PSCC2020

HVDC Loss Factors in the Nordic Power Market

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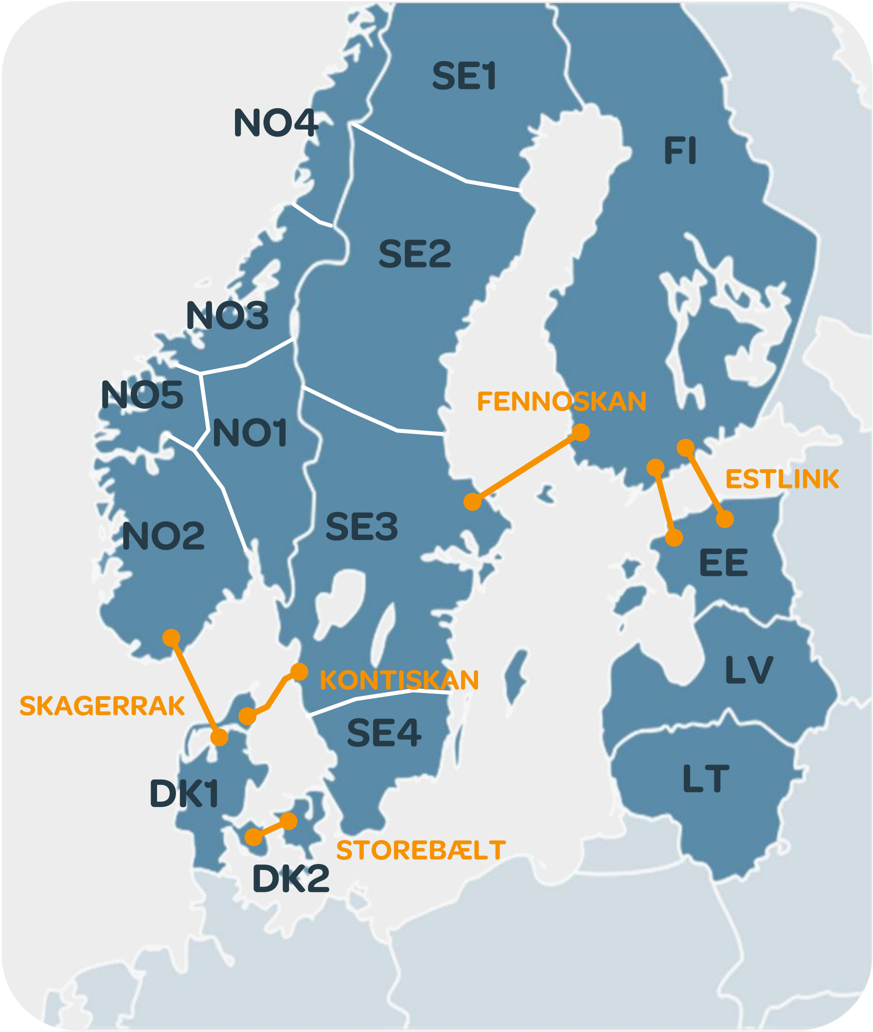
July 2, 2020
XXI Power System Computation Conference

Zero-price difference between zones



Hours of operation with zero-price-difference

and corresponding losses (€)

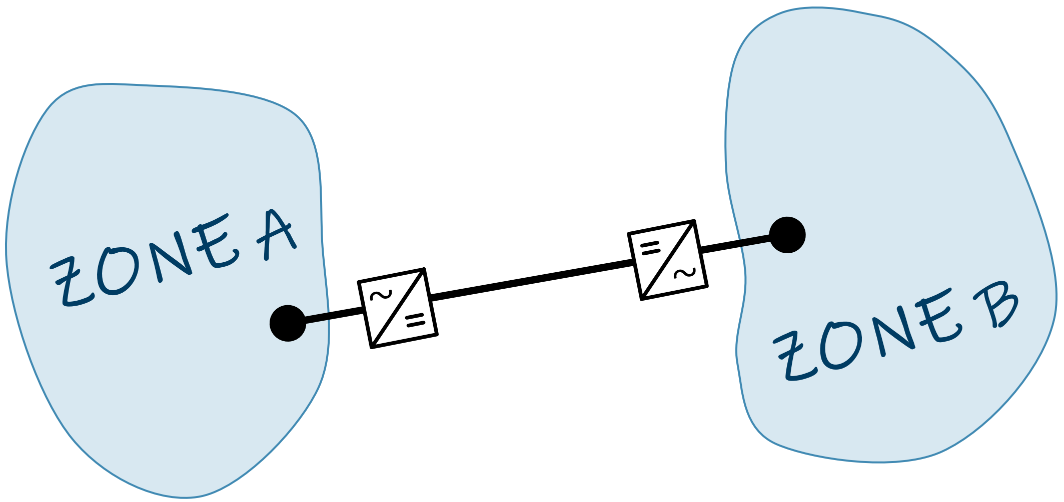
	2017		2018	
	%	LOSSES	%	LOSSES
KONTISKAN	61%	1.2 M€	53%	1.5 M€
STOREBÆLT	73%	0.8 M€	74%	1.1 M€
SKAGERRAK	47%	3.2 M€	46%	4.7 M€
ESTLINK	76%	3.1 M€	95%	6.7 M€
FENNOSKAN	99%	3.8 M€	80%	4.2 M€
		12 M€		**18 M€**

Source: https://www.nordpoolgroup.com/

Introduction of HVDC loss factors

- With the current practice, **losses** are **not considered** in the market clearing process.

Price of electricity = Cost of **energy** + Cost of **congestion**



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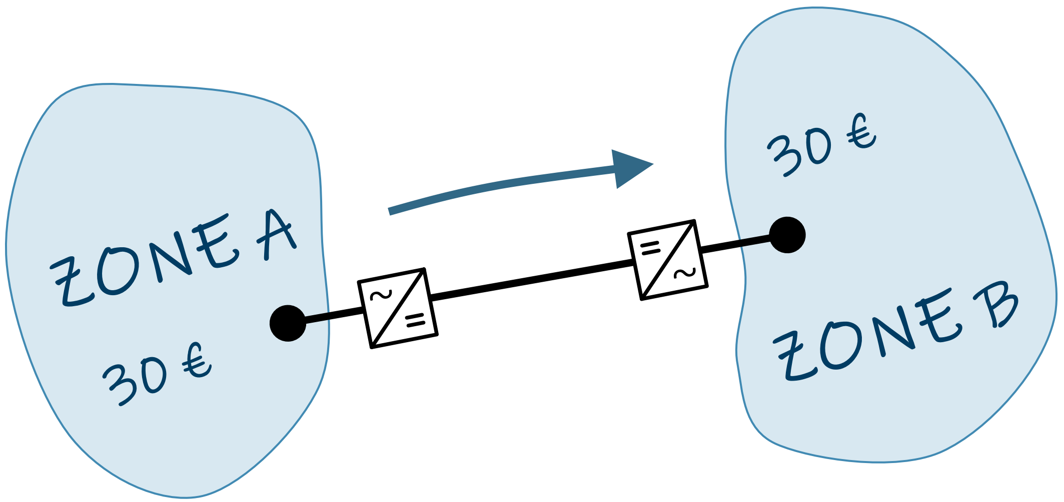

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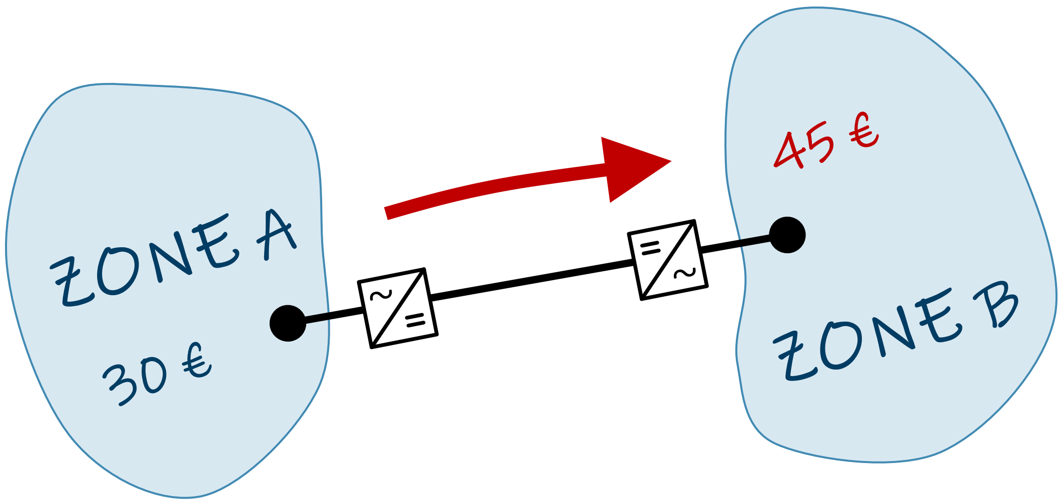

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- With the current practice, **losses** are **not considered** in the market clearing process.
- The **Nordic TSOs** have proposed the introduction of linear **HVDC loss factors***.

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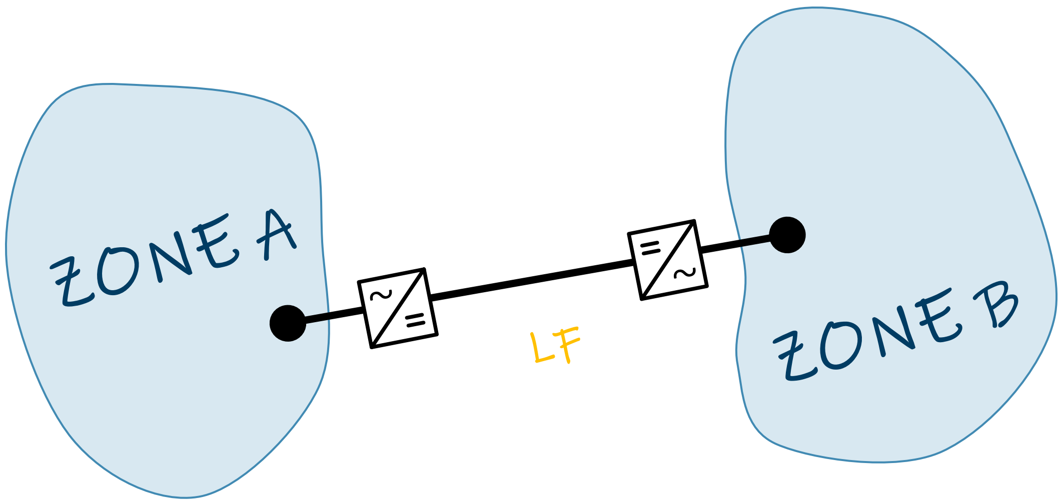

SVENSKA KRAFTNÄT Statnett ENERGINET FINGRID

* Fingrid, Energinet, Statnett, Svenska Kraftnät, *Analyses on the effects of implementing implicit grid losses in the Nordic CCR*, Tech. Rep., April 2018

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- The introduction of HVDC loss factors creates **price differences** to cover the cost of losses.

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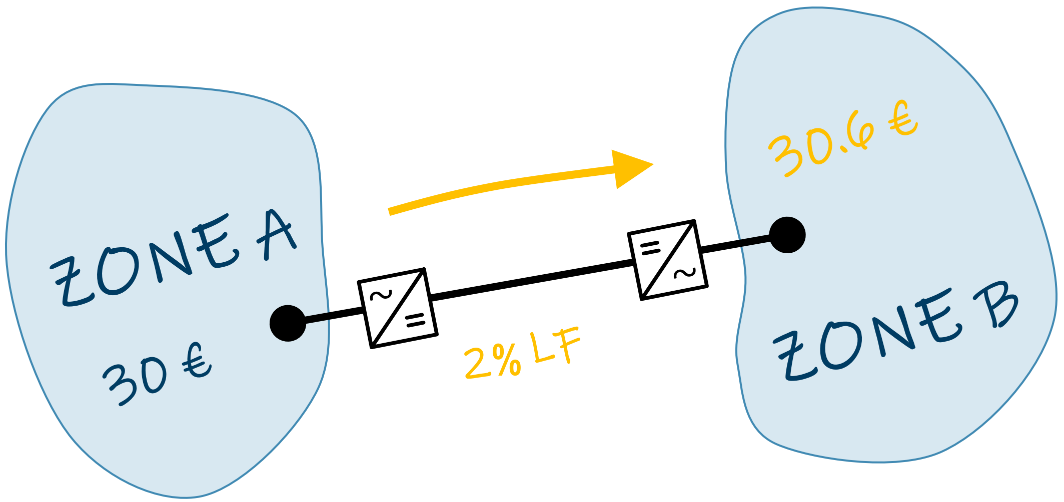

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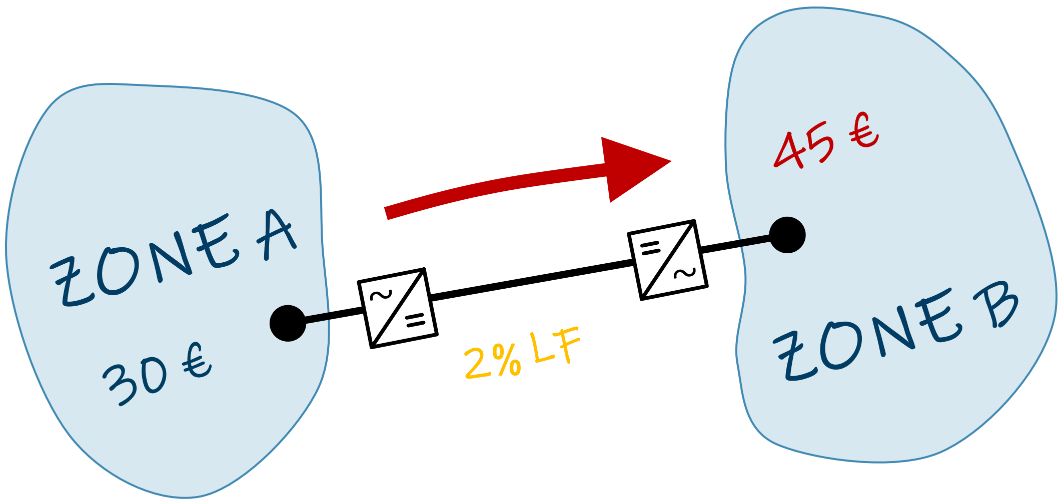

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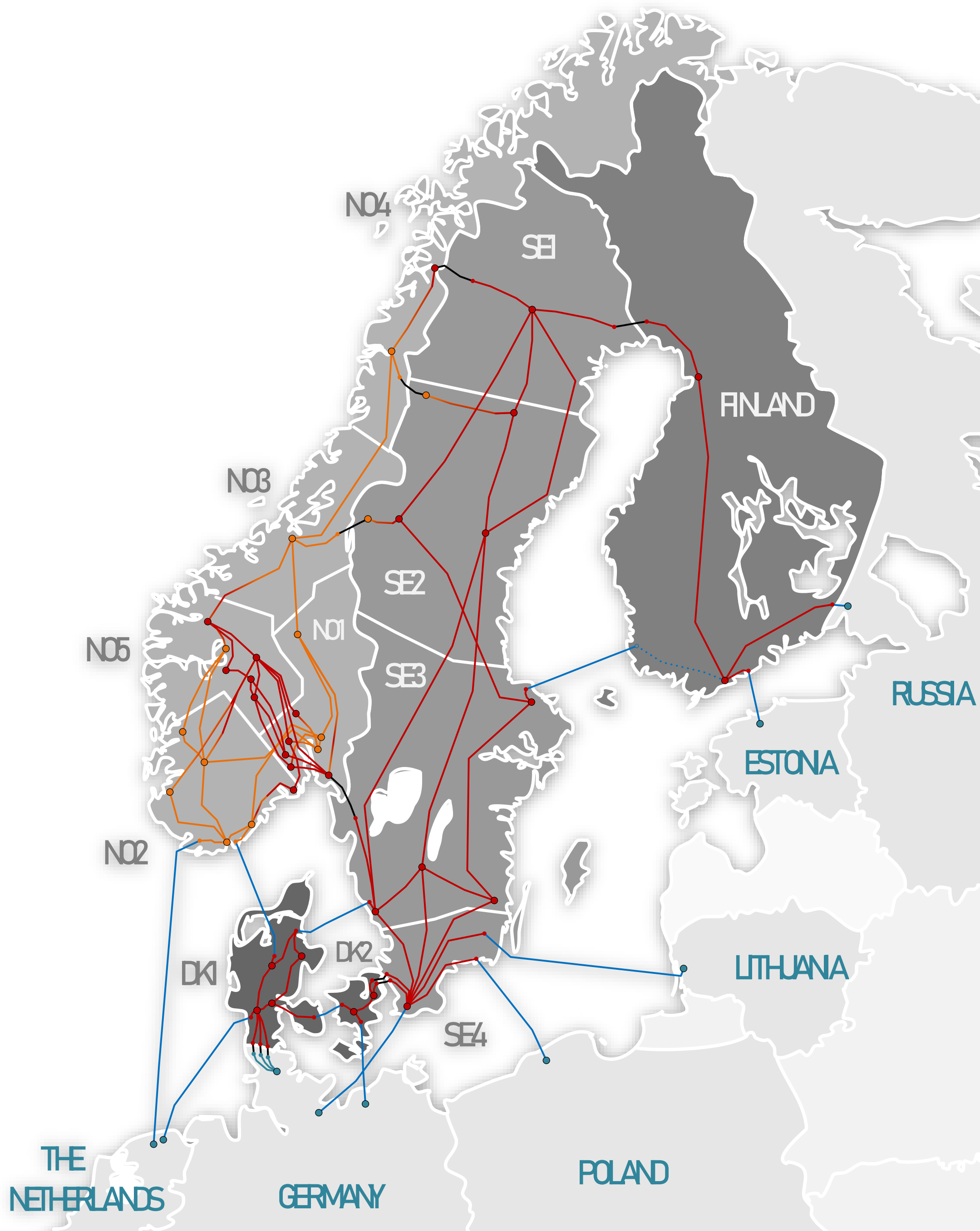
Introduction of HVDC loss factors

Stage	AC losses	HVDC losses: Current practice	HVDC losses: TSOs proposal
D-2	• TSOs **estimate** losses	• TSOs **estimate** losses • Bilateral **agreements**	-
D-1	• Price-independent **bids** in the market	• Price-independent **bids** in the market	• Losses are calculated using **loss factors** • The ones who **create** losses **pay**
RT	• Any mismatch is covered in the **balancing** market	• Any mismatch is covered in the **balancing** market	• If losses calculated with loss factors are **exact**, society pay less

Nordic test network

- **Test case**:
  - 369 nodes, 362 AC and 10 HVDC transmission lines;
  - 631 generating units;
  - Actual wind, solar and load profiles from 2017.



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Nordic test network

- **Test case**:
  - 369 nodes, 362 AC and 10 HVDC transmission lines;
  - 631 generating units;
  - Actual wind, solar and load profiles from 2017.

- **Nordic market:**
  - Zonal-pricing market;
  - Nodes aggregated into bidding zones;
  - Actual transfer capacities from NordPool.

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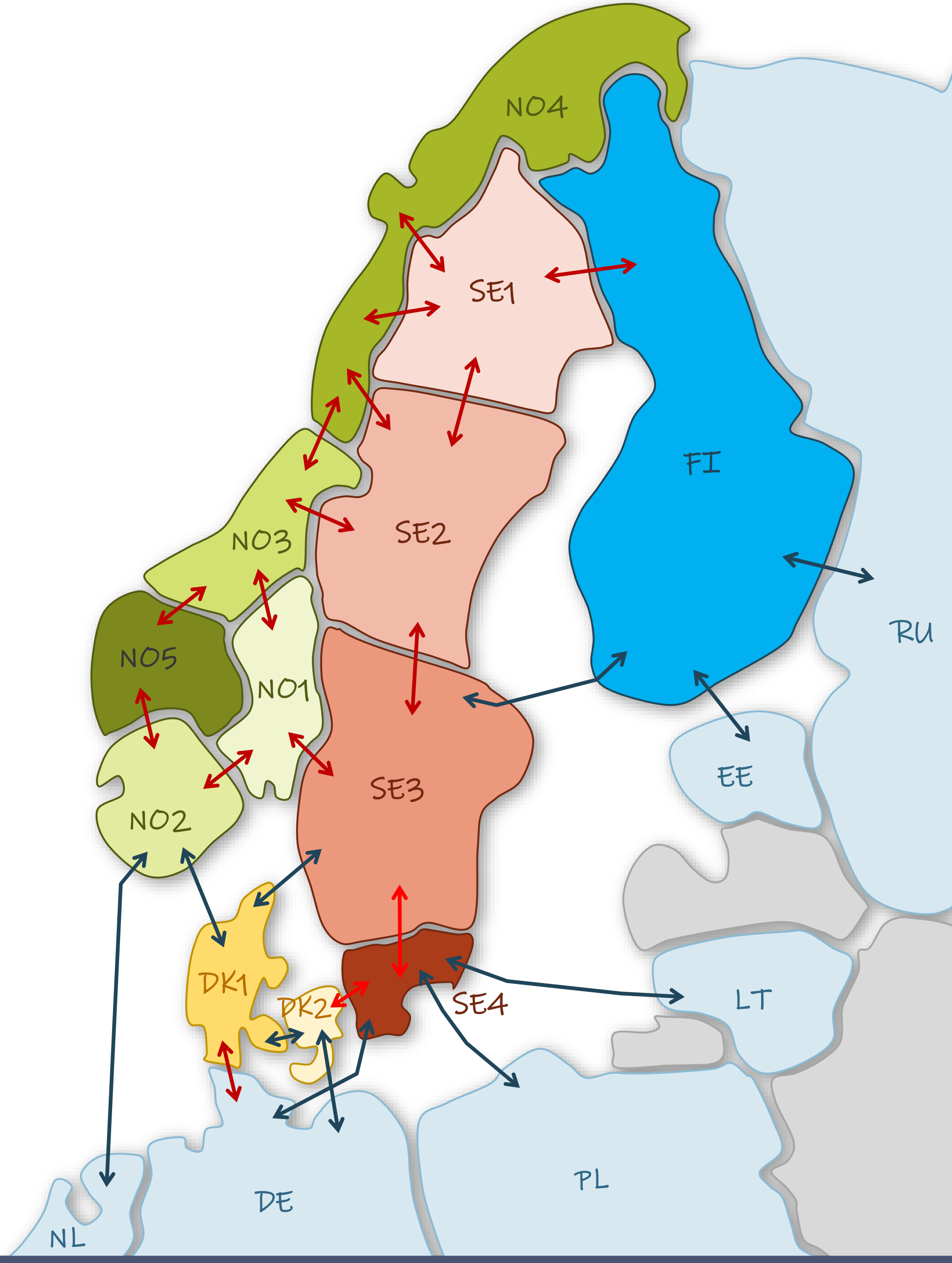
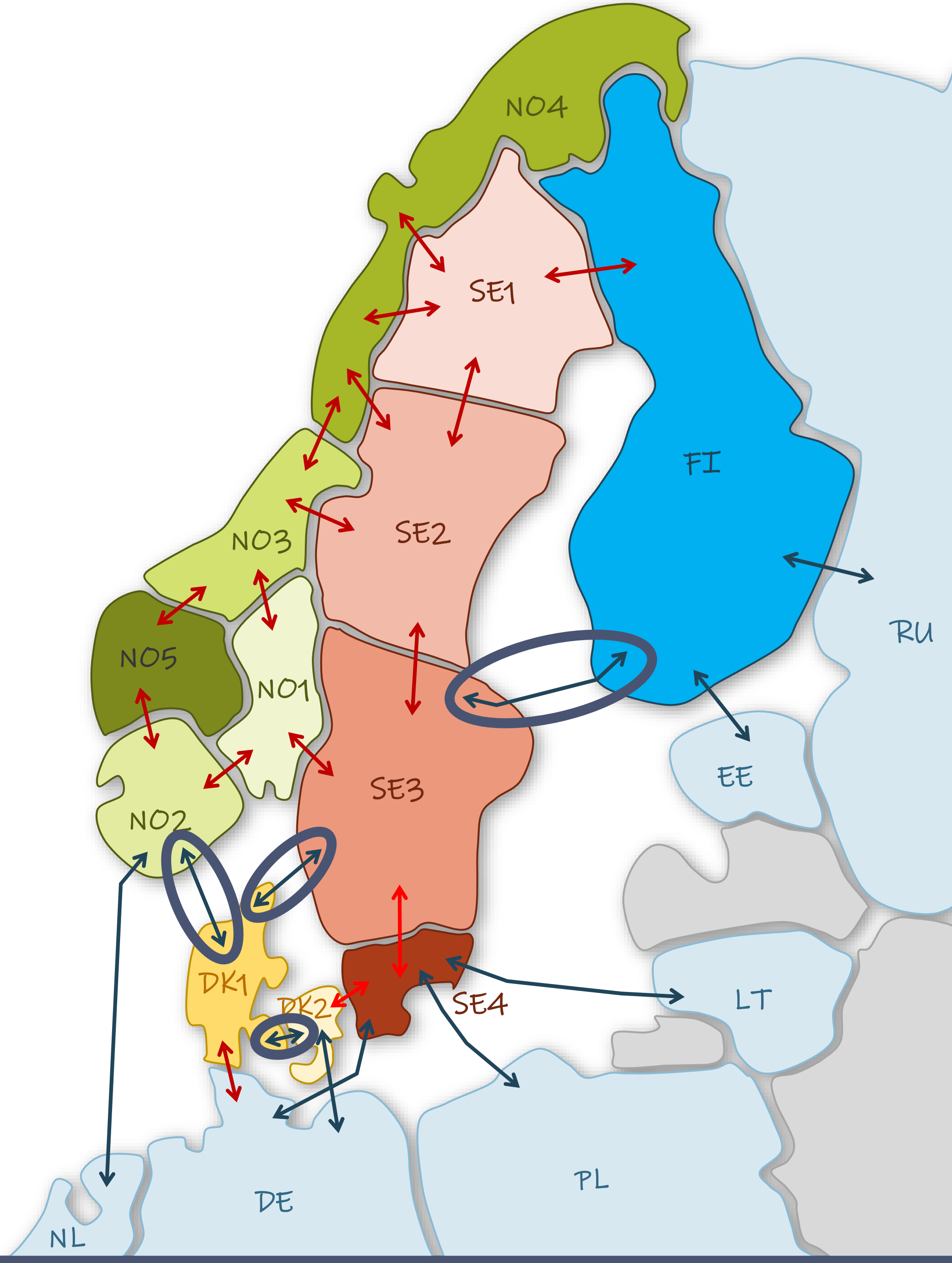


Nordic test network

- **Simulations:**
  - Focus on intra-Nordic HVDC lines;
  - Two analyses:
    1. **Linear** vs. **piecewise-linear**
    2. **HVDC** vs. **AC+HVDC**



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Market clearing algorithm

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- Market clearing algorithm based on Available Transmission Capacities (**ATC**)

$$\min_{\mathbf{g},\mathbf{f}} \quad c^T \mathbf{g}$$

$$\text{s.t.} \quad \underline{G} \leq \mathbf{g} \leq \overline{G}$$

$$-\underline{ATC} \leq \mathbf{f} \leq \overline{ATC}$$

$$I^d d - I^g \mathbf{g} + I^f \mathbf{f} + p{*}^{loss} = 0$$

Market clearing algorithm

- Market clearing algorithm based on Available Transmission Capacities (**ATC**)
- Quadratic loss functions are used to calculate **linear approximations** to be introduced in the market.
- Utilization of **binary variables** to determine the direction of the flows.

$$\min_{g,\, f,\, f^{\pm},\, u,\, p^{loss}} \quad c^T g$$

$$\text{s.t.} \quad \underline{G} \le g \le \overline{G}$$

flow definition

$$f = f^{+} - f^{-}$$

$$0 \le f^{+} \le u\, \overline{ATC}$$

$$0 \le f^{-} \le (1-u)\, \underline{ATC}$$

$$u \in \{0,1\}$$

loss definition

$$p^{loss} = \alpha\,(f^{+} + f^{-}) + \beta$$

$$I^d d - I^g g + I^f f + D^{loss} p^{loss} = 0$$

Market clearing algorithm

- Market clearing algorithm based on Available Transmission Capacities (**ATC**)
- Quadratic loss functions are used to calculate **linear approximations** to be introduced in the market.
- Utilization of **binary variables** to determine the direction of the flows.
- Investigation of:
  - **linear** and **piecewise linear** loss factors.
  - **HVDC** and **AC** loss factors.

$$\min_{g,\, f,\, f_k^{\pm},\, u_k^{\pm},\, p^{loss}} \quad c^T g$$

$$\text{s.t.} \quad \underline{G} \leq g \leq \overline{G}$$

flow definition

$$\begin{cases} f = \sum_k (f_k^+ - f_k^-) \\ (u_k^{\pm} - u_{k+1}^{\pm})\,\overline{F}_{k-1} \leq f_k^{\pm} \leq (u_k^{\pm} - u_{k+1}^{\pm})\overline{F}_k \quad \forall\, k \neq K \\ u_K^{\pm}\,\overline{F}_{K-1} \leq f_K^{\pm} \leq u_K^{\pm}\,\overline{F}_K \\ u_k^{\pm} \geq u_{k+1}^{\pm} \quad \forall\, k \neq K \\ u_k^{\pm} \in \{0,1\} \quad \forall\, k \neq K \end{cases}$$

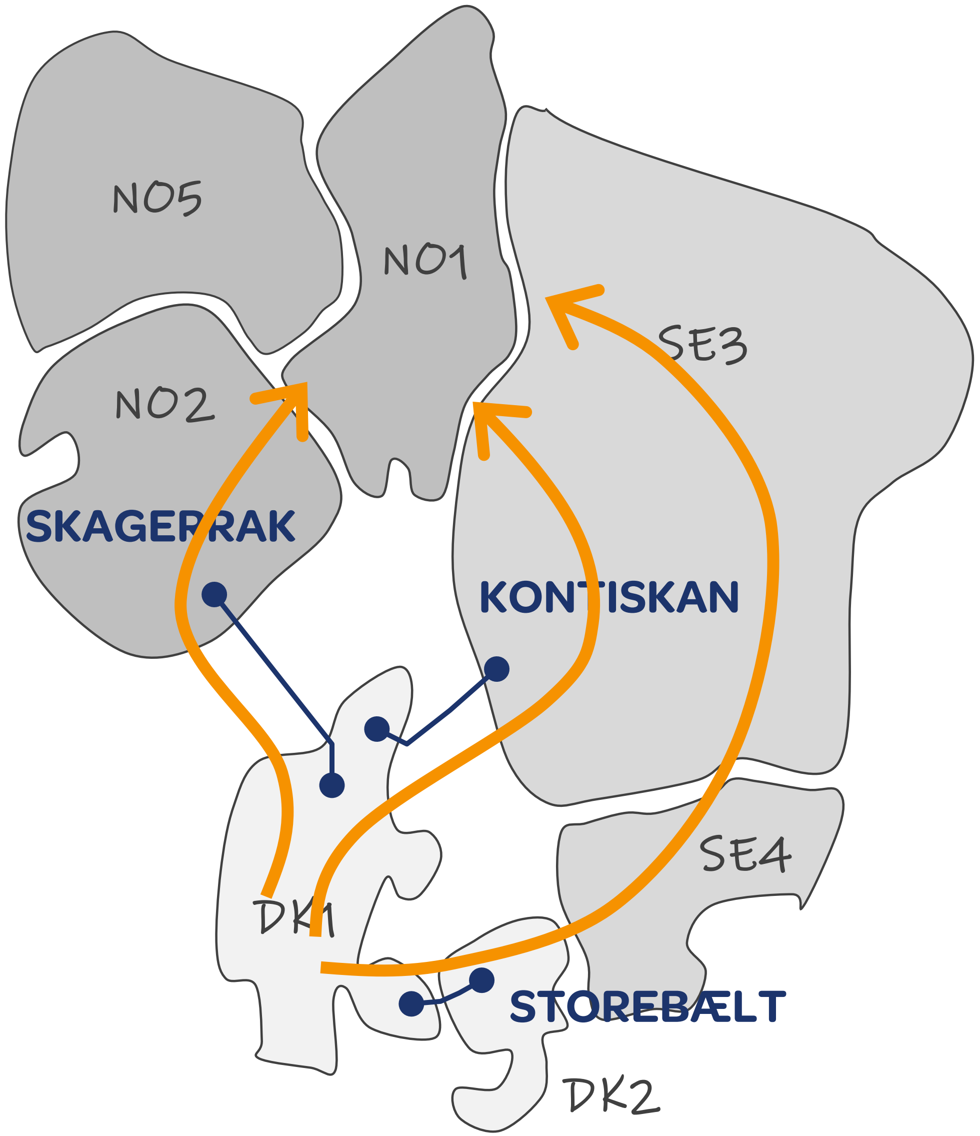
loss definition

$$\begin{cases} p^{loss} = \sum_k \alpha_k (f_k^+ - f_k^-) + \\ \quad + \sum_{k \neq K} \beta_k (u_k^+ - u_{k+1}^+ + u_k^- - u_{k+1}^-) + \\ \quad + \beta_K (u_K^+ + u_K^-) \end{cases}$$

$$I^d d - I^g g + I^f f + D^{loss} p^{loss} = 0$$

Linear vs. Piecewise-linear

- Losses are **non-linear**.
- Linear loss factors **unfairly penalize one HVDC** line over the other.
- What happens if there are several **parallel** HVDC paths?
  - This is the case of Skagerrak, Kontiskan and Storebælt.



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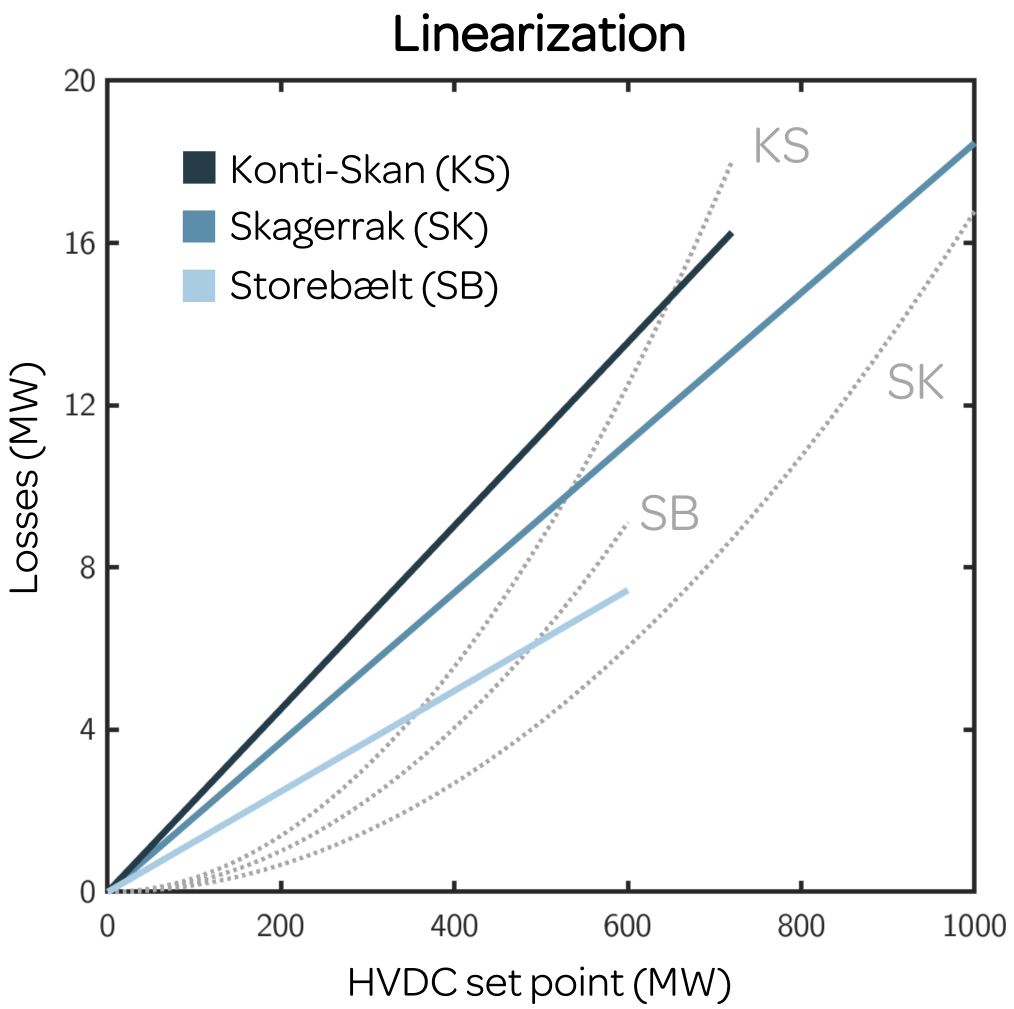

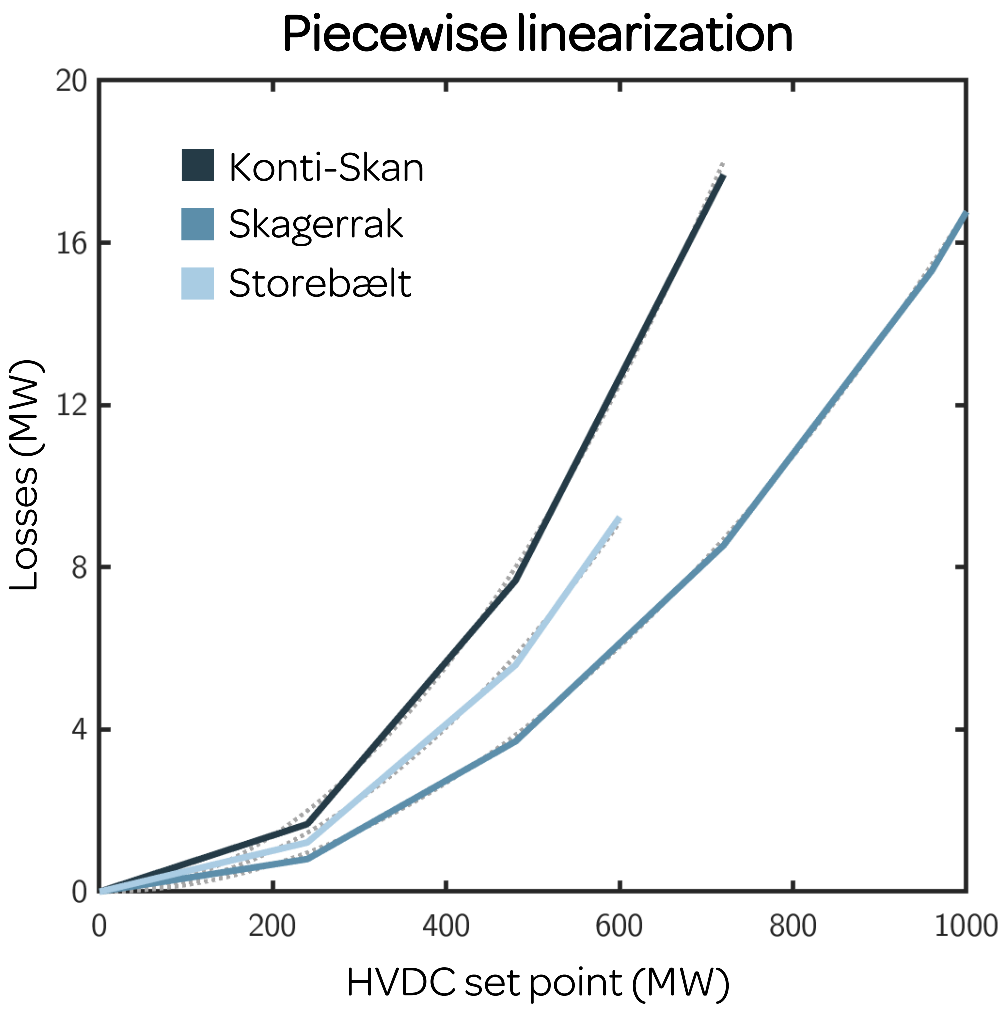

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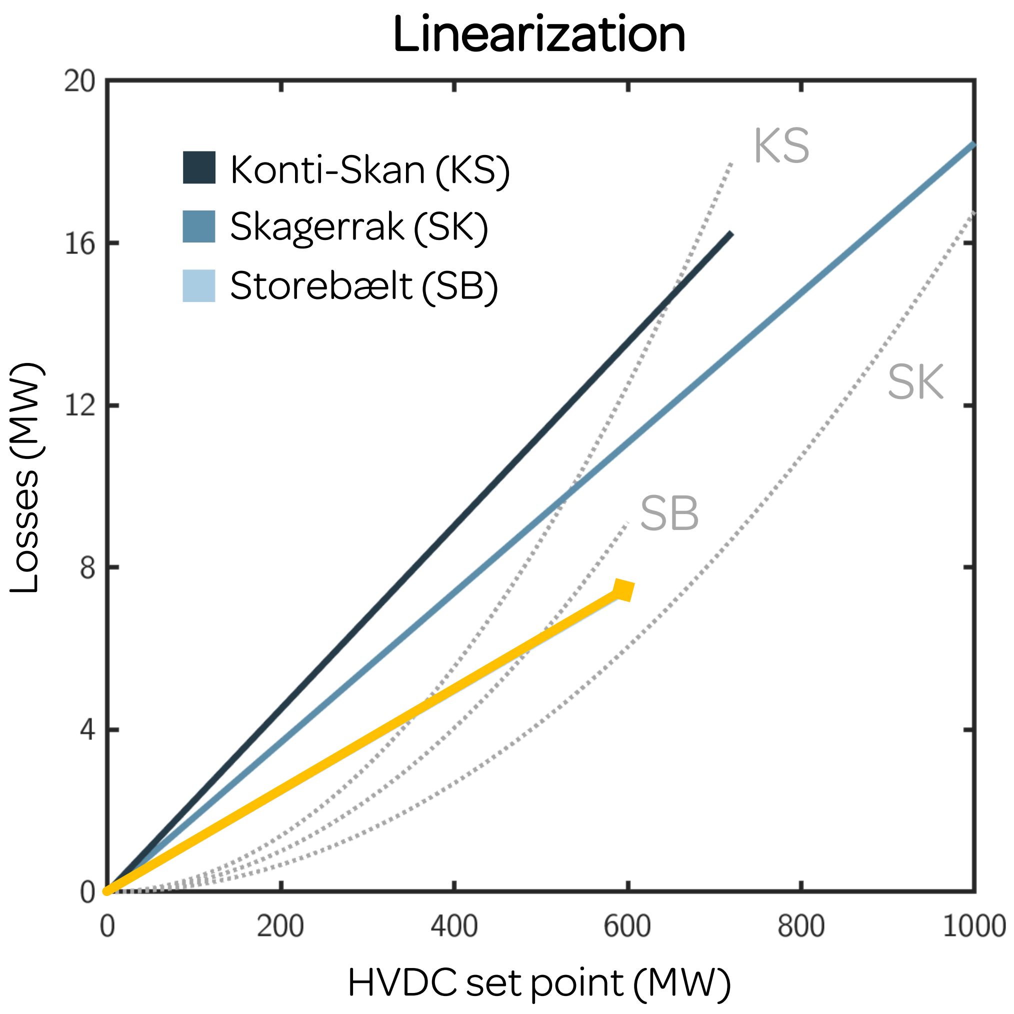

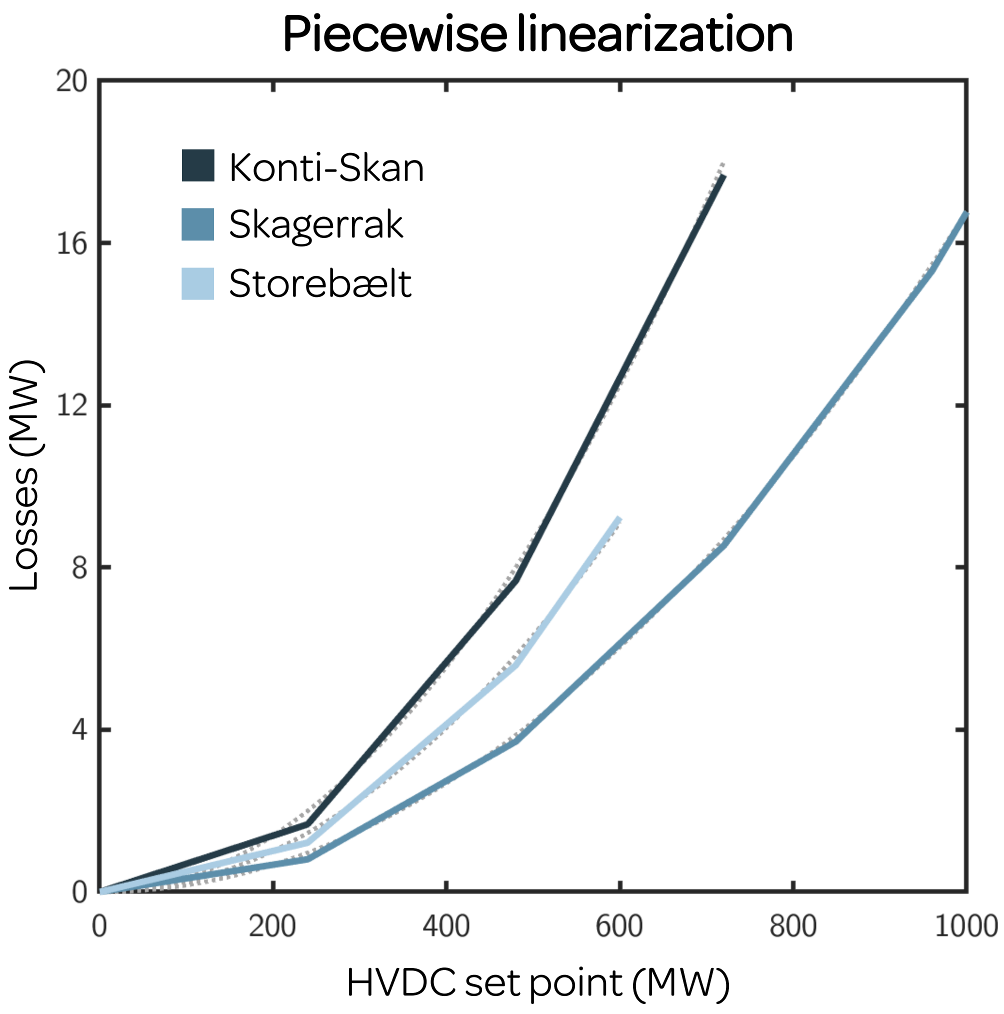

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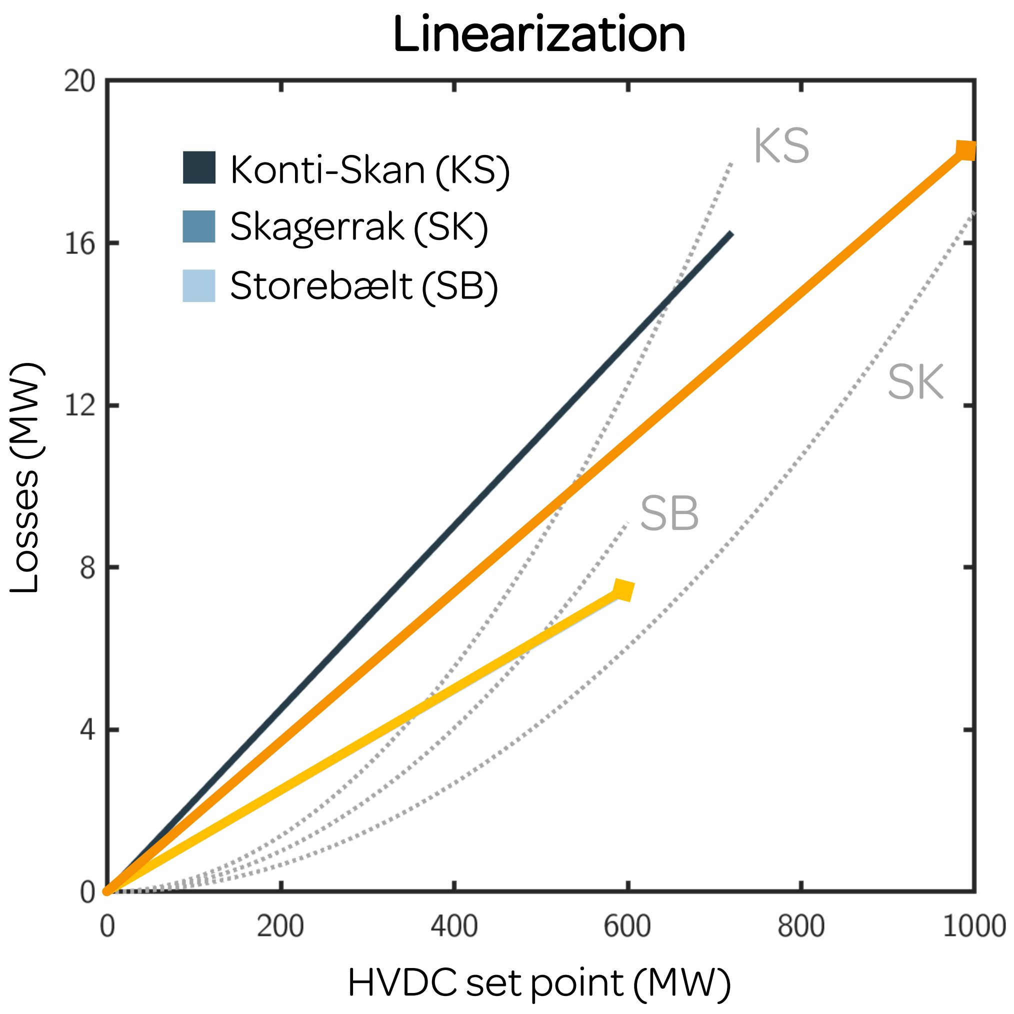

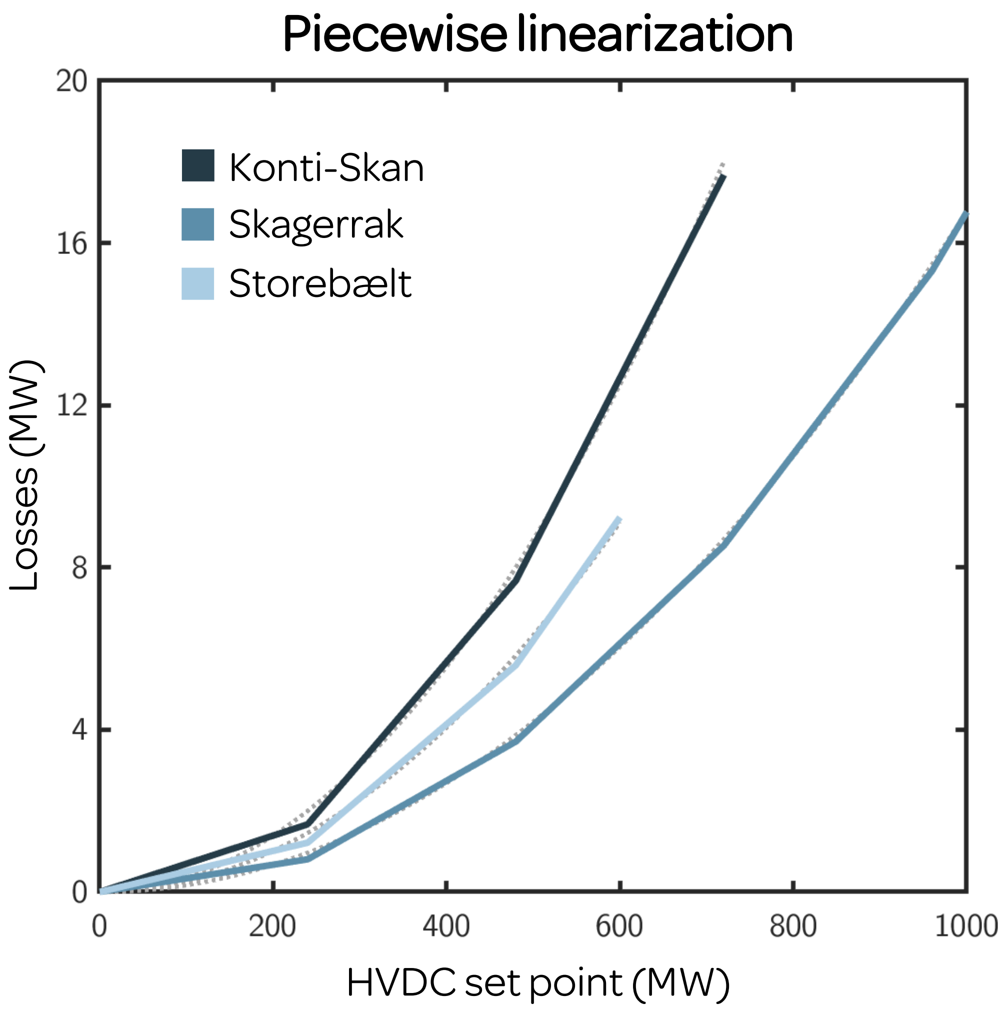

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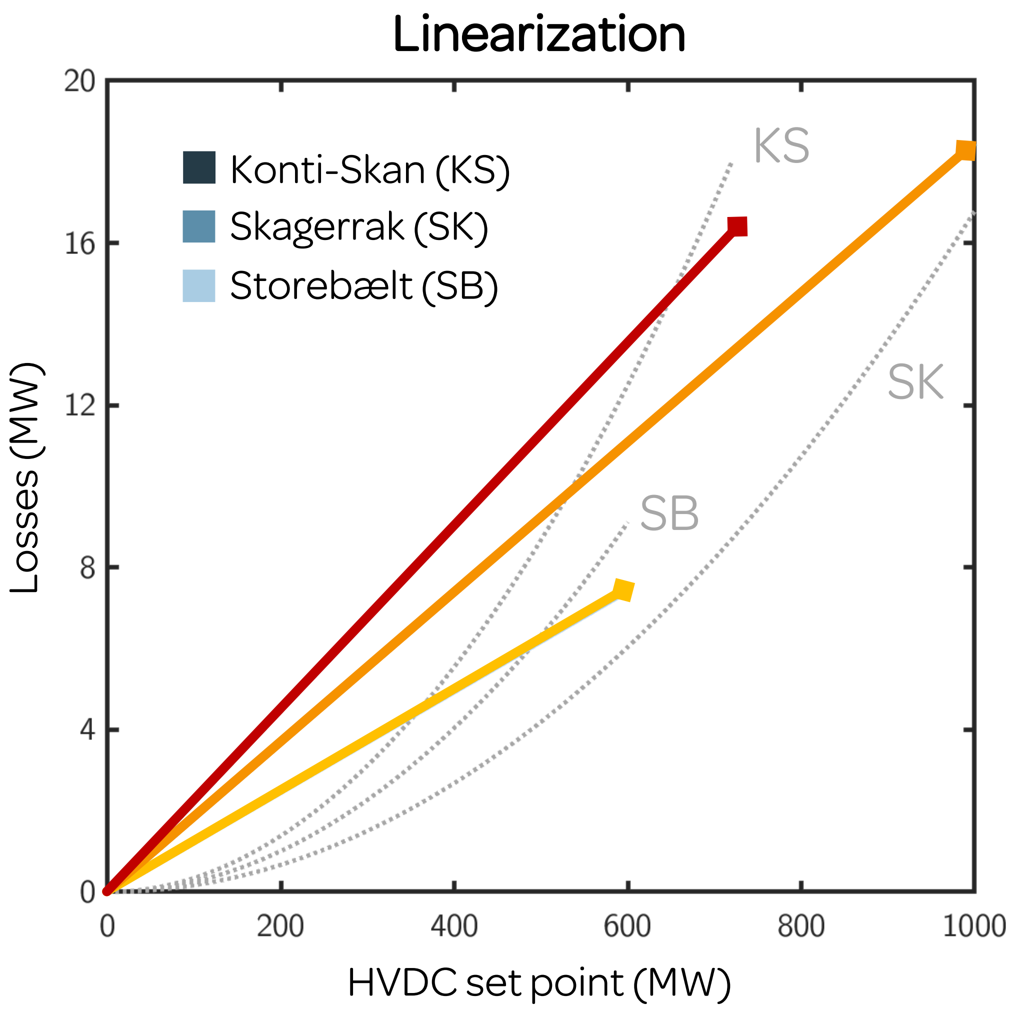

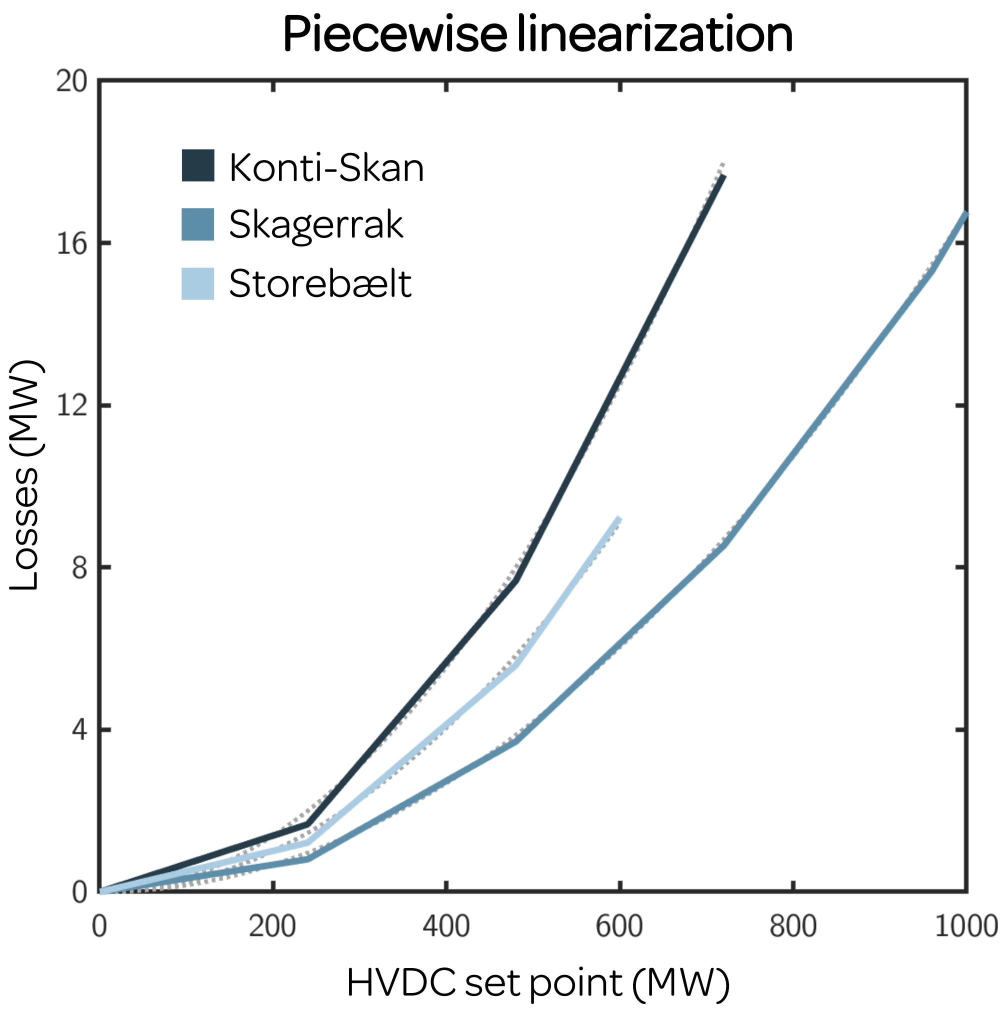

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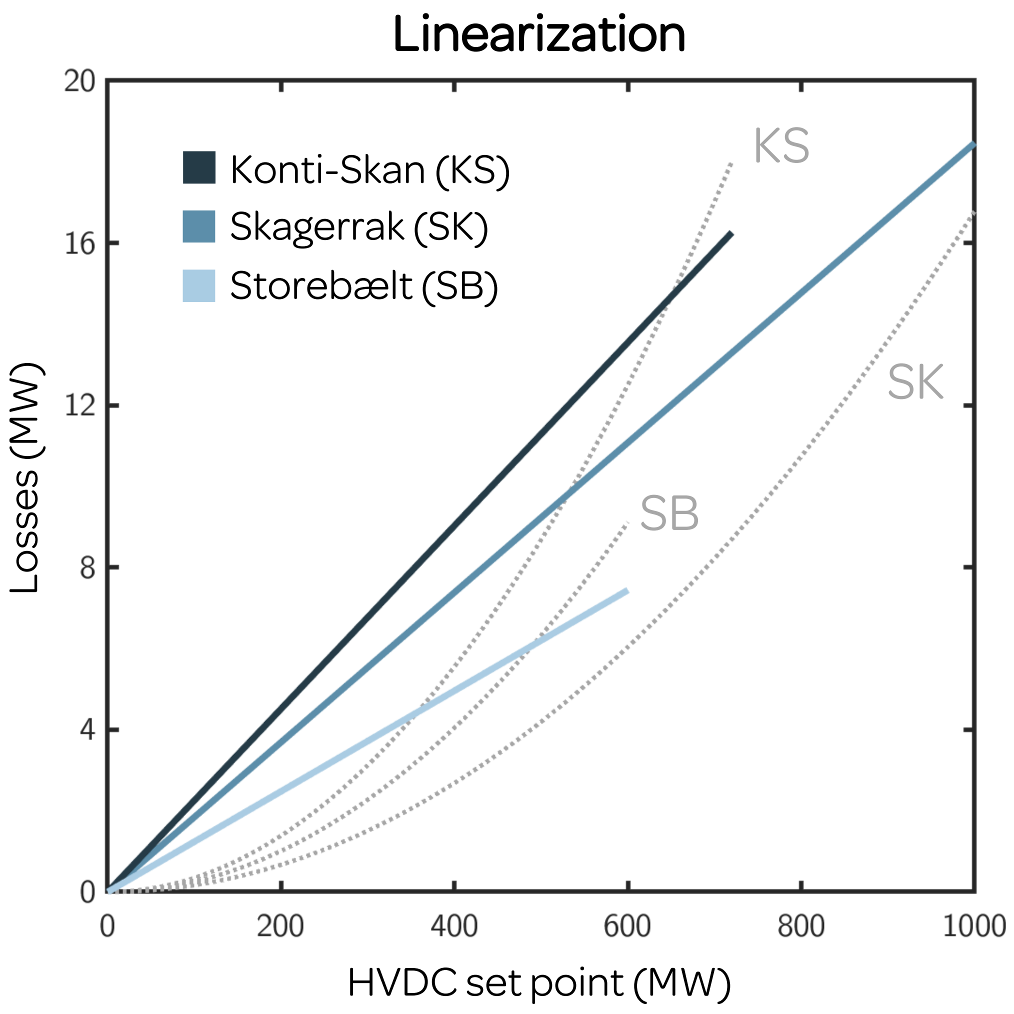

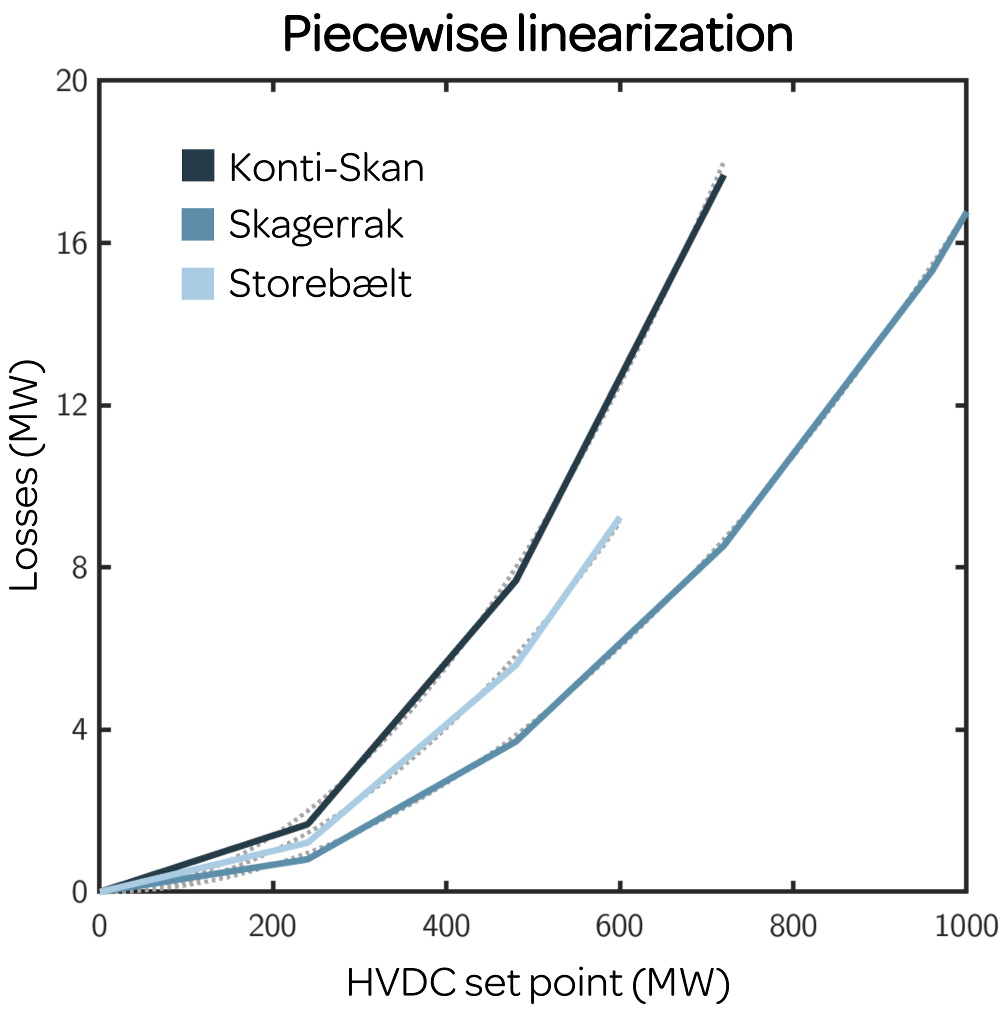

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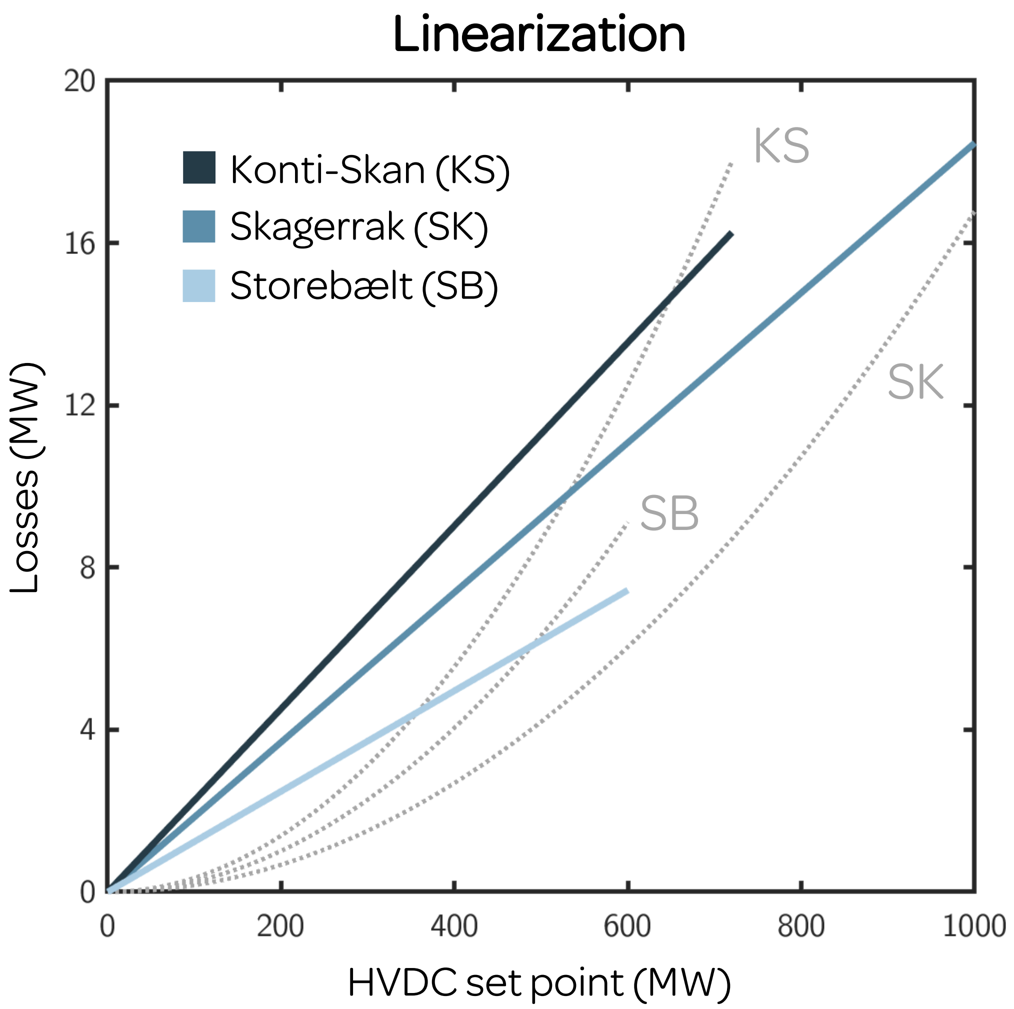

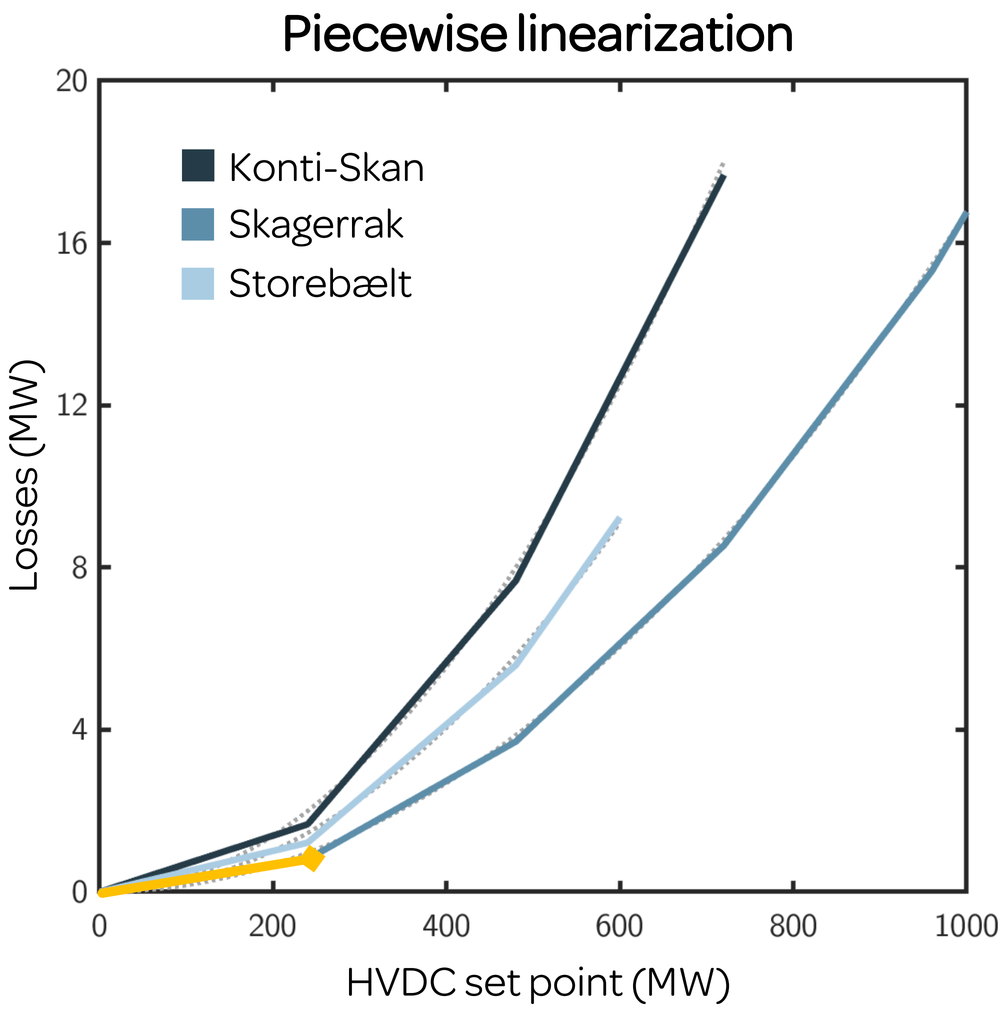

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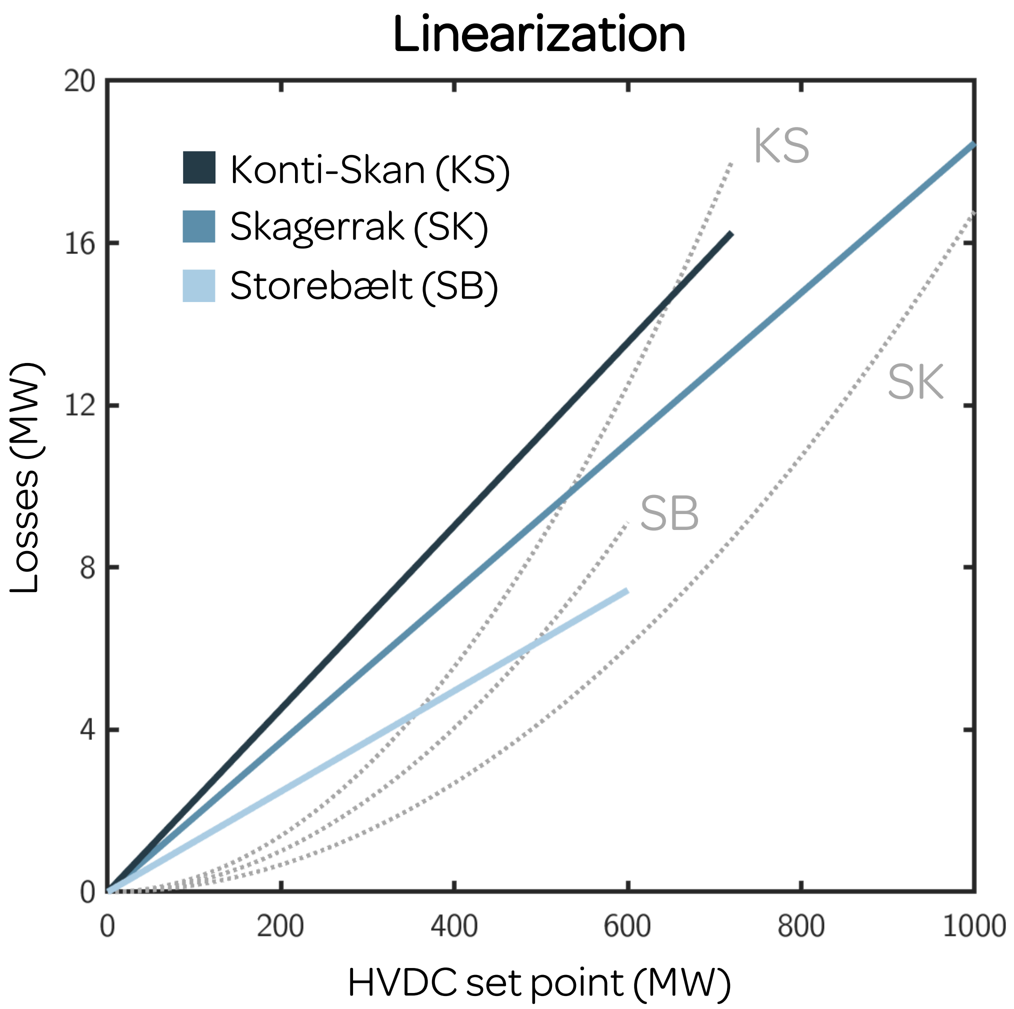

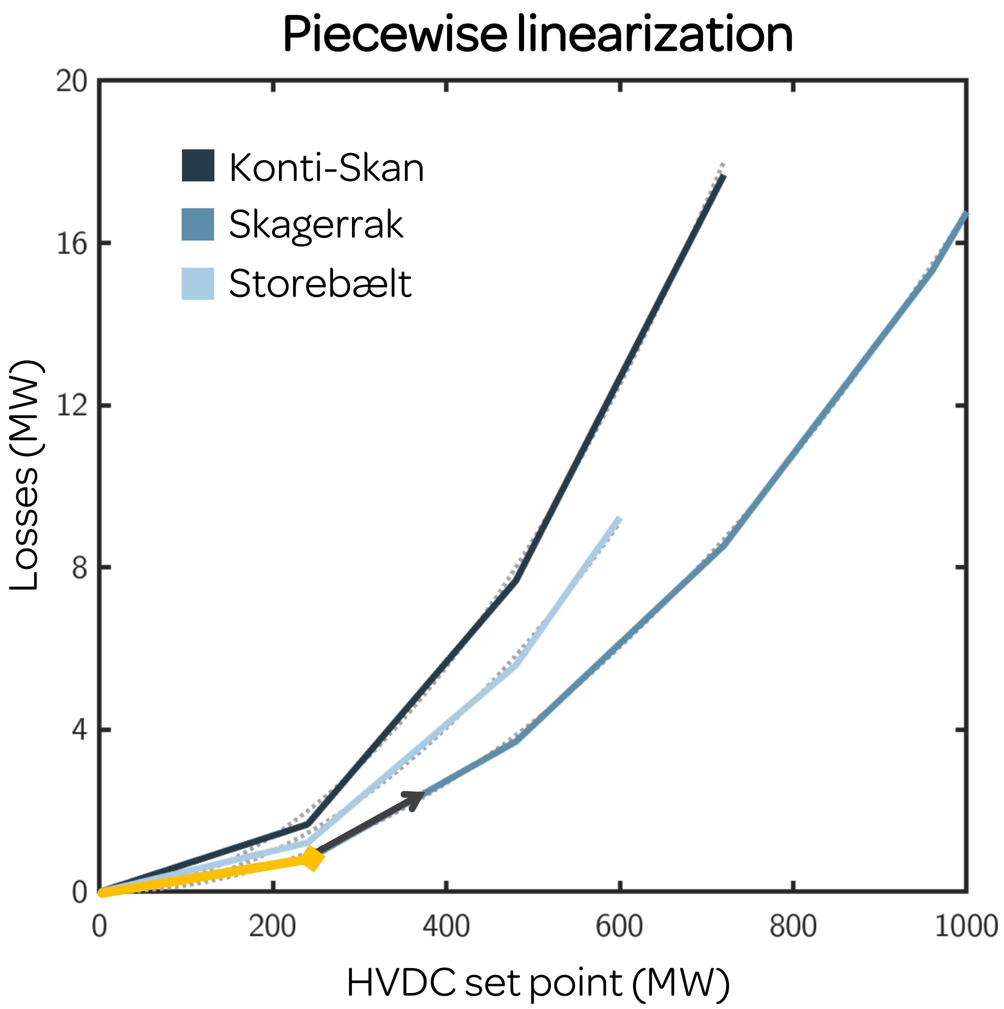

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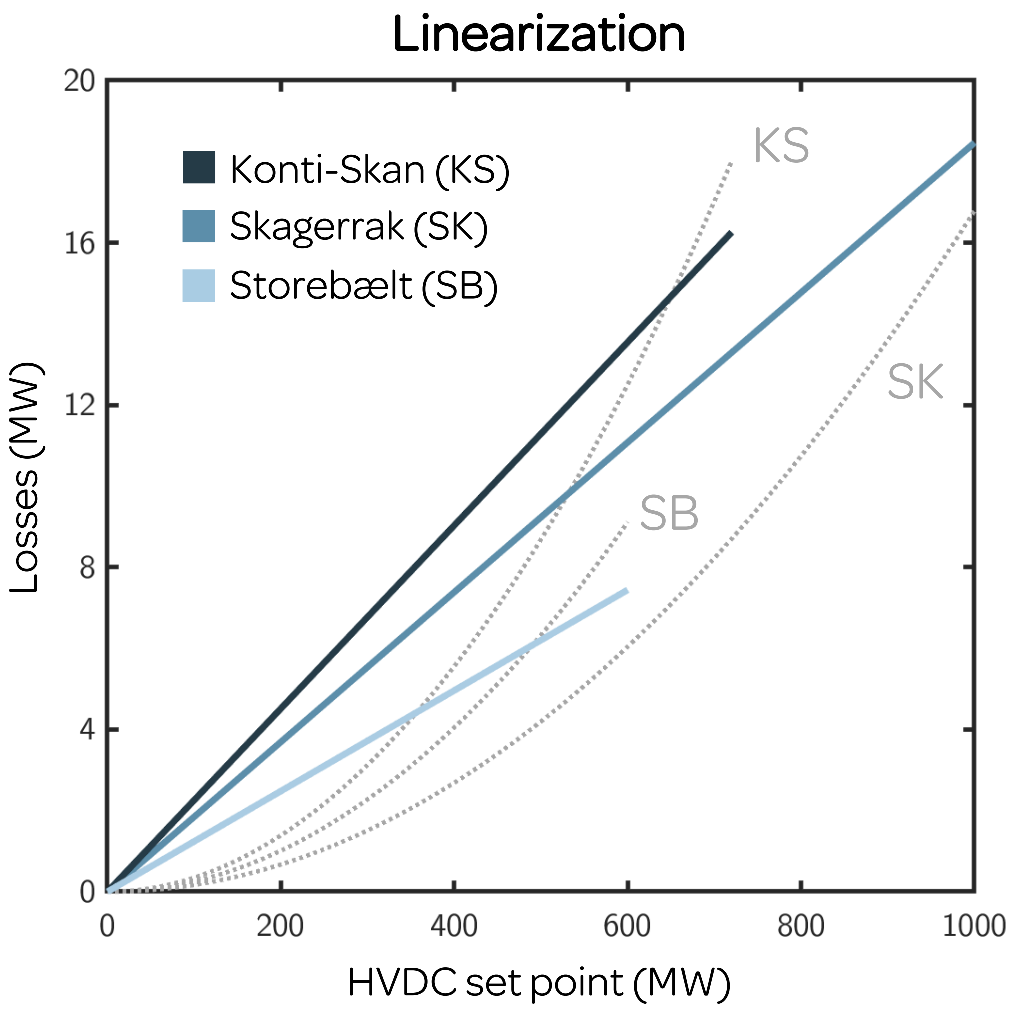

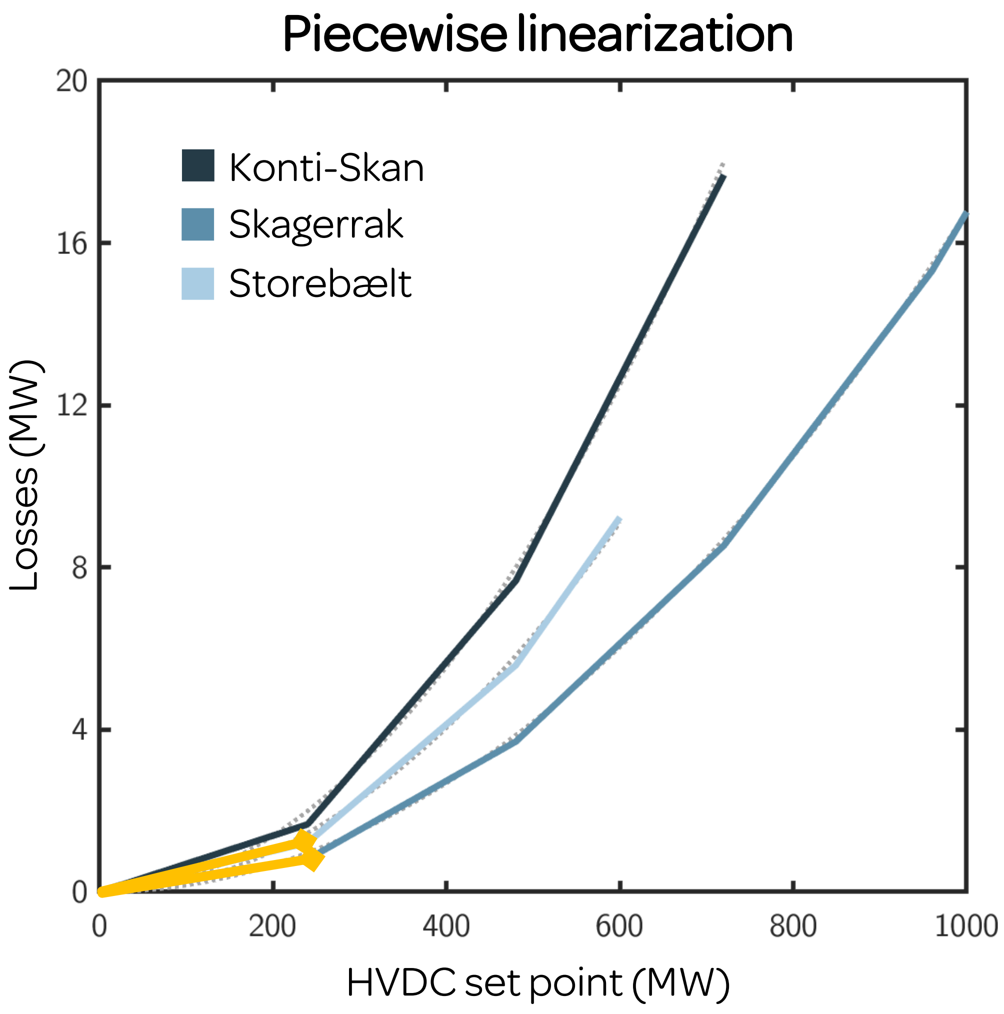

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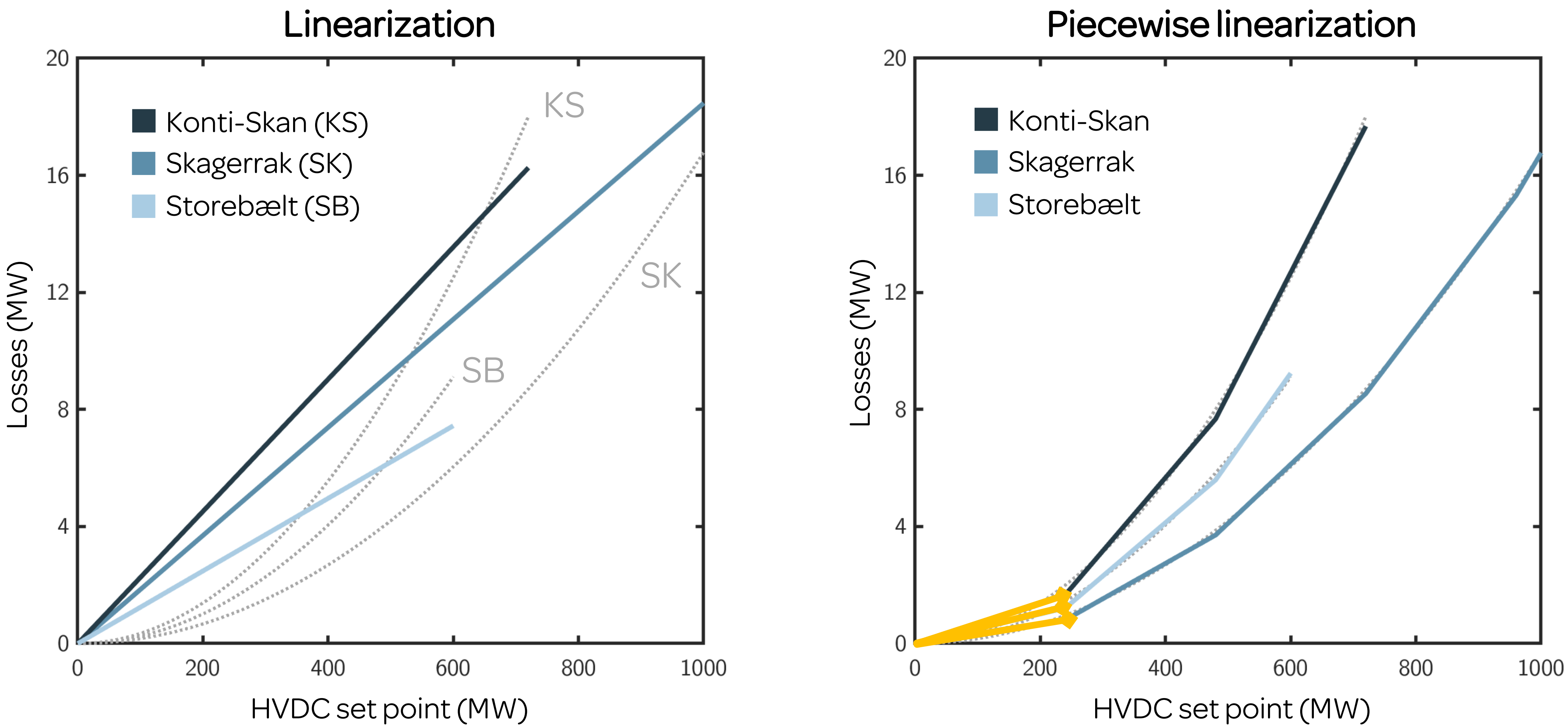

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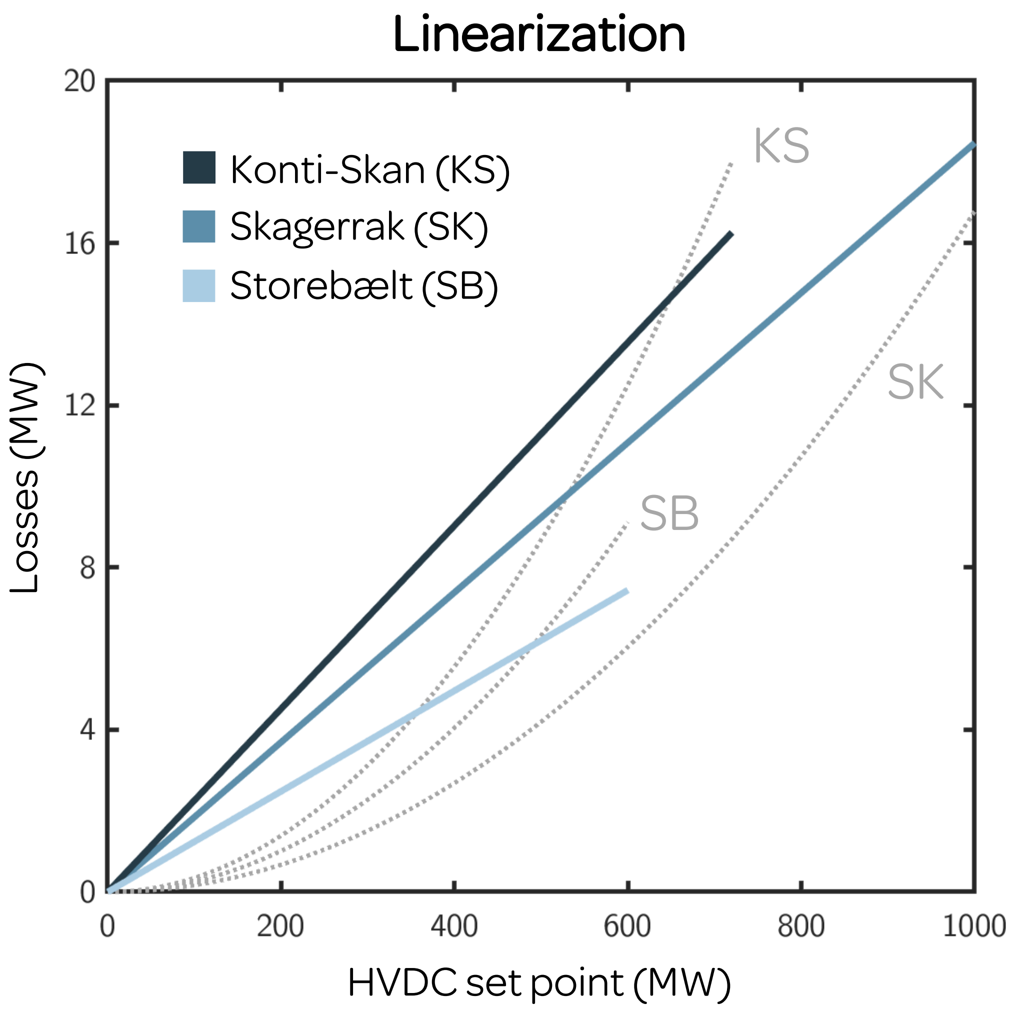

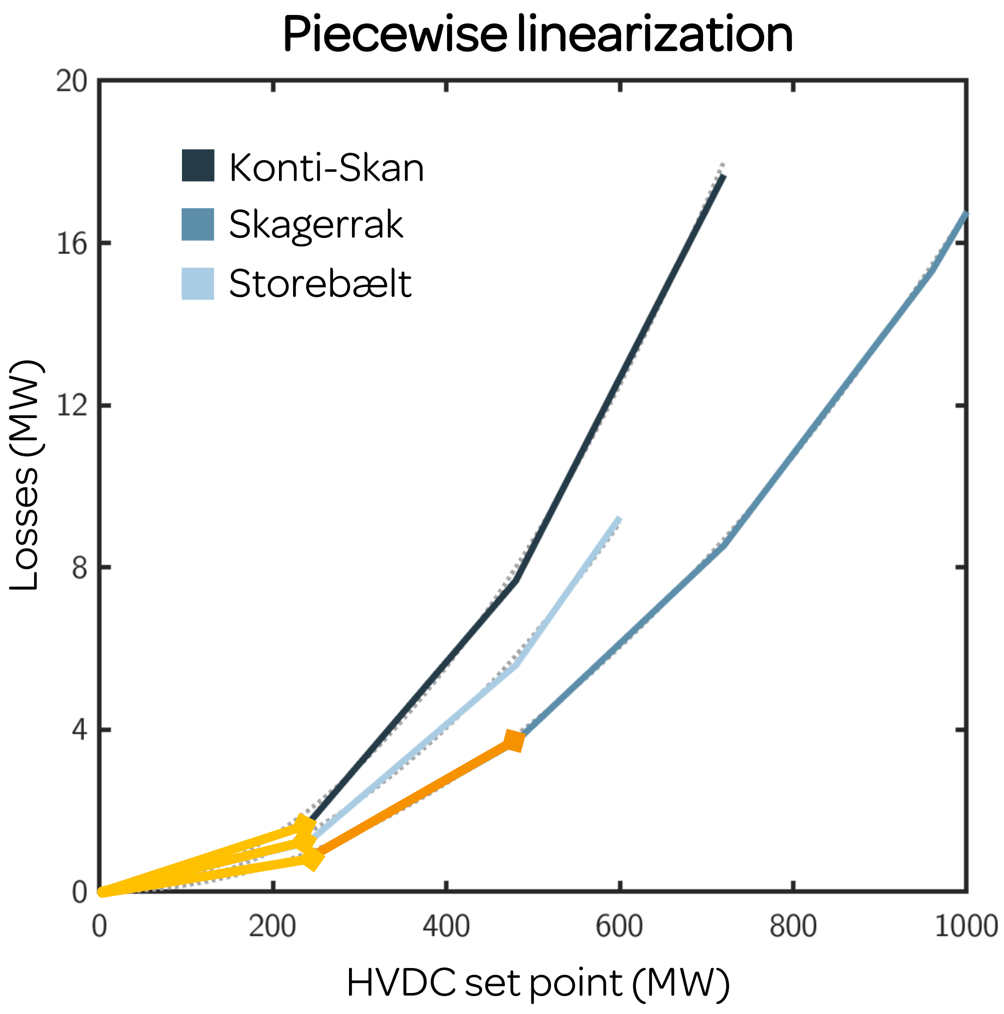

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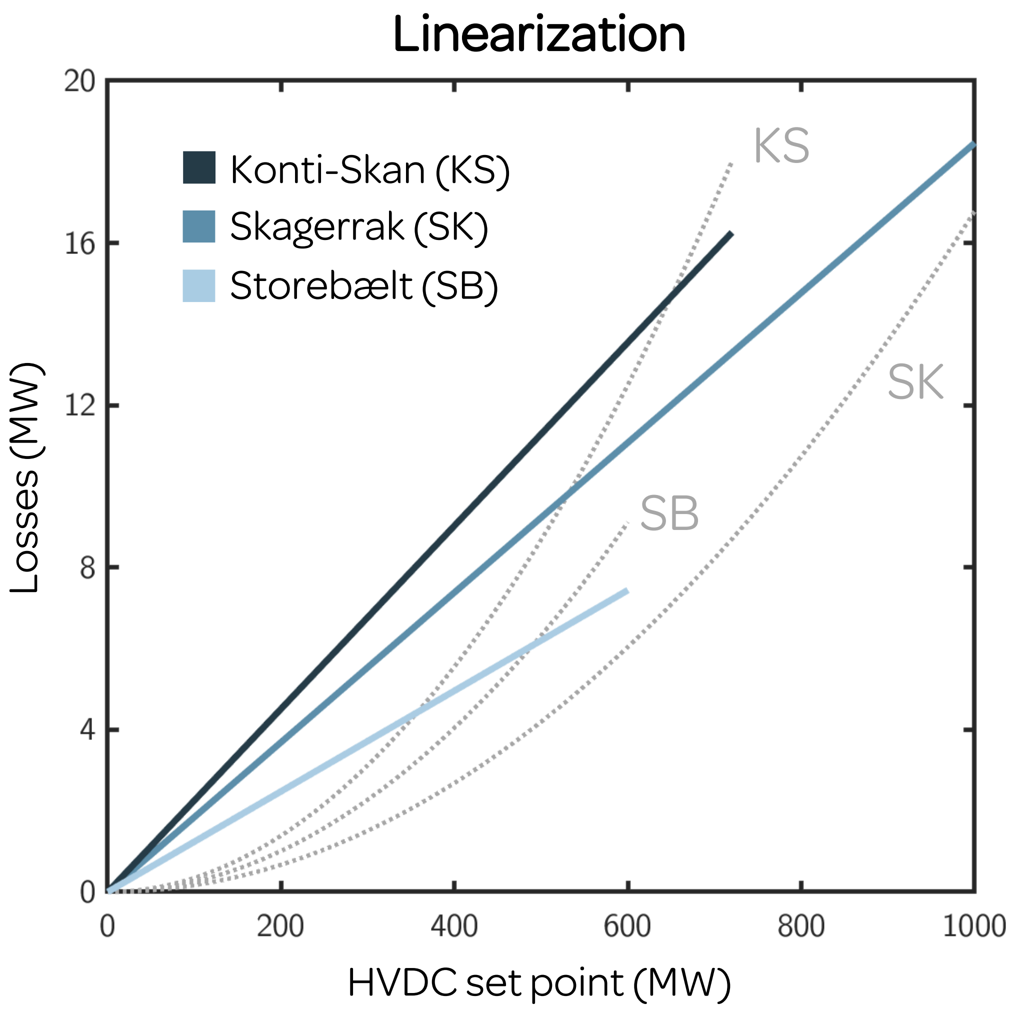

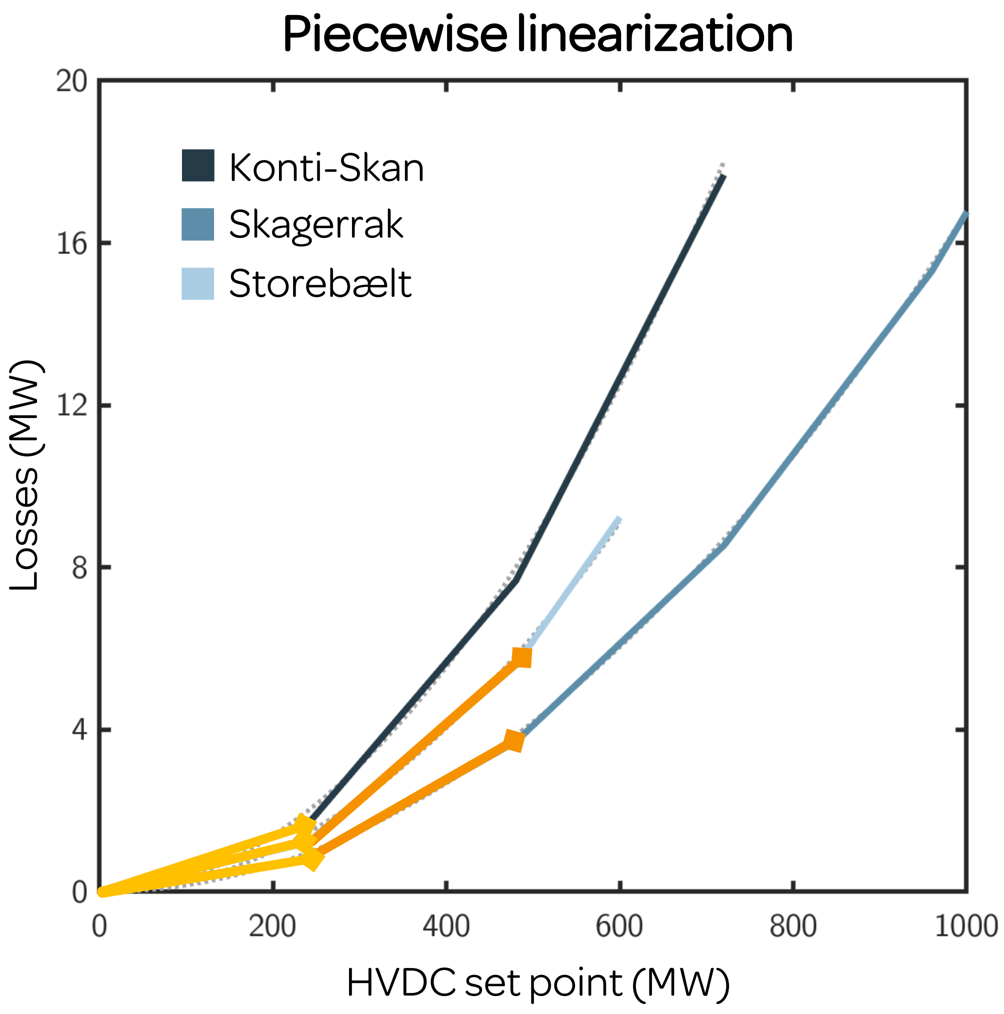

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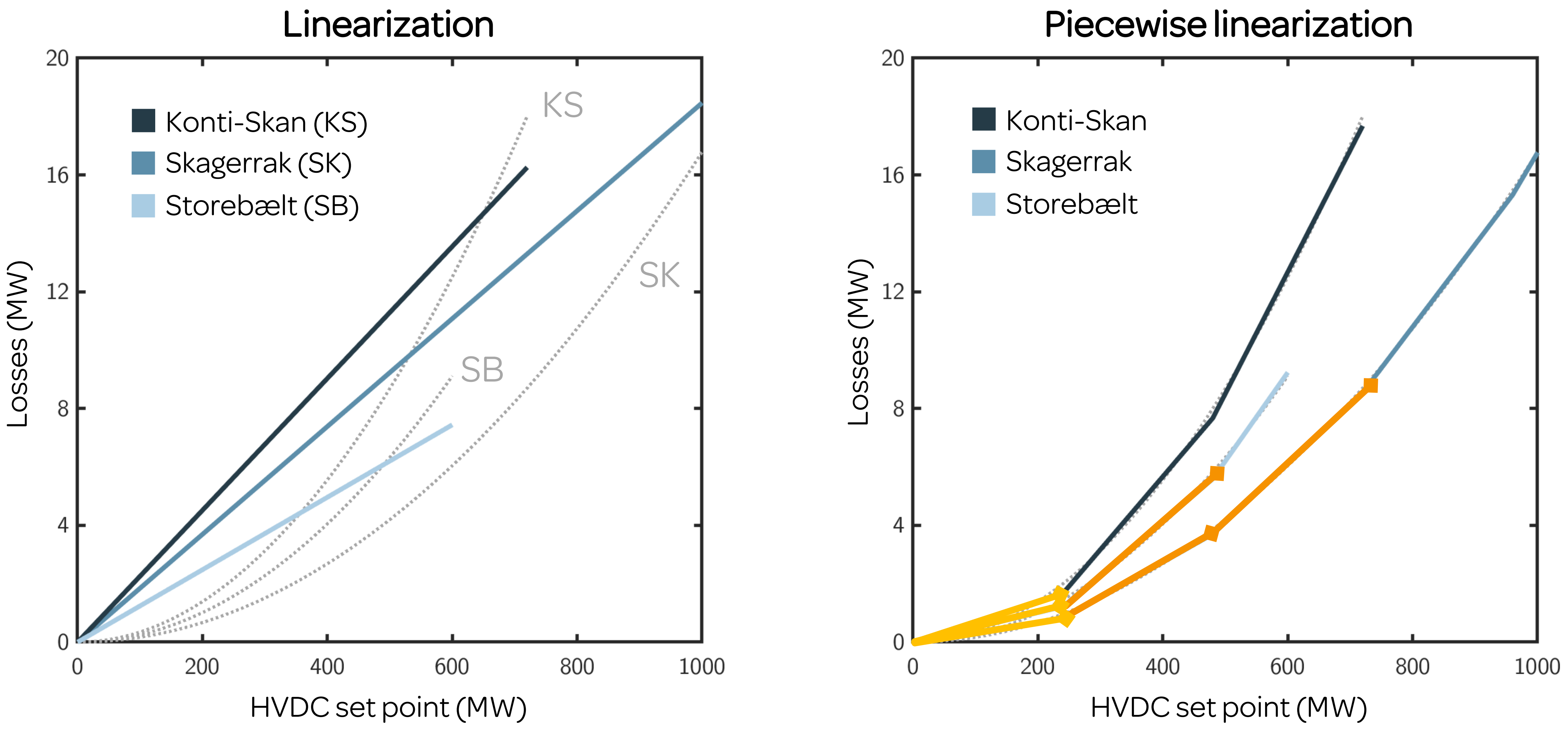

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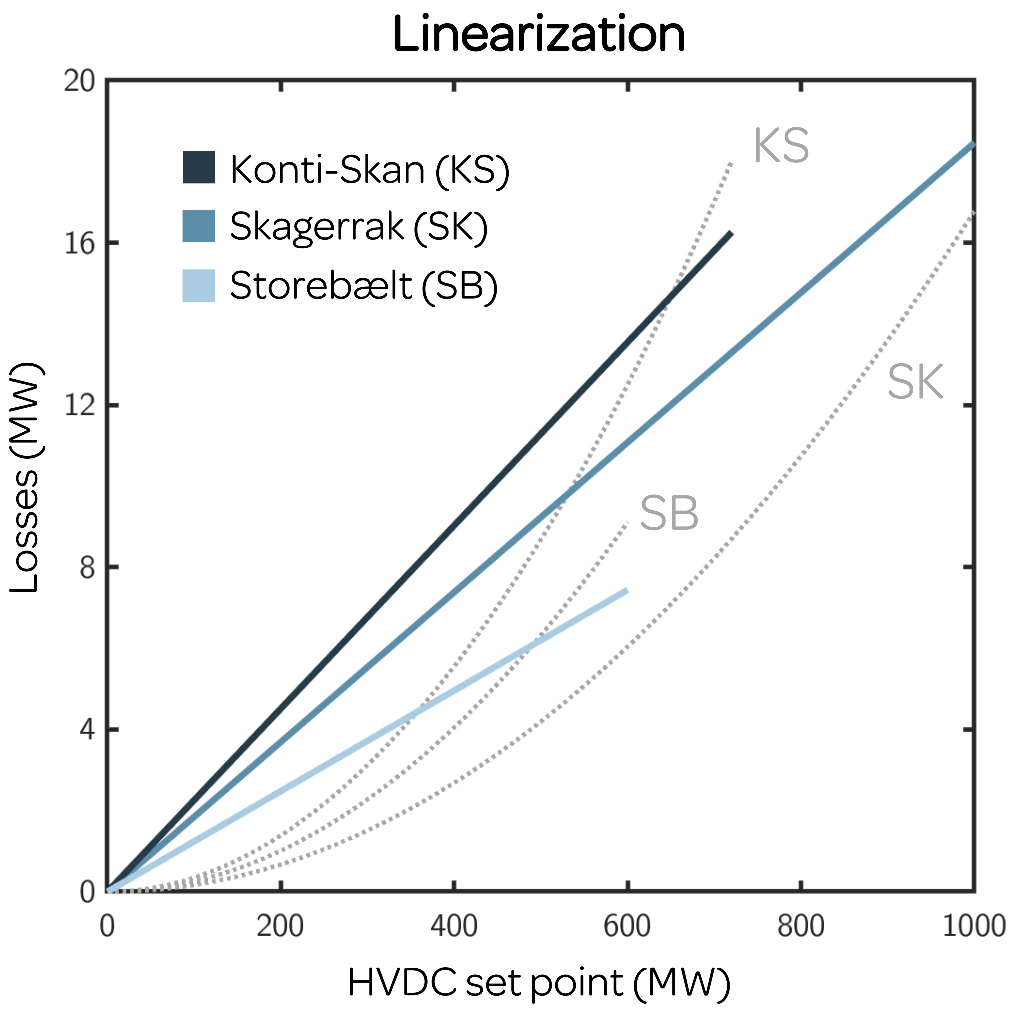

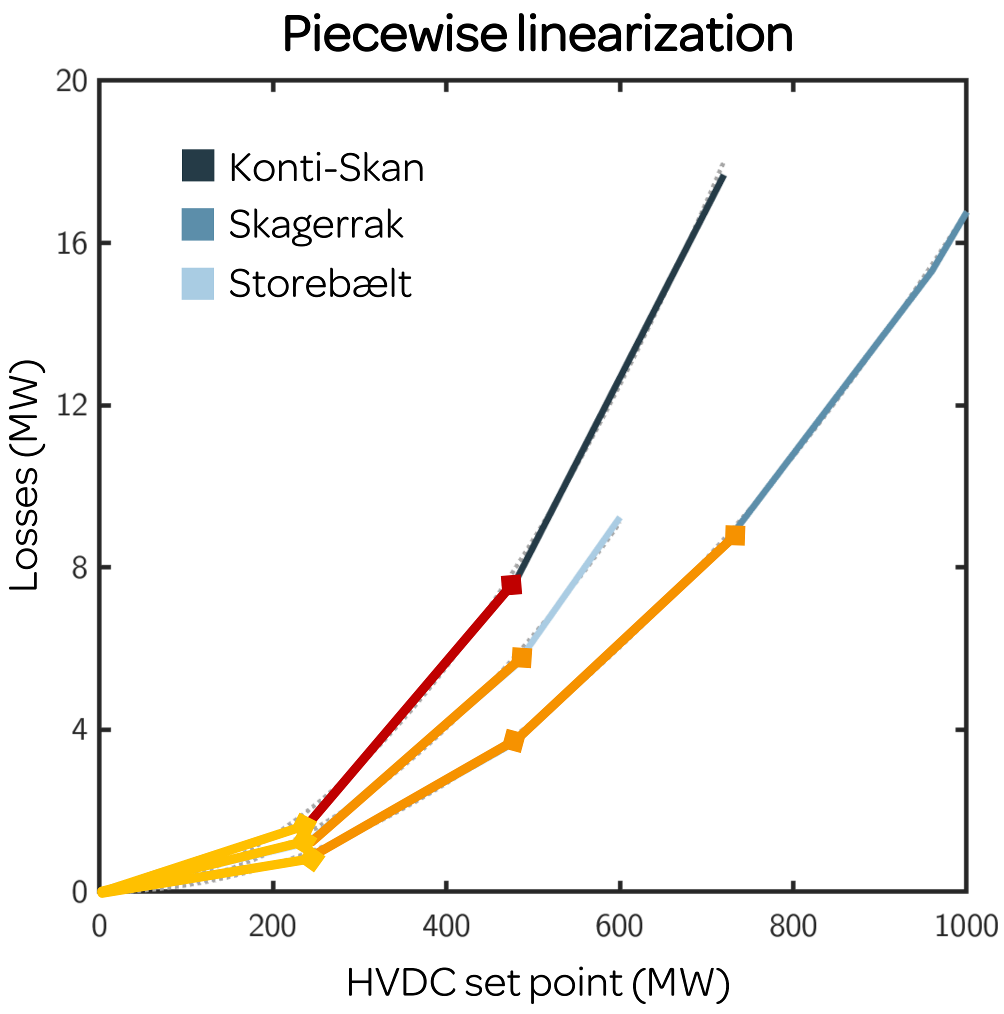

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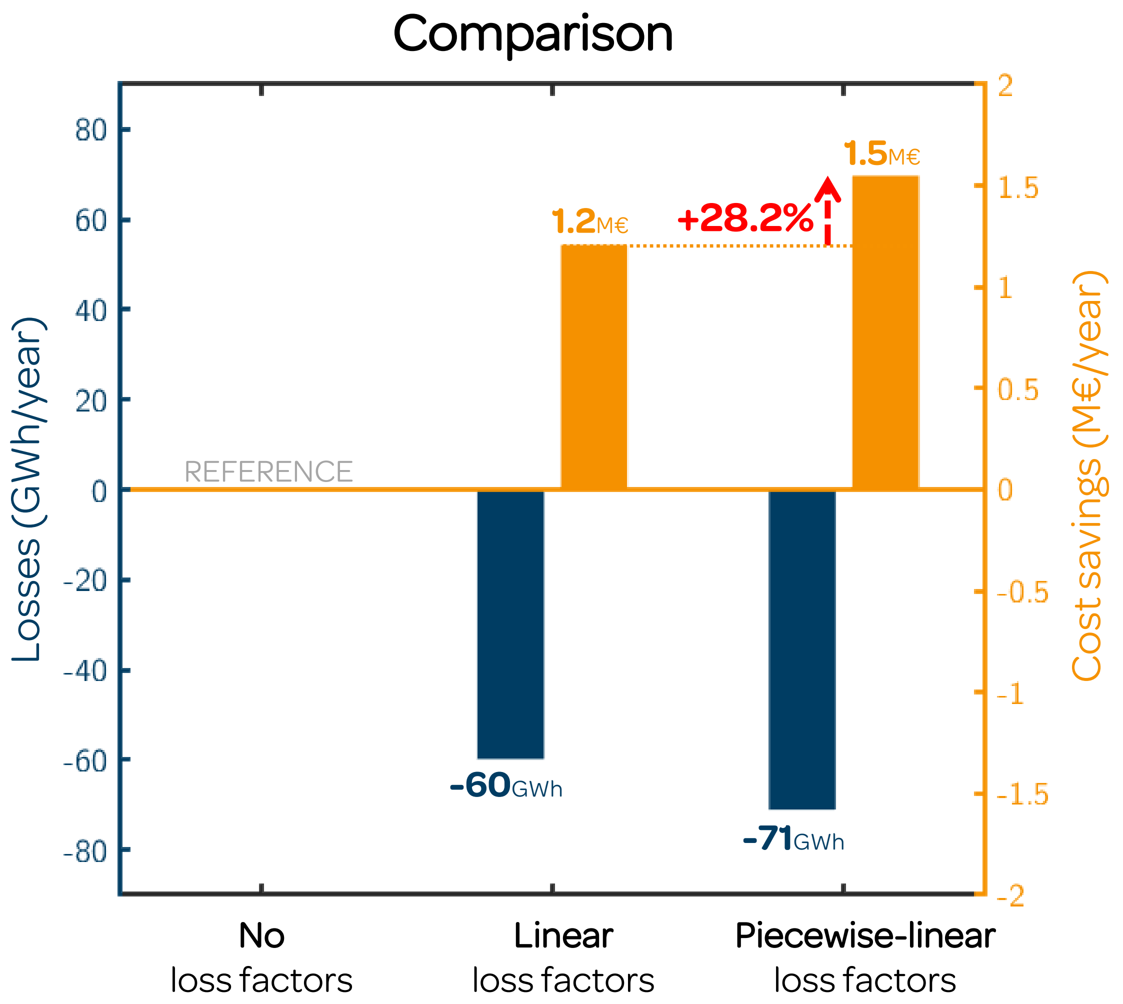
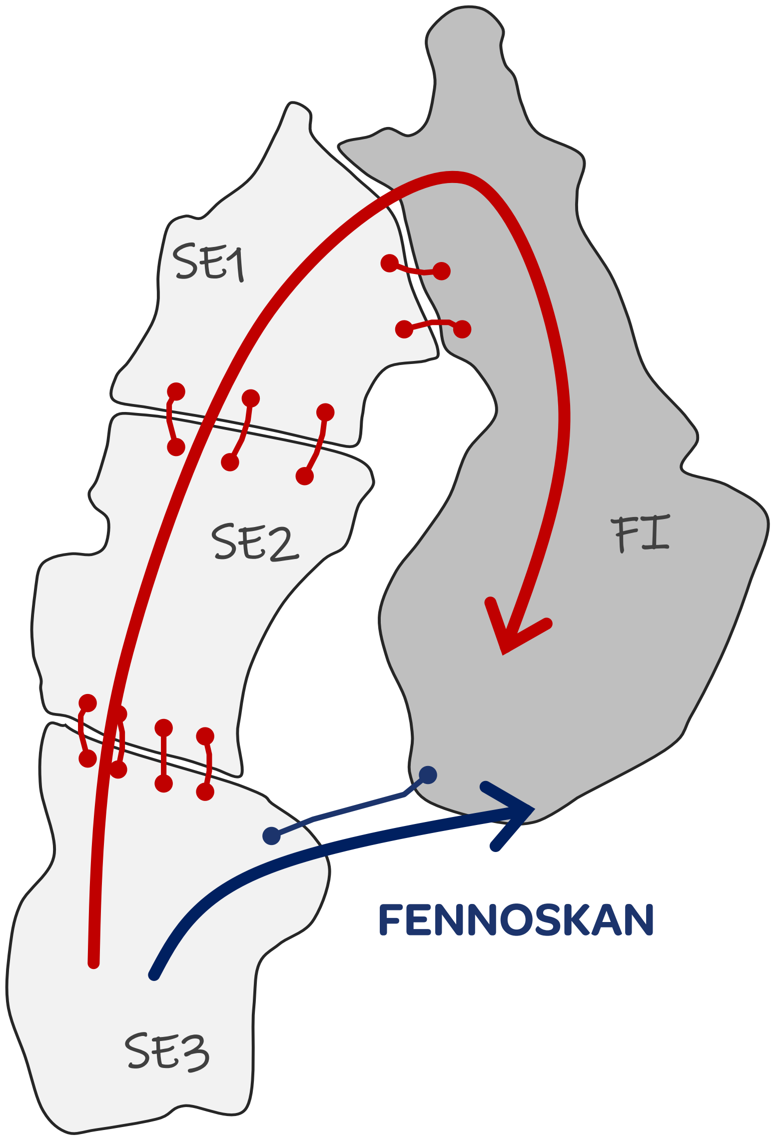
Linear vs. Piecewise-linear

- Piecewise-linear loss factors **better distribute the flows** over HVDC lines and losses are further decreased.
- Better **representation** of loss functions:
  - No under/over estimation of losses;
  - No discrimination in case of **merchant** lines.
- Cost savings increase by ~**30%**.
- **Recommendation**: use **piecewise-linear** loss factors.



HVDC vs. AC+HVDC

- If introduced on only HVDC interconnectors, loss factors can **unfairly penalize** HVDC lines.
- What happens if there are parallel **AC paths**?
  - This is the case of Fennoskan.
- The solver will see the AC corridor as "**less costly**" and will reroute all the power through those lines.



HVDC vs. AC+HVDC (linear loss factors)

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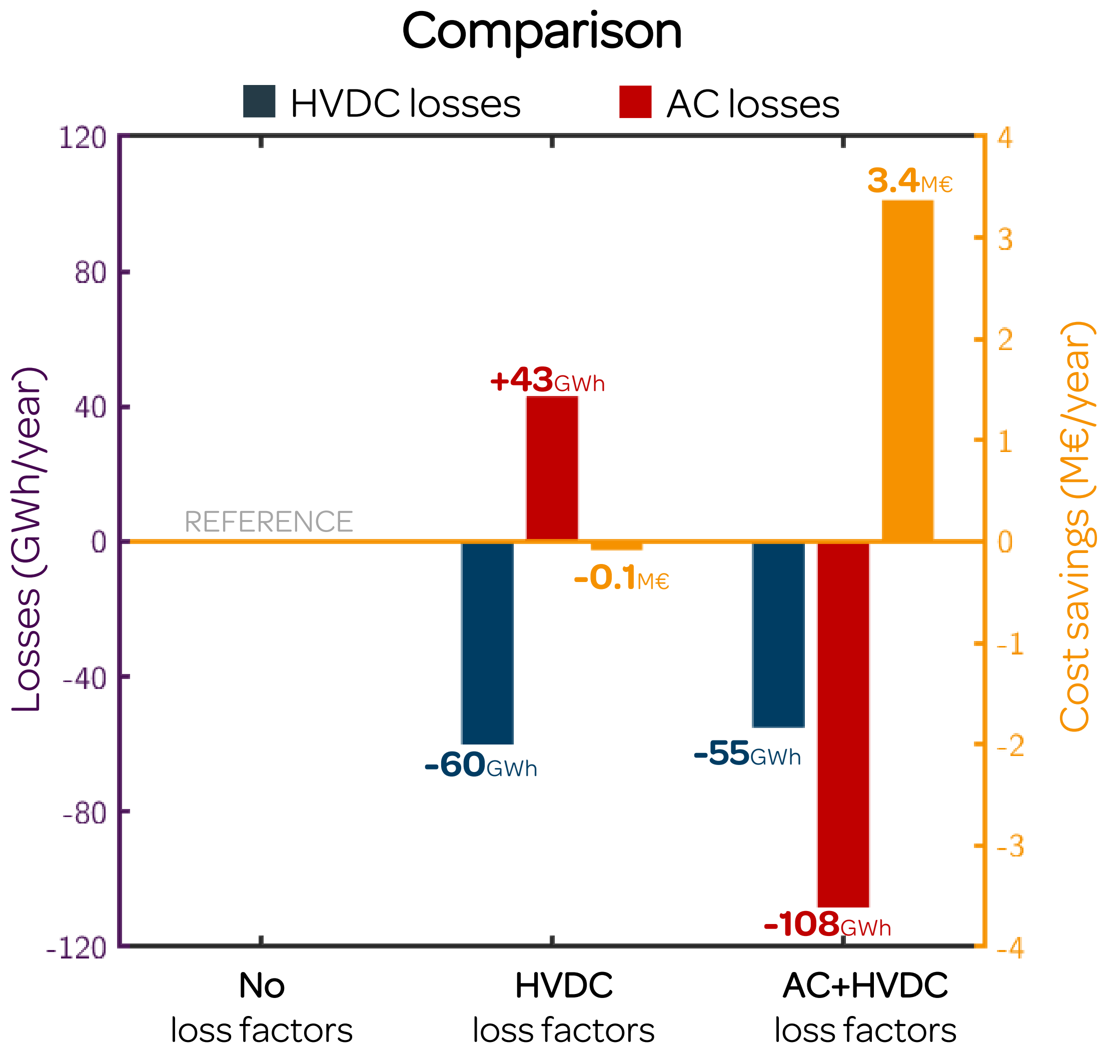
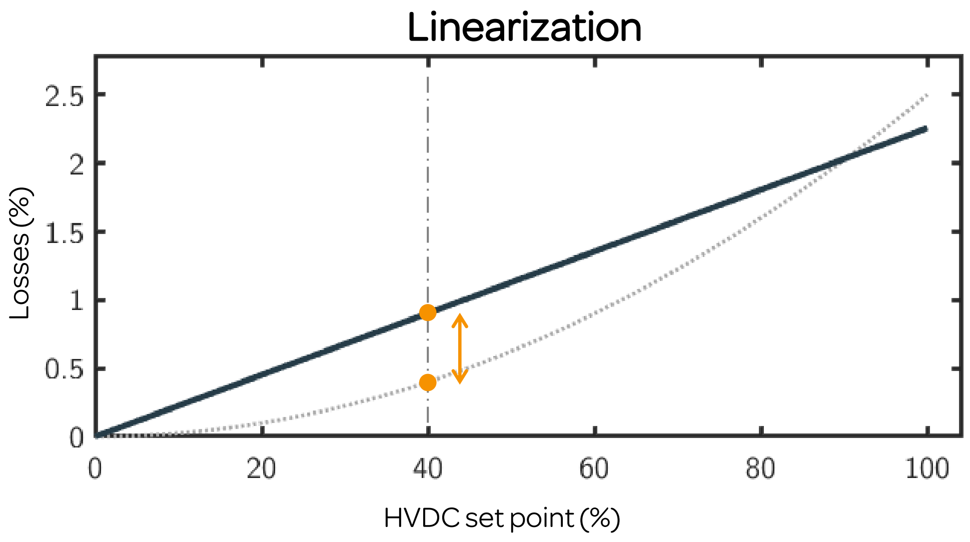
- If we consider losses on AC interconnectors, HVDC loss factors are no longer effective.
- With both AC and HVDC loss factors, the total losses are **minimized** (**-7.4%**).
- Substantial **cost savings** can be achieved.

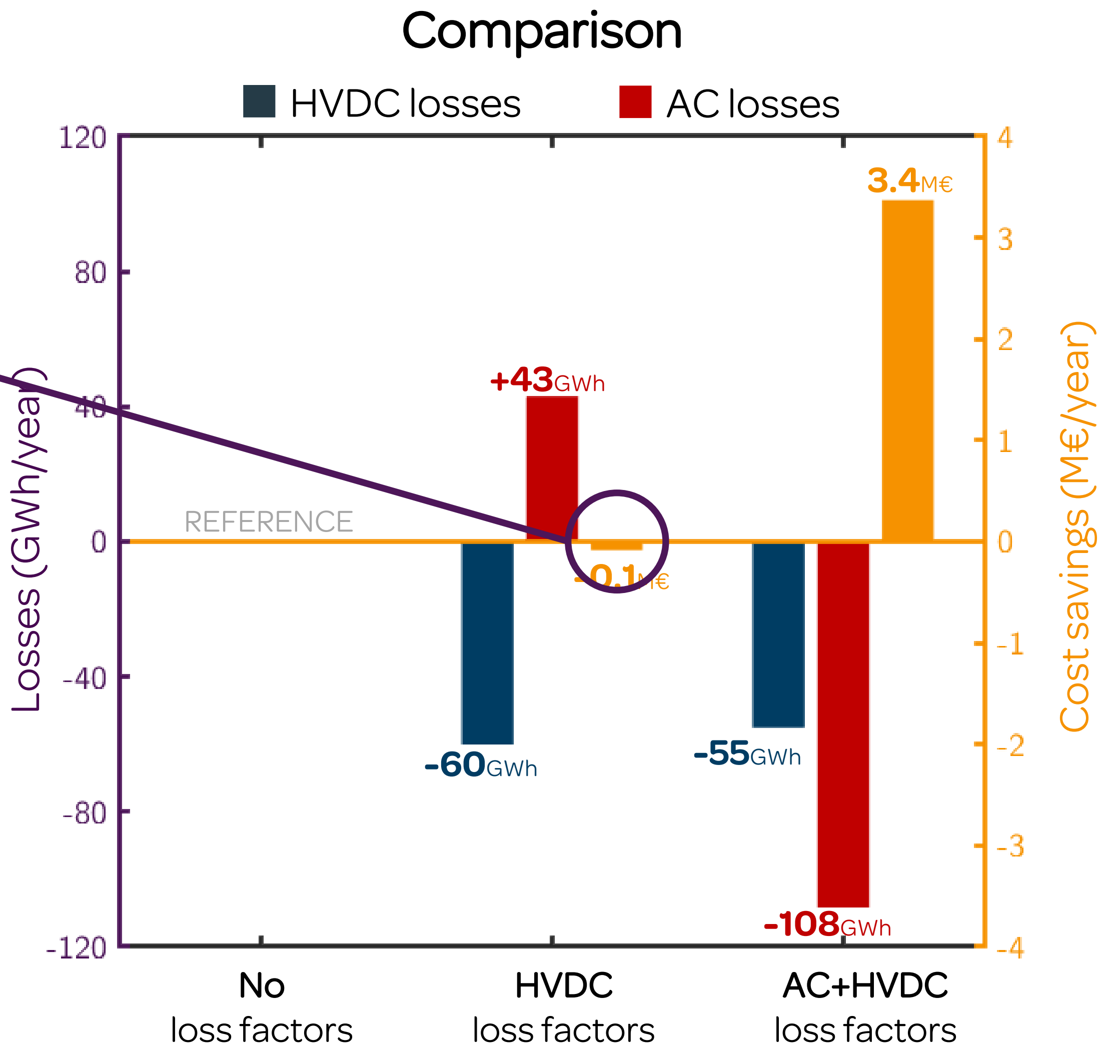


HVDC vs. AC+HVDC (linear loss factors)



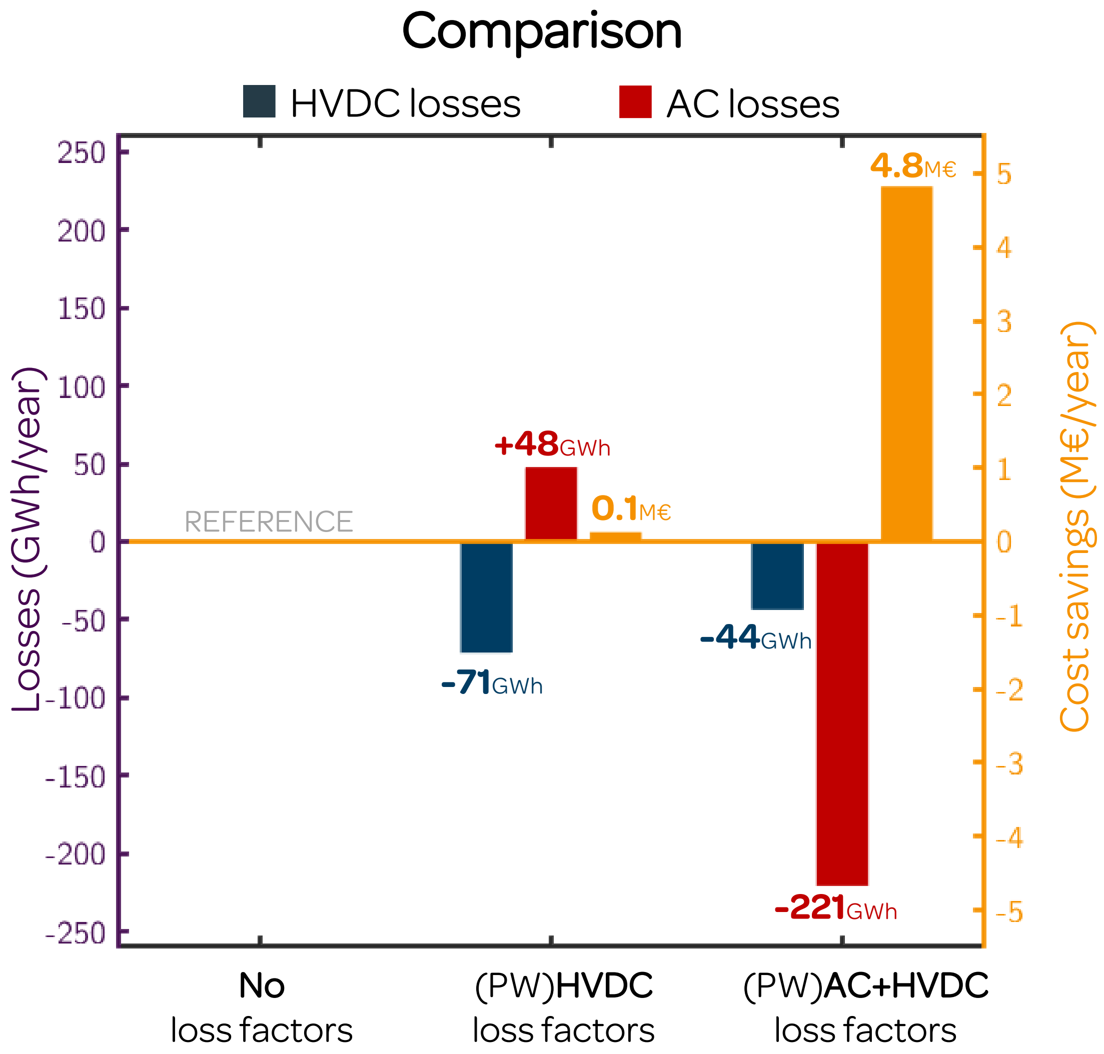
- The utilization of linear loss factors leads to an overestimation of losses.

Extra power = **extra costs**



HVDC vs. AC+HVDC (piecewise-linear loss factors)

- With piecewise-linear loss factors loss functions are **better represented**.
- Only the **necessary power** is purchased in the market.
- With both AC and HVDC piecewise loss factors, the total losses are **minimized** (**-12.1%**), resulting in cost savings of **4.8 million** Euros.



HVDC vs. AC+HVDC (piecewise-linear loss factors)

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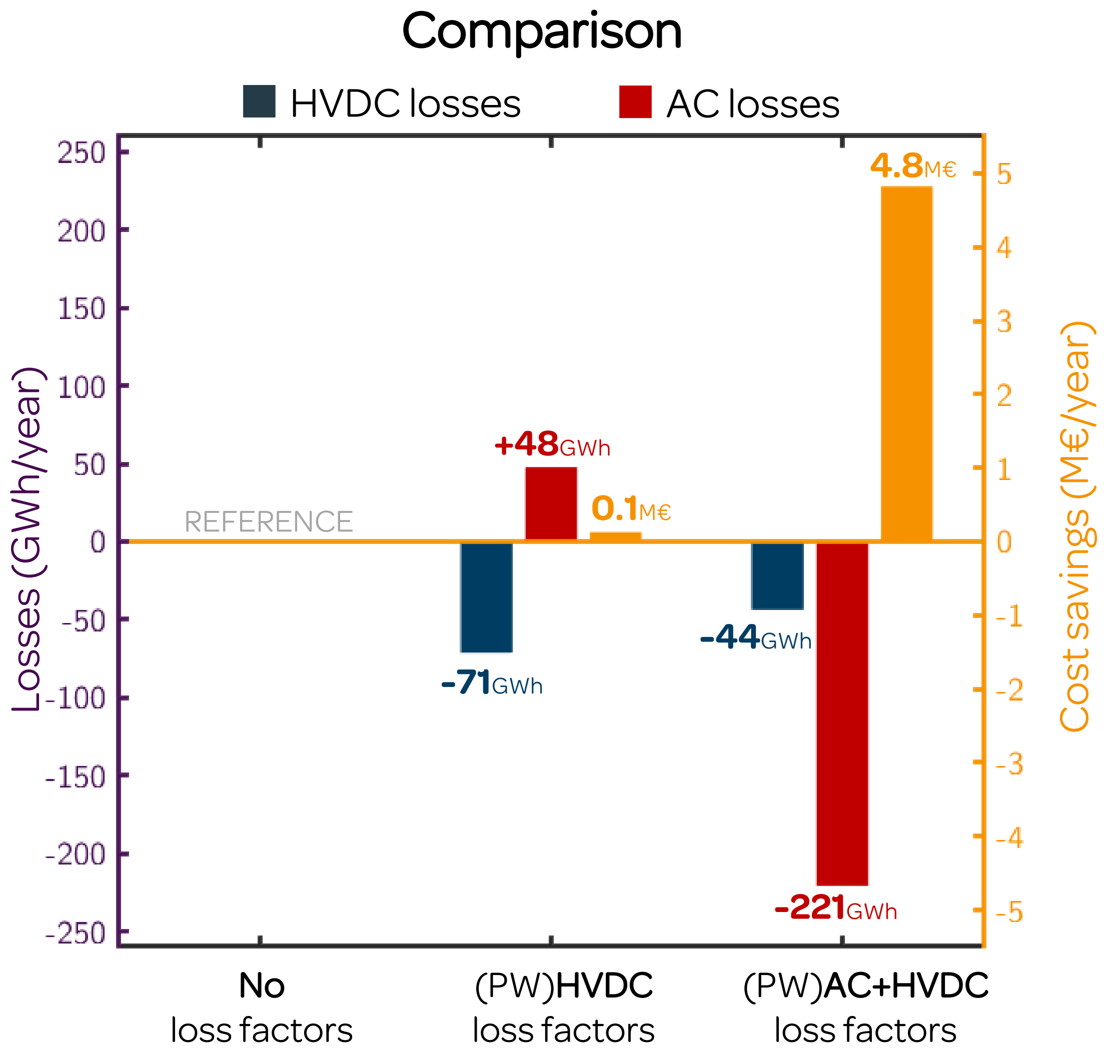
- With piecewise-linear loss factors loss functions are **better represented**.
- Only the **necessary power** is purchased in the market.
- With both AC and HVDC piecewise loss factors, the total losses are **minimized** (**-12.1%**), resulting in cost savings of **4.8 million** Euros.
- **Recommendation**: introduce loss factors for **AC interconnectors** as well.



Main takeaways

1. Piecewise linear loss factors **better represent** the quadratic loss functions and allow for a **better distribution** of power flows.
2. Losses are **minimized** only if both AC and HVDC loss factors are introduced.
3. Internalizing losses results is cost savings for **TSOs** and for the **society**.

Thank you for the attention!

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