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Loss minimization in AC export cables

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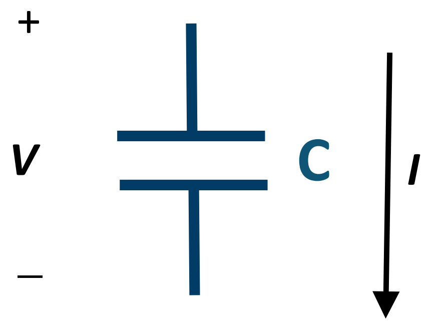
Cable electrical losses

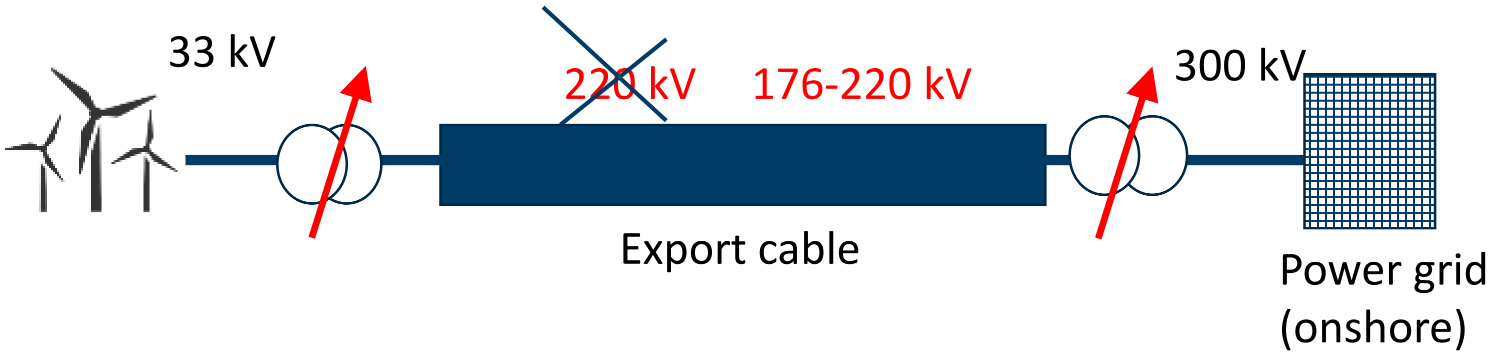
- The electric power is usually transferred to shore using an AC export cable
- The use of AC voltage (50/60 Hz) causes capacitive charging currents to flow along the cable.
- Charging current gives additional losses in the cable.
- Additional losses become dominating in the case of very long cables
- Nowitech activity:
  Simple operating scheme which reduces the cable losses



$$I(\omega) = j\omega C \cdot V(\omega)$$

Proposed scheme for loss reduction

- Vary the operating voltage ***V*** as function of the wind farm power production, ***P*** (MW)
  - High ***P*** → High ***V***
  - Low ***P*** → Low ***V***
- Voltage control achieved using existing transformers at cable ends



Optimization problem

- The cable has two "types" of losses:
  - ***Charging current losses:*** ***-increase with increasing voltage***
  - ***Transmission losses:*** ***-decrease with increasing voltage***
    -increase with increasing wind farm production

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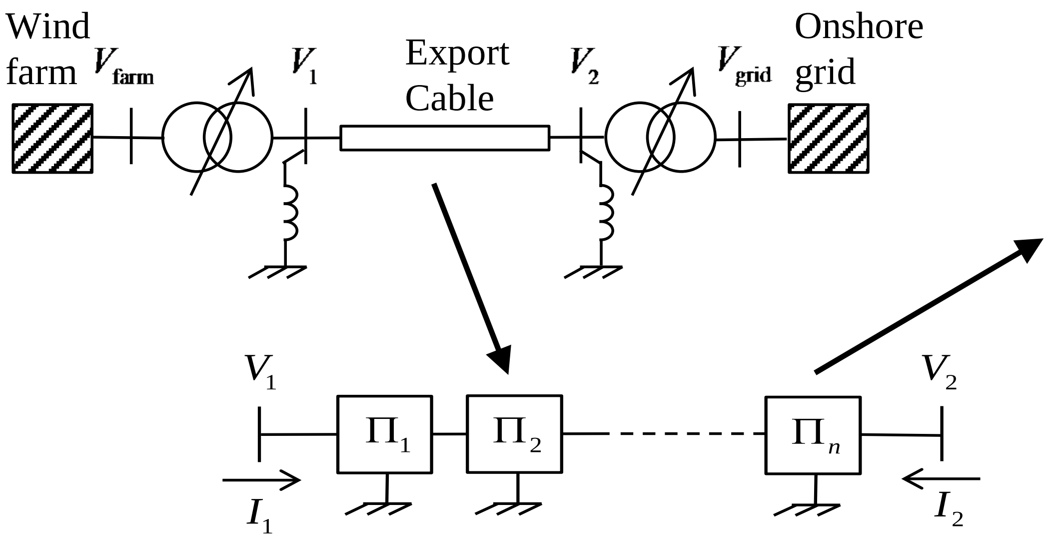
- For each level of power production in the farm there exists an "optimal voltage" which minimizes total losses

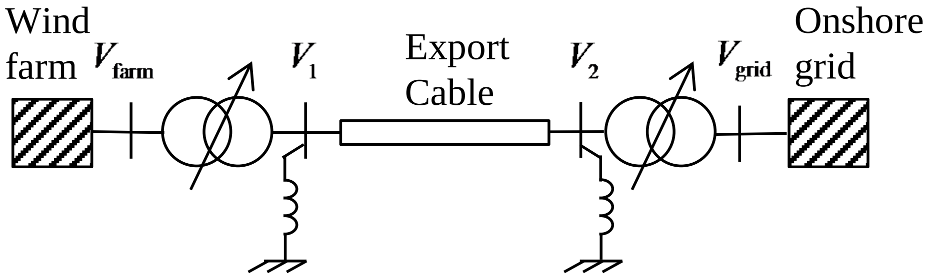
Solving the optimization problem

- Mathematical model of cable
  - ***Standard cable parameters (R, L, C)***
  - ***Distributed parameter effects***



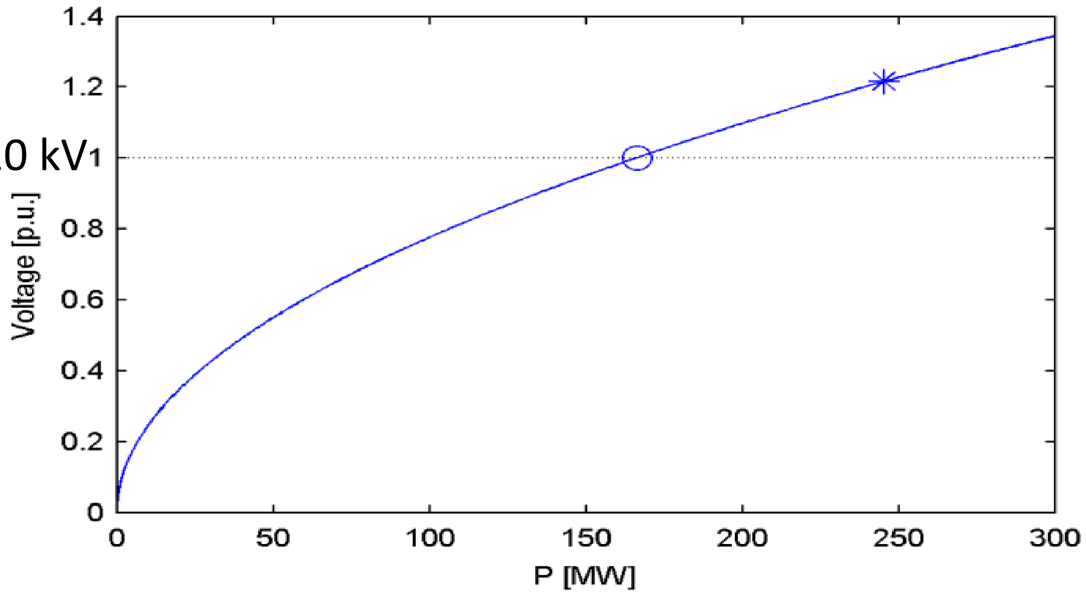
$$\mathbf{Y}_{\Pi} = \begin{bmatrix} \frac{\coth(\gamma l)}{Z_C} & \frac{-1}{Z_C \sinh(\gamma l)} \\ \frac{-1}{Z_C \sinh(\gamma l)} & \frac{\coth(\gamma l)}{Z_C} \end{bmatrix}$$

Optimal voltage



"Optimal voltage" vs. wind farm production

220 kV



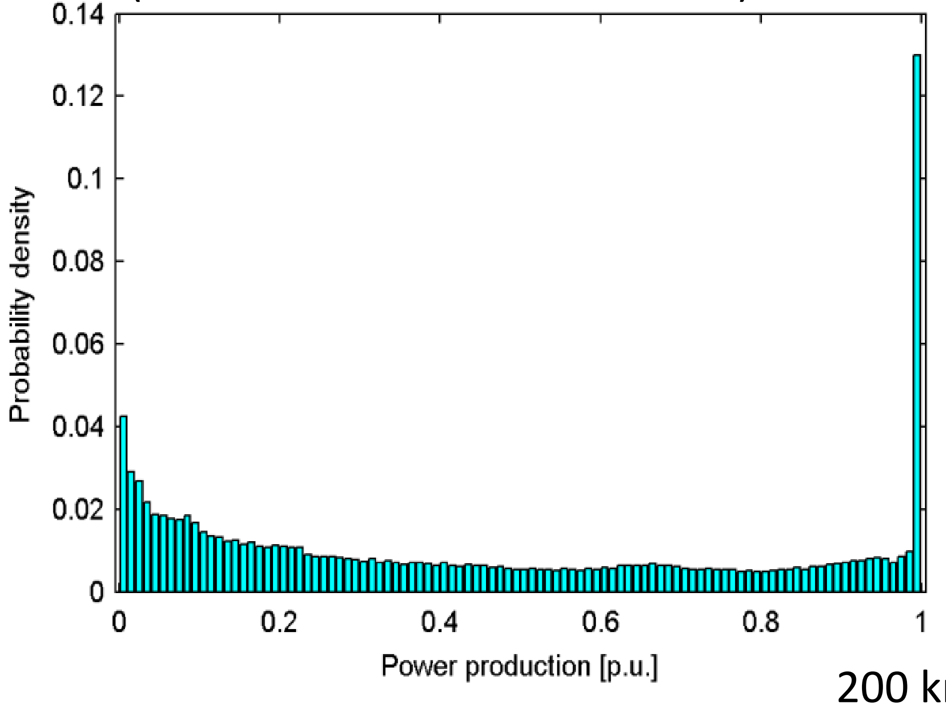
200 km cable
220 kV nominal voltage

Loss reduction

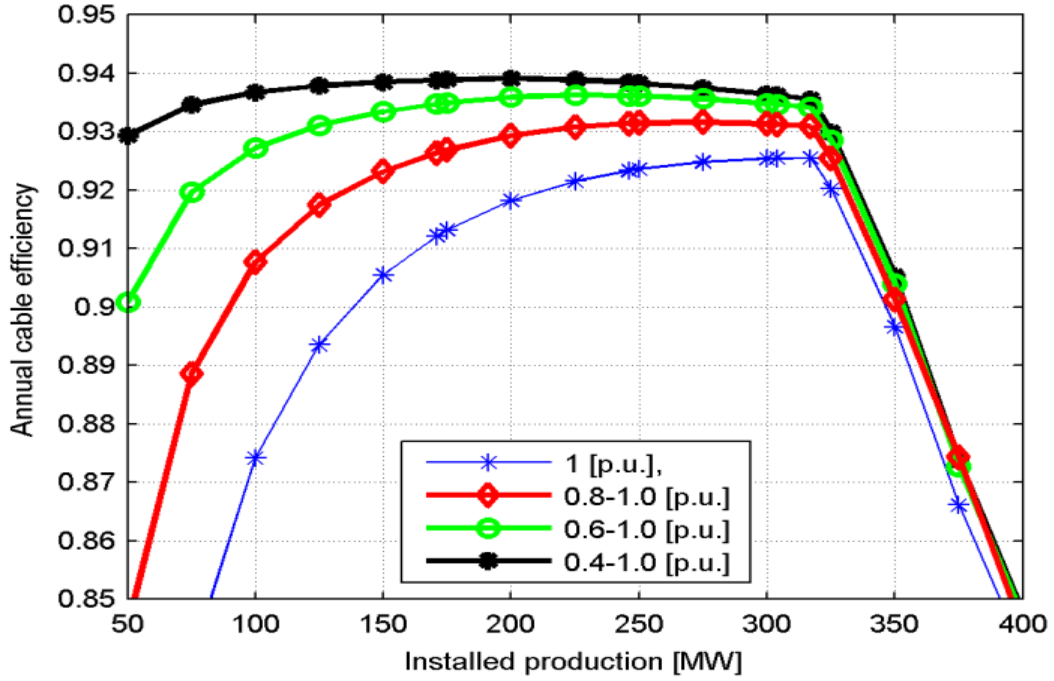
$$\eta_{\text{annual}} = \frac{\sum_{i=1}^{N} \Delta t_i P_{\text{grid},i}}{\sum_{i=1}^{N} \Delta t_i (P_{\text{farm},i} + P_{\text{curtail},i})}$$

Annual efficiency

Distribution of annual power production
(Nowitech reference wind farm)



Annual efficiency vs. Installed production



200 km cable
220 kV nominal voltage

High potential for value creation

Wind farm rating [MW]	Operation	Annual efficiency improvement	Percent reduction in annual losses
320	Variable voltage 0.4–1.0 p.u.	$0.925 \rightarrow 0.935$	13%
200	Variable voltage 0.4–1.0 p.u.	$0.92 \rightarrow 0.94$	25%

200 km cable
220 kV nominal voltage

- Implementation using well-proven technology
  - Voltage regulation by transformer on-line tap changers (OLTC)
  - Control using pre-calculated look-up tables (voltage vs. production)

Further reading

B. Gustavsen, O. Mo,
"Variable transmission voltage for loss minimization in long offshore wind farm AC export cables",
IEEE Trans. Power Delivery, vol. 32, no. 3, pp. 1937-4208, June 2017.