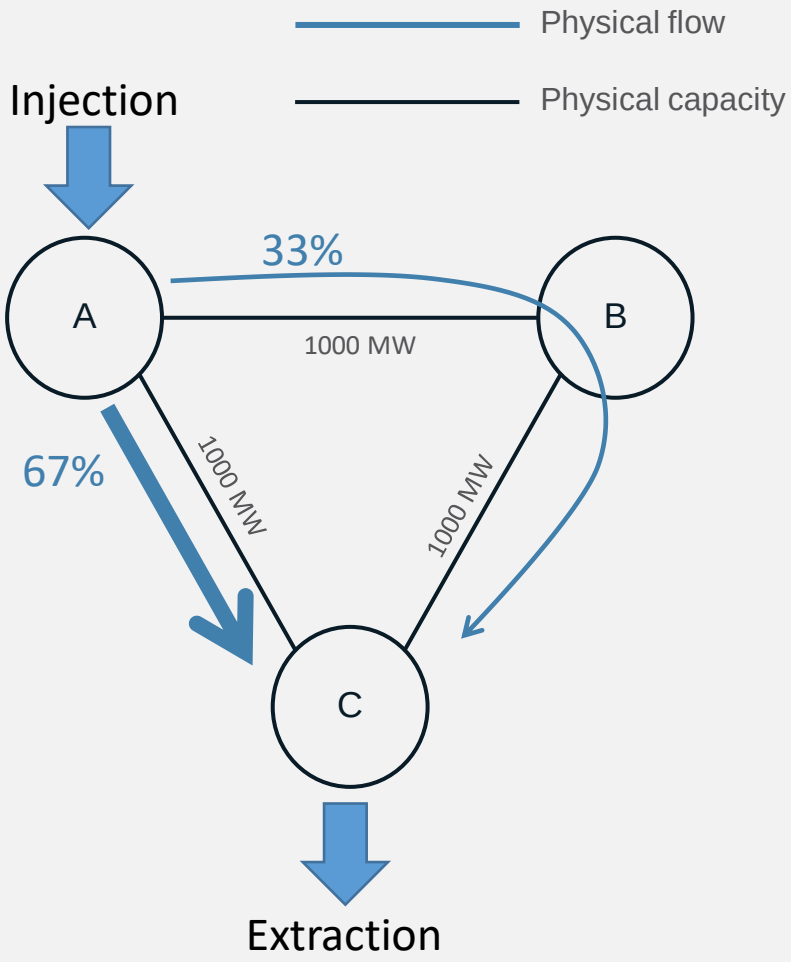
- **NTC** = Net transfer capacity between pair of bidding zones

- **CGM** = Common Grid Model describing the individual components and the state of the Nordic Grid in a particular MTU (24 CGMs for each day)
- **CNEC** = A limiting grid component (CNE) considering a contingency (C)
- **PTDF** = A parameter indicating how much of a MW injected in a certain bidding zone occurs on a particular CNEC
- **RAM** = A parameter defining how many MWs of electricity can be allowed on a particular CNEC due to cross border trade

- **F_{max}** = A parameter defining how many MWs of electricity can be carried by a particular CNEC
- **F_0** = Flows occurring on a particular CNEC caused by trades within a certain bidding zone
- **RA** = Available tools to mitigate overloads applied to increase capacity on specific CNECs
- **FRM** = Security margin to manage linearization errors and activation of frequency containment reserves
- **IVA** = Individual validation assessment to mitigate last minute security issues

ENERGINET SVENSKA KRAFTNÄT FINGRID Statnett

Physical flows & physical capacity in AC grids

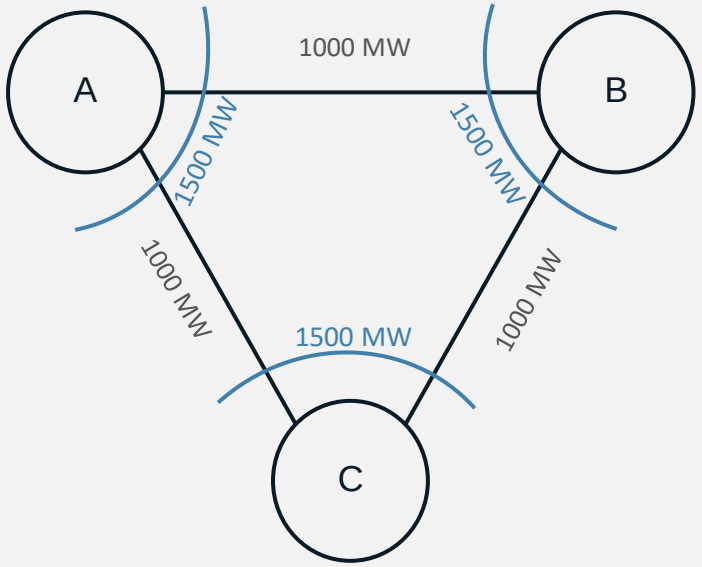


- All lines, cables and other components in the grid have a physical limit to how much electricity they can carry
- Physical flows in AC grids follow the path of least resistance. HVDCs are controllable

- TSOs have to consider both when calculating and providing capacity to the power exchange
- TSOs applies grid models when calculating capacity, but in the current NTC system, these are distributed to the different borders based on operator experience

ENERGINET SVENSKA KRAFTNÄT FINGRID Statnett

The Net Transfer Capacity (NTC) model



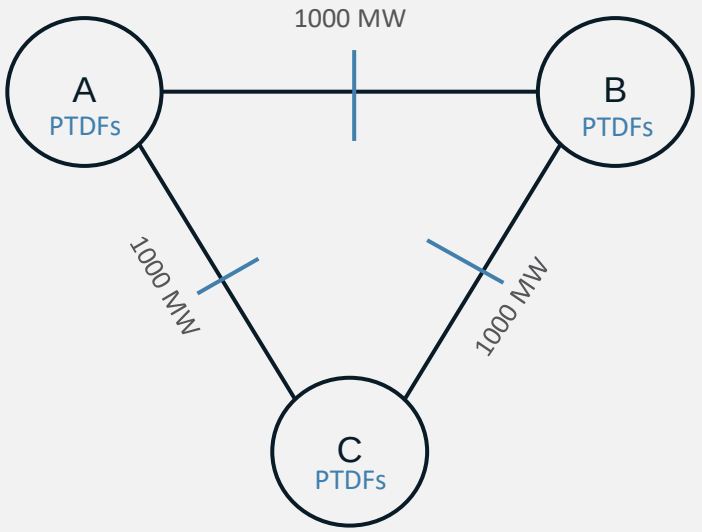
Line	NTC max	NTC min
A -> B	750 MW	-750 MW
B -> C	750 MW	-750 MW
A -> C	750 MW	-750 MW

- Flows are not observable to the NTC market coupling
- Each bidding zone is limited to a max export and import
- Limitations are expressed by NTCs on each border
- Secure grid operation → no overloads allowed
  - The distribution of NTCs on borders is an operational assessment based on operational security consideration

- The NTC market constraints are:
  - $Supply_i - Demand_i = NP_i \leq \sum_j NTC_{ij}$
  - $Supply_i - Demand_i = NP_i \geq \sum_j NTC_{ji}$

ENERGINET SVENSKA KRAFTNÄT FINGRID Statnett

The Flow Based (FB) model



CNECs	RAM	A PTDFs	B PTDFs	C PTDFs
A -> B	1000 MW	33 %	- 33 %	0
B -> C	1000 MW	33 %	67 %	0
A -> C	1000 MW	67 %	33 %	0

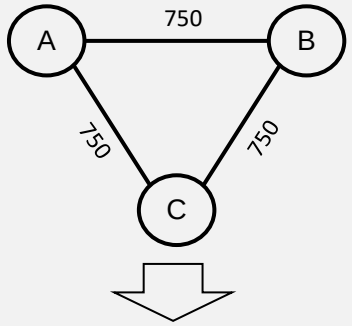
- Secure grid operation requires no overloads to be allowed
- Limitations are expressed by RAMs
- Flows on all CNECs are monitored by PTDFs
- Physical capacity is allowed for all CNECs
- NP limitations are expressed by PTDFs and RAM
  - PTDFs and RAM are uniquely defined by the CGM

- The FB market constraints are:
  - $\sum_i NP_i * PTDF_i \leq RAM$ *: For each CNEC*

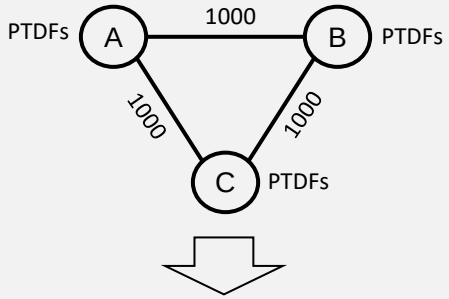
ENERGINET SVENSKA KRAFTNÄT FINGRID Statnett

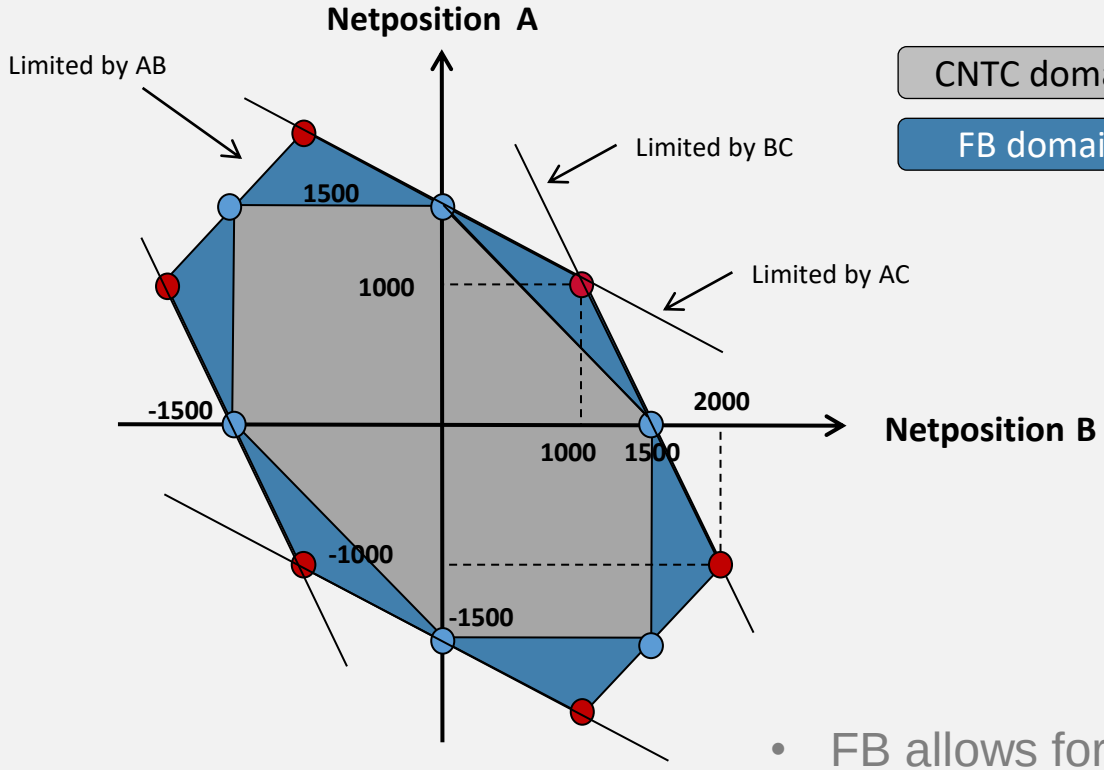
The FB and CNTC domains – Valid market positions

NTC (1)



FB





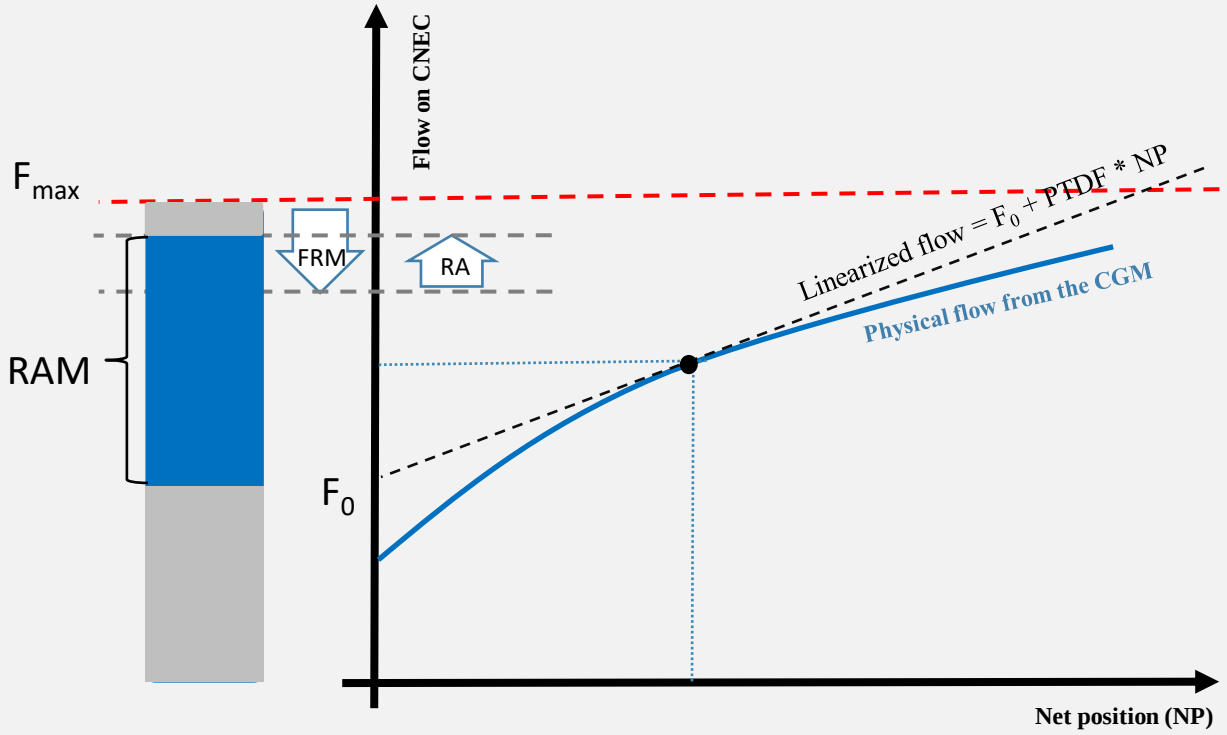
CNTC domain

FB domain

- FB allows for net positions that cannot be obtained in NTC
- All obtainable net positions in NTC can be obtained in FB

ENERGINET SVENSKA KRAFTNÄT FINGRID Statnett

PTDFs and RAM is computed from the CGM



- **Physical (AC) flow: The general relation between power injection and physical flows are embedded in the CGM**
- The market algorithm applies linearized relations only (Y = A + b*X)
- Linearized flow: Is calculated in one particular point in the CGM (Base case)
- Market constraint in FB:

$$F_0 + PTDF * NP \leq F_{max} - FRM + RA$$

$$F_{max} - FRM + RA - F_0 = RAM$$

PTDF * NP ≤ RAM

(NP = Supply – Demand)

ENERGINET SVENSKA KRAFTNÄT FINGRID Statnett

Advanced topics not covered

- Intraday capacity calculation → Intermediate translate FB to NTC
- GSK strategy: Node to zone aggregation
- Remedial Actions: Tools to mitigate overloads and increase capacity
- Advanced Hybrid Coupling: Management of HVDCs
- Ramping: Limits to flow changes of HVDCs between MTUs

Questions so far?

ENERGINET SVENSKA KRAFTNÄT FINGRID Statnett

Coffee break

ENERGINET SVENSKA KRAFTNÄT FINGRID Statnett

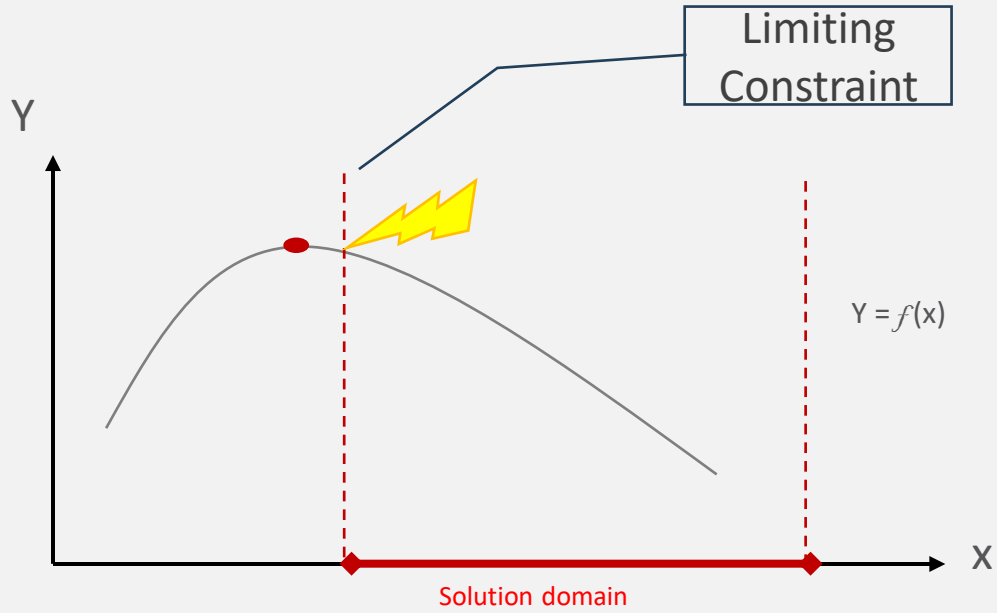
Introduction to market coupling and capacity allocation

ENERGINET SVENSKA KRAFTNÄT FINGRID Statnett

The objective of the market algorithm

- Find a market equilibrium for the European electricity market (Prices and Net Positions)

- By maximizing the welfare economic surplus in the electricity market within the boundaries of grid constraints and global energy balance



- $f(x)$ = Welfare economic surplus
- x = Net position (Supply - Demand)
- Solution domain = All valid net positions
  ⇒ Fowbased Domain
  ⇒ NTC-domain

ENERGINET SVENSKA KRAFTNÄT FINGRID Statnett

Management of constraints in NTC and flow based

- The market algorithm finds a market equilibrium by maximizing the welfare economic surplus, requiring a global energy balance, and being constrained by grid limitations
  - The objective function (welfare economic surplus) is the same for NTC and flow based
  - The requirement for a global energy balance is the same for NTC and flow based
  - Flow based changes the way grid limitations are provided to the algorithm (NTC → PTDFs and RAMs)

The equilibrium solution for bidding zone prices are defined by "shadow prices / shadow costs" on limiting constraints:

- NTC: $p_i = \lambda + \tau_i^{imp} - \tau_i^{exp}$
- FB: $p_i = \lambda - \sum_n \rho_n * PTDF_i^n$

A shadow price is the increased value of the objective function (welfare economic surplus) obtained by a marginal increase of the constraint. Shadow prices are positive only if the constraint is limiting

Shadow price for the energy balance:	λ	≥ 0
Shadow prices for NTC-constraints:	τ_i^{imp}, τ_i^{exp}	≥ 0
Shadow prices for FB-constraints:	ρ_n	≥ 0

ENERGINET SVENSKA KRAFTNÄT FINGRID Statnett

Characteristics for NTC and flowbased pricing

NTC

$$p_i = \lambda + \tau_i^{imp} - \tau_i^{exp}$$

- Equal prices in all BZ when no bottlenecks in the system
- Higher prices in import limited bidding zones
- Lower prices in export limited bidding zones

$$p_i - p_j = \tau_i^{imp} + \tau_j^{exp}$$

- The price difference between two bidding zones in the traded direction cannot be negative (with positive capacity)

Flow based

$$p_i = \lambda - \sum_n \rho_n * PTDF_i^n$$

- Equal prizes when no bottlenecks in the system
- Higher prices in BZs relieving bottlenecks
- Lower prices in BZs loading bottlenecks
- Unique BZ prices when bottlenecks in the system

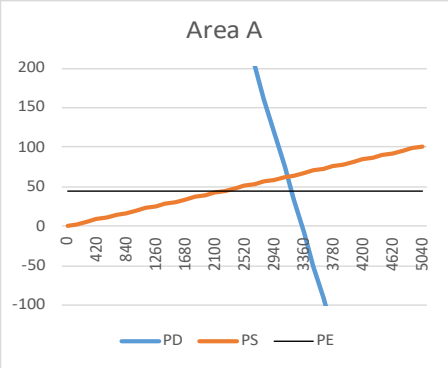
$$p_i - p_j = \sum_n \rho_n * PTDF_{ji}^n$$

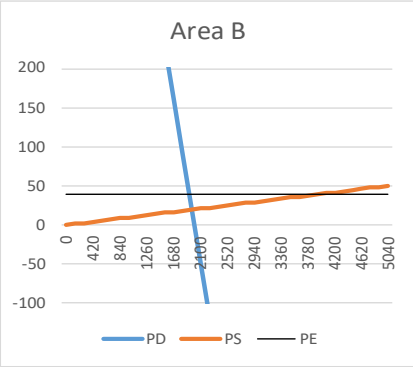
- The price difference for a bilateral trade might be negative in the traded direction if the trade is relieving the flow on a constraining CNEC

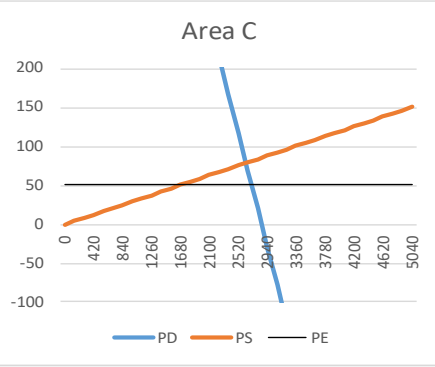
ENERGINET SVENSKA KRAFTNÄT FINGRID Statnett

Small example of a FB market coupling result

CNEC	RAM	Biding-zone A	Biding-zone B	Biding-zone C (Slack-zone)	ΣPTDF * NP	Shadow price
NP		-946	1973	-1027		
Price		44,76	38,95	50,7 (λ)		
A → B	1000 MW	33%	- 33%	0%	-973	$\rho_1 = 0$
B → C	1000 MW	33%	67%	0%	1000 MW	$\rho_2 =$ 17,43
A → C	1000 MW	67%	33%	0%	27 MW	$\rho_3 = 0$







- All prices are defined by "shadow prices":

$$p_i = \lambda - \rho * PTDF_i$$

  - λ = Welfare economic cost of delivering electricity in the slack-zone
  - ρ = Welfare economic value of an extra MW on the limiting CNEC

- Equal prices in all bidding zones when no limiting CNECs
- All prices are unique when one or several CNECs are limiting

- Flow based will provide flows from a high-price, to a low-price bidding zone if that flow generates a welfare economic gain by reducing congestion cost:

$$p_i - p_e = \rho * (PTDF_e - PTDF_i)$$

ENERGINET SVENSKA KRAFTNÄT FINGRID Statnett

Results of EPR

Krishna Solberg

Krishna.Solberg@statnett.no

ENERGINET SVENSKA KRAFTNÄT FINGRID Statnett

Flow-based external parallel run

- In EPR, the capacity calculation process for both FB and NTC is performed in parallel. Market results are available for:
  1. NTC = actual day-ahead market coupling results, “production”
  2. FB = simulated market coupling results with FB constraints
- Assumption in the EPR: Different capacity calculation method, but same market coupling algorithm and same order books
  - Changing nothing else as the capacities enables a fair comparison of the two capacity calculation methods. It isolates the impacts solely from FB capacity calculation without further assumptions.
- Goals of the EPR:
  1. Ensure that the capacity calculation process works
  2. Show the differences between FB and NTC capacity calculation methods
  3. Intended for market participants to become familiar with FB capacity calculation and the impacts FB may have on the market outcome
  4. “Learning by doing” for TSOs

ENERGINET SVENSKA KRAFTNÄT FINGRID Statnett

Impact of changing the capacity calculation

- In a power system with large amounts of storage hydropower, prices are very much affected by water value
  - This is the case for many bidding zones in the Nordics
- Changing the capacity also changes the water value, which again changes the bidding strategy for the producers
- As we will see, the simulations indicate higher cross-border capacities between most bidding zones
  - This will affect the water value, so the simulated prices, flows and SEW are not generalizable
  - Still important to analyze the difference in capacity calculation between the two methodologies

EPR simulation results and trends

General trends for 2023

- For the vast majority of days and weeks, flow-based provides a higher socio-economic welfare than NTC by increasing capacities and sending power where it is most needed
- There is a higher price convergence in the Nordic area, meaning more similar prices across the bidding zones
  - The "low-price" areas increase their prices, and the "high-price" areas decrease their prices

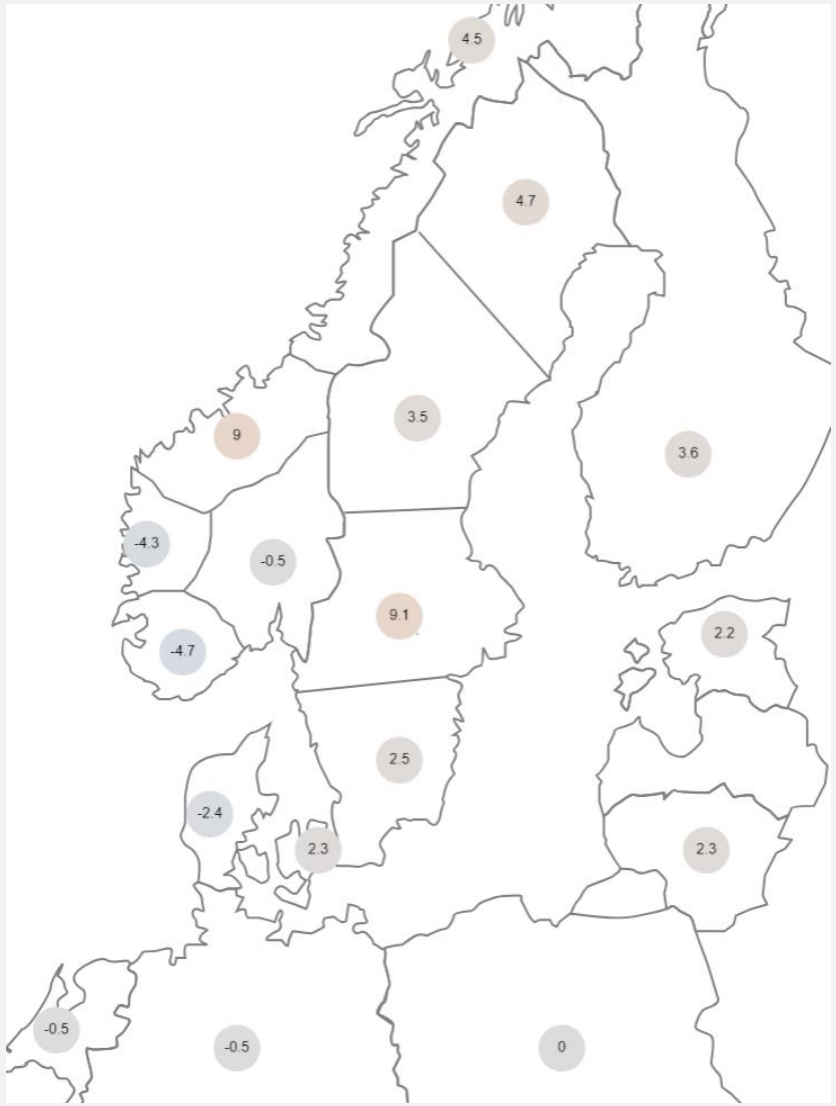


Figure: FB-NTC mean prices for all of 2023

ENERGINET SVENSKA KRAFTNÄT FINGRID Statnett

EPR simulation results and trends

General trends for 2023

- Higher flows North → South
- Higher flows Nordic → Continent
- Higher flows on SE3 → NO1 and NO2 → NO2

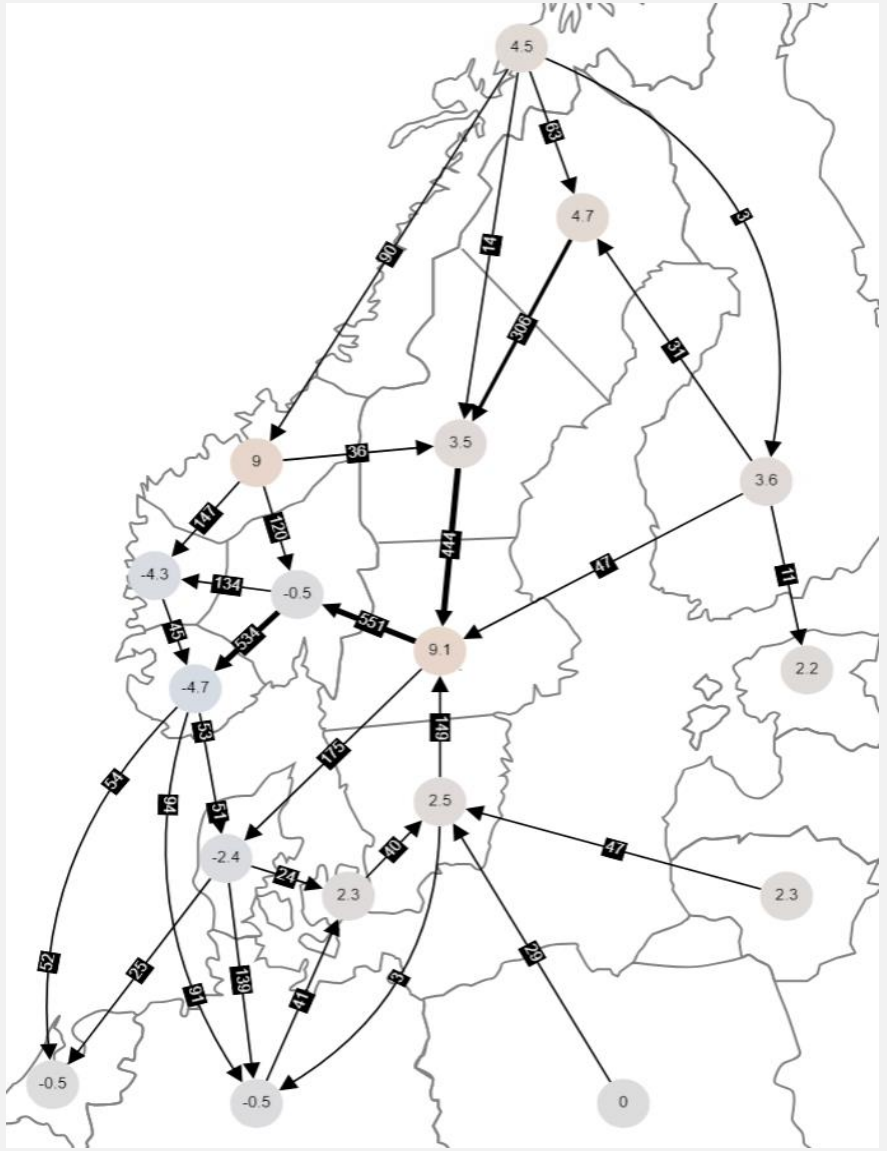


Figure: FB-NTC mean prices and flows for all of 2023

ENERGINET SVENSKA KRAFTNÄT FINGRID Statnett

2023-09-11 MTU 21:

FB increases the price convergence

- Very high prices in the continent, low in most of the Nordic bidding zones in NTC
- Clear congestion between the Nordics and the continent (+NO2 and DK) in NTC
- FB increases flow from the North to South, decreasing the price differences → higher SEW

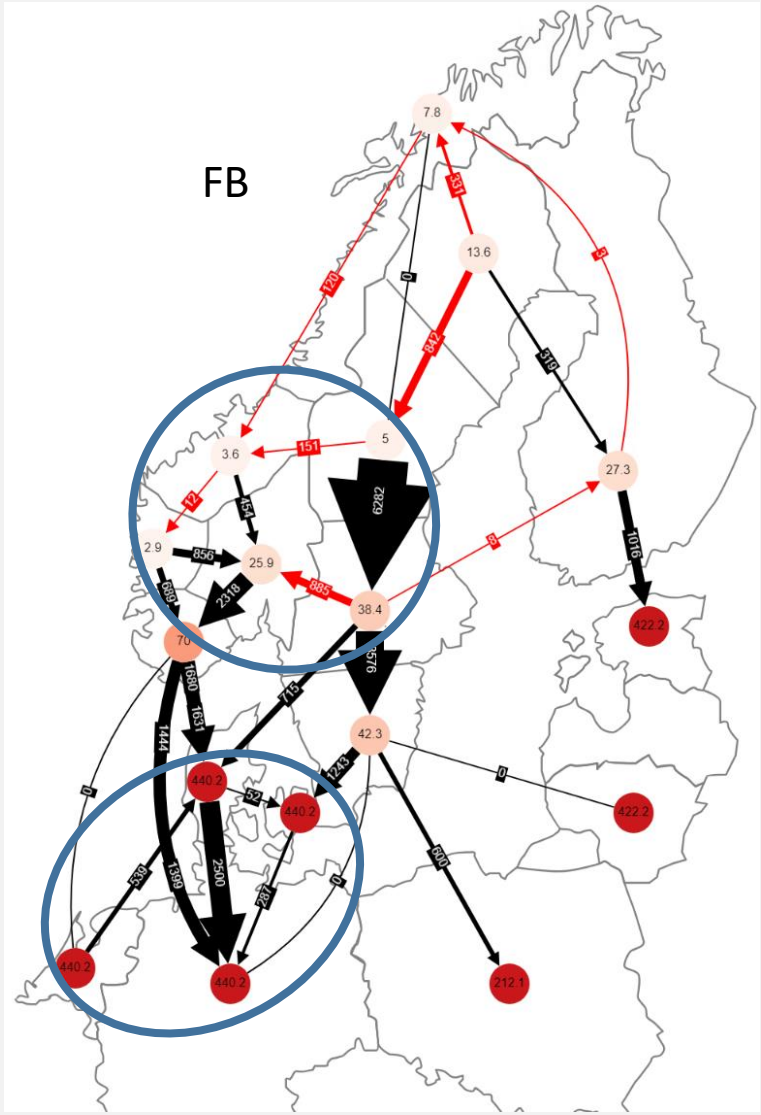


Figure: flows and prices in FB

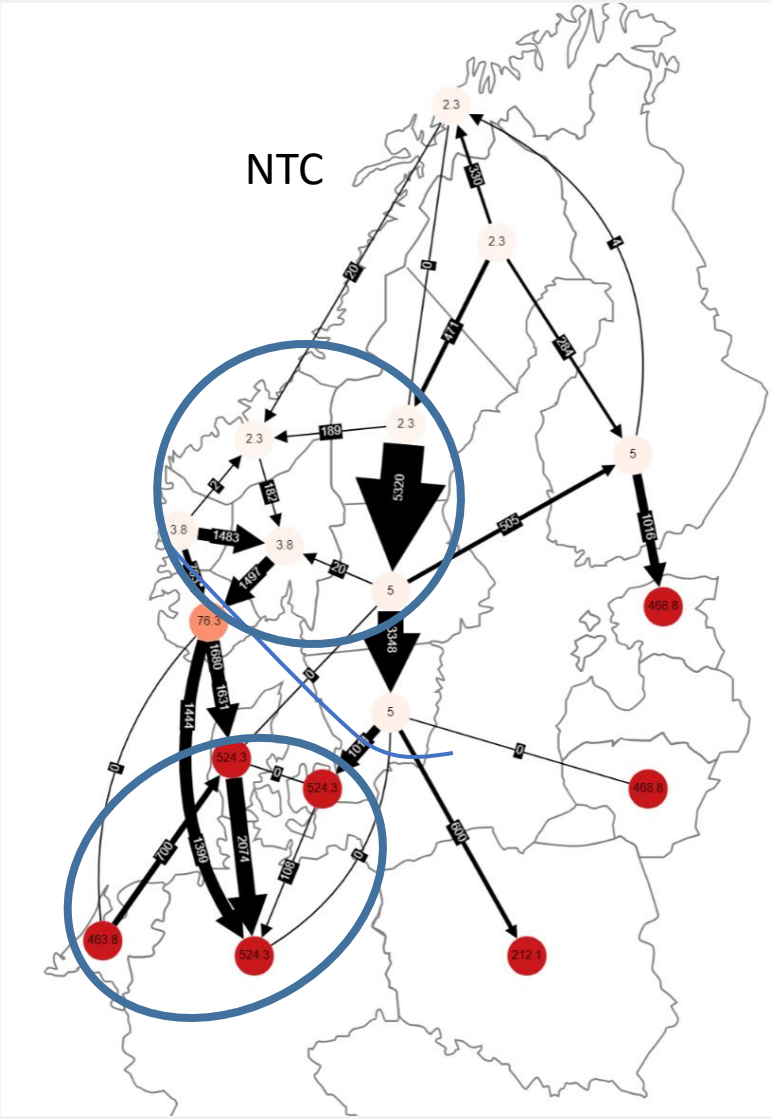


Figure: flows and prices in NTC

ENERGINET SVENSKA KRAFTNÄT FINGRID Statnett

2023-05-07 MTU 12:

FB increases the price convergence

- Low price in Germany and south of the Nordics, import to the Nordics
- Clear congestion between DK and SE4 and the rest of the Nordics in NTC
- FB allows for more flow from Germany and more flow up into the Nordics.
- Prices are more similar across the region → higher SEW

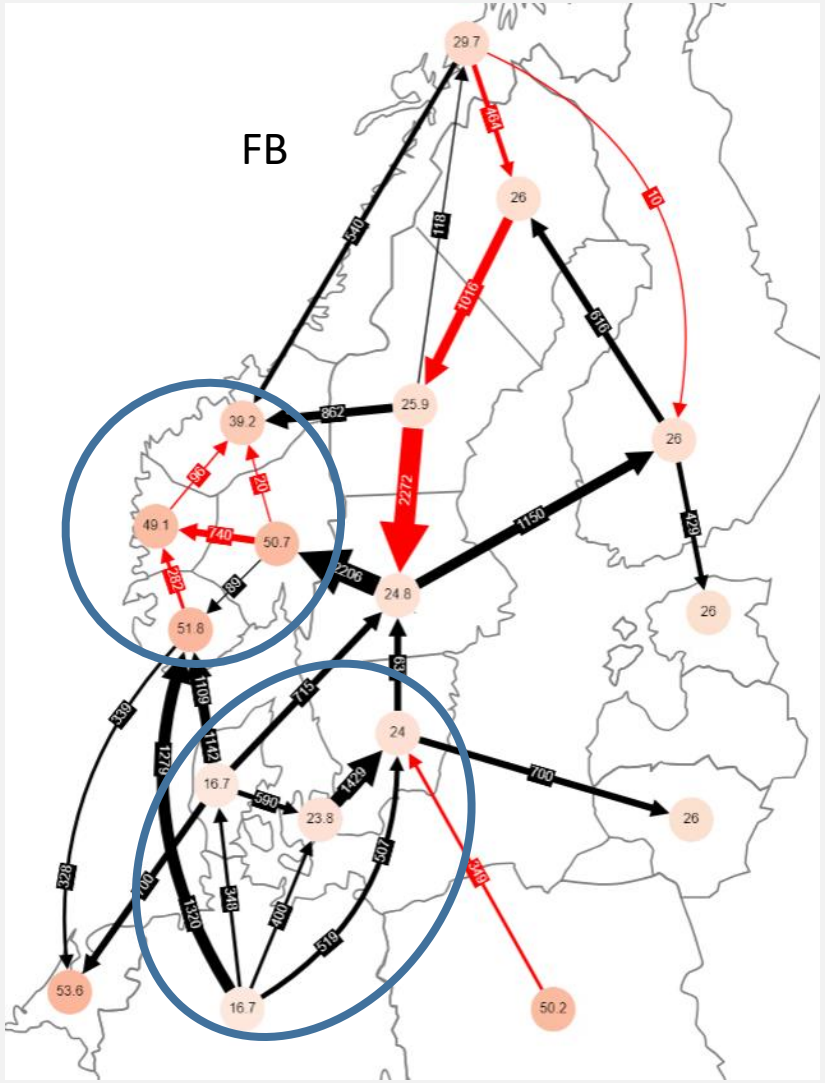


Figure: flows and prices in FB

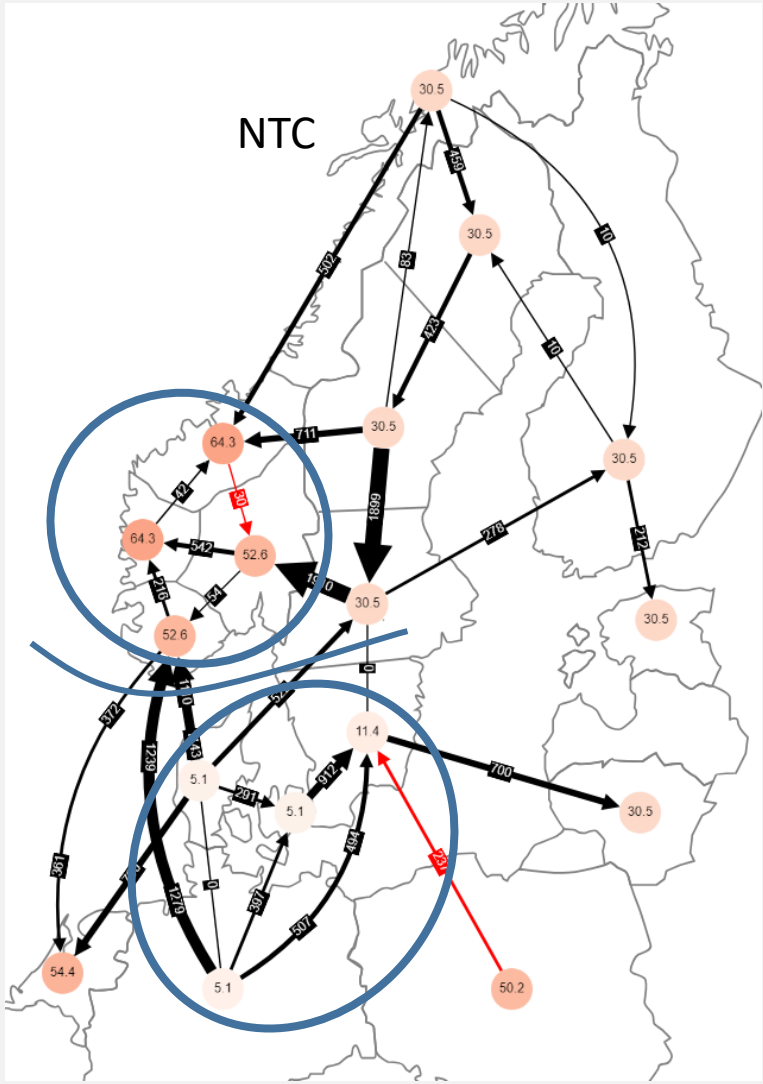


Figure: flows and prices in NTC

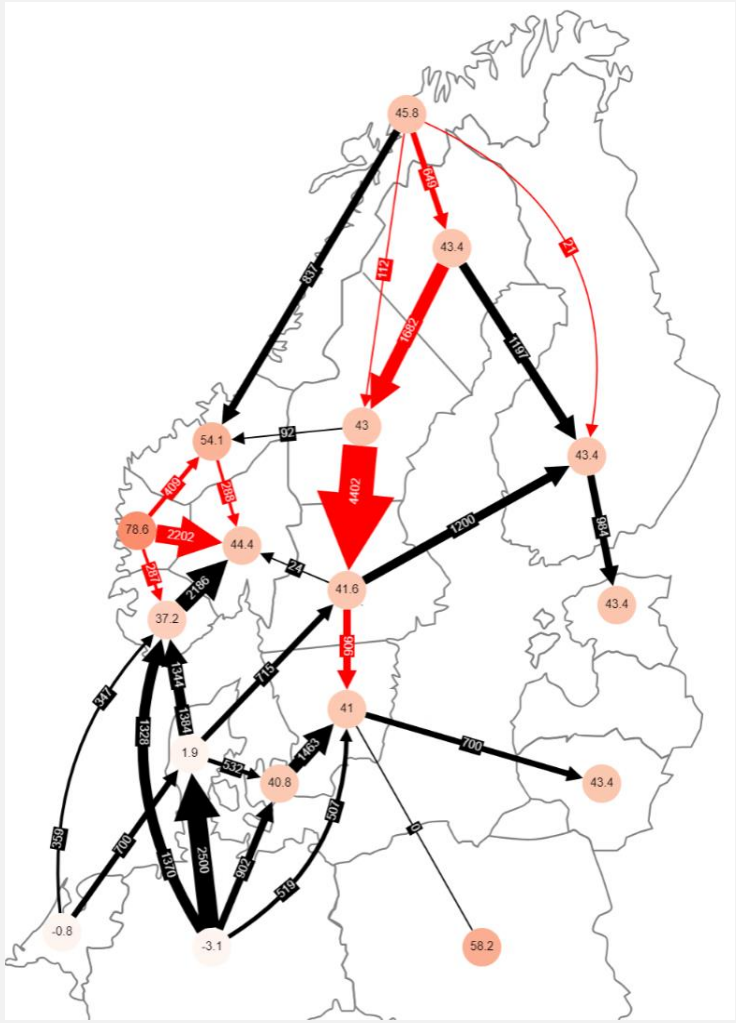
ENERGINET SVENSKA KRAFTNÄT FINGRID Statnett

Sauda transformers

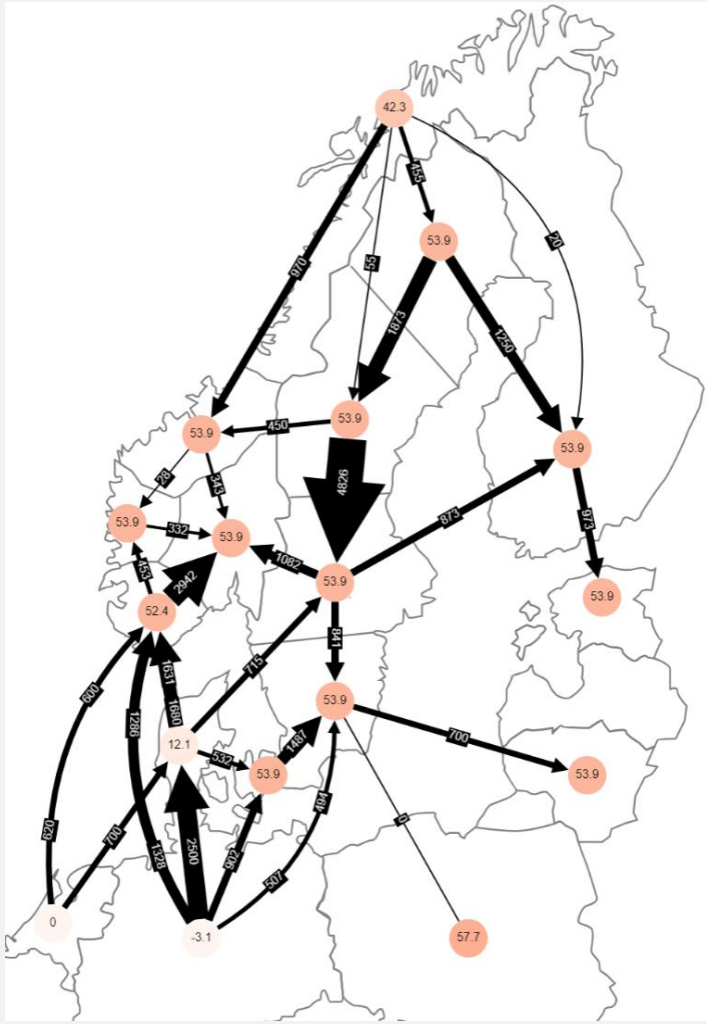
2023-12-24 MTU 11

Handling of constraining internal CNEC

- Transformers located in NO2
- During high import and lower consumption, these transformers are very loaded (in both NTC and FB)
- In NTC, the operators use a lot of counter trade to avoid overloads.
- In flow-based, the model forces production in NO5, increasing the price, but avoiding overload (and avoid counter trade)
- We are still analyzing this case, but the operators seem happy with the FB solution.



Map: Price and flows from FB



Map: Prices and flows from NTC

ENERGINET

SVENSKA KRAFTNÄT

FINGRID

Statnett

The road ahead

- Go-live in October 2024
- We will continue to analyze and report on results from the EPR
  - We still find new situations and cases we learn from
- The operators are still learning from the CNECs they are sending in, and how flow-based provides capacities
  - The training will continue, and increase towards go-live
- Intraday values will also be analyzed

ENERGINET SVENSKA KRAFTNÄT FINGRID Statnett

Where to find more information?

ENERGINET SVENSKA KRAFTNÄT FINGRID Statnett

Further information

- EPR results: RCC - https://nordic-rcc.net/flow-based/simulation-results/
- FB parameters: JAO - PuTo Nordic CCR TEST (jao.eu)
- Methodology: RCC - https://nordic-rcc.net/flow-based/methodology/
- Stakeholder events: RCC - https://nordic-rcc.net/flow-based/documents-presentations/
- TSOs own webpages: statnett.no, fingrid.fi, svk.se, energinet.dk
- Newsletter - https://nordic-rcc.net/updatesnewsletters/

ENERGINET SVENSKA KRAFTNÄT FINGRID Statnett