Minimizing Losses in Long AC Export Cables

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Background

- HVAC compared to HVDC cables have
    - less transfer capacity
    - significantly larger losses

- HVAC are however technically simple and well-proven and seems to still be considered as an attractive alternative

- A natural question to ask is then:

    Is it possible to improve efficiency of the export cable?

The simple motivation

- x % transmission loss

+ x % revenue

This presentation will show that

Long AC export cable annual efficiency can be increased by:

Operating the export cable with variable, optimized voltage

alternatively by:

Operating at a fixed, optimal voltage for a given cable based on the actual wind farm production profile

Example study of cable designed for 220kV

Nominal voltage	~~132 kV~~	**220 kV**	~~400 kV~~
Cable section [mm^2]	~~1000~~	**1000**	~~1200~~
R [Ω/km]	~~0.048~~	**0.048**	~~0.0455~~
L [mH/km]	~~0.34~~	**0.37**	~~0.39~~
C [µF/km]	~~0.23~~	**0.18**	~~0.18~~
Nominal current [A]	~~1055~~	**1055**	~~1200~~

Used for all calculations in this presentation

From: "Loss evaluation of HVAC and HVDC transmission
solutions for large offshore wind farms", N. Barberis Negra, J. Todorovic, T. Ackermann

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The loss calculation
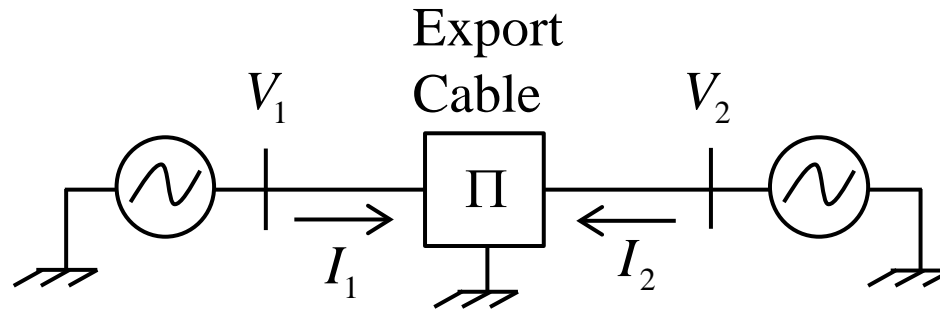
- Cable represented by exact PI-equivalent
  - 50Hz losses can be accurately determined if parameters are known
  - Parameter and temperature uncertainty is the challenge

- Takes into account:
  - Distributed parameter effects
  - Current and voltage variation along the cable

- Losses in other components is ignored in the work presented here

Cable efficiency as function of wind park active power production (200km).
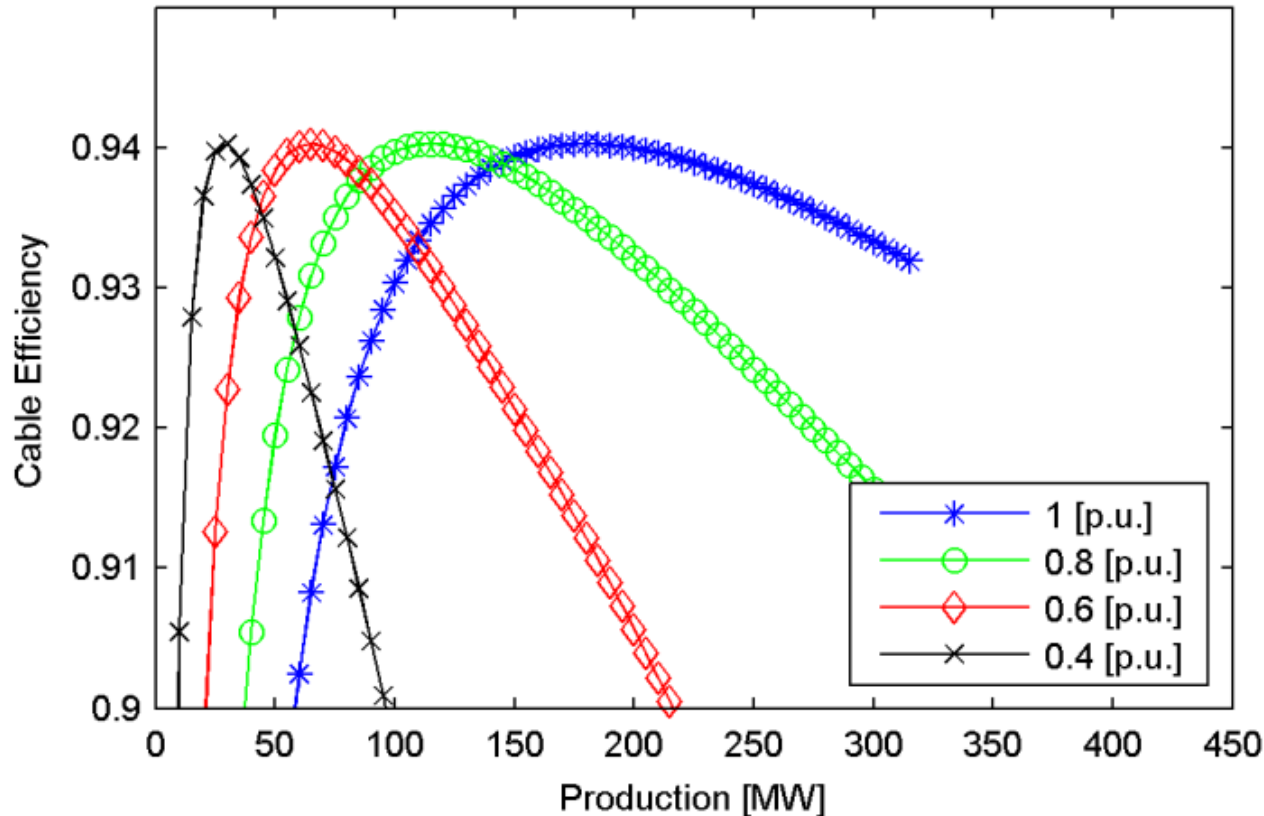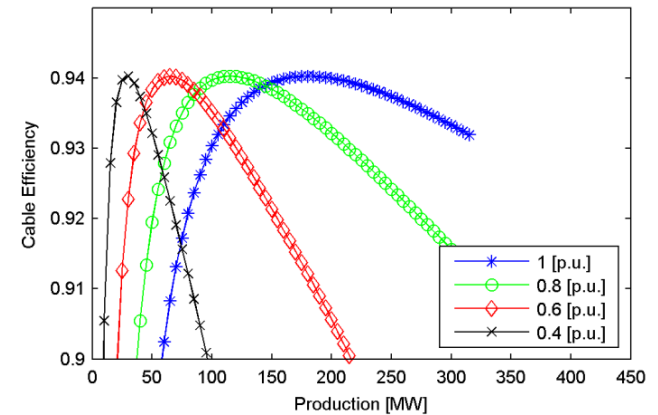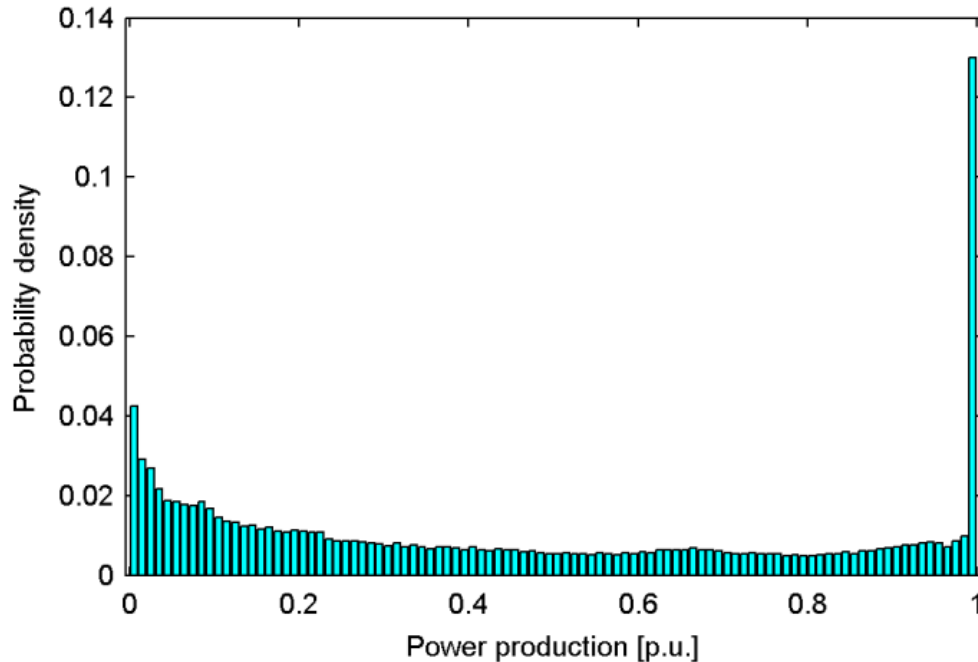

(Note: Constant production assumed here)

The important observation:

Efficiency does not necessarily improve with increasing voltage <u>at long distances</u>

The optimum depends on the production !

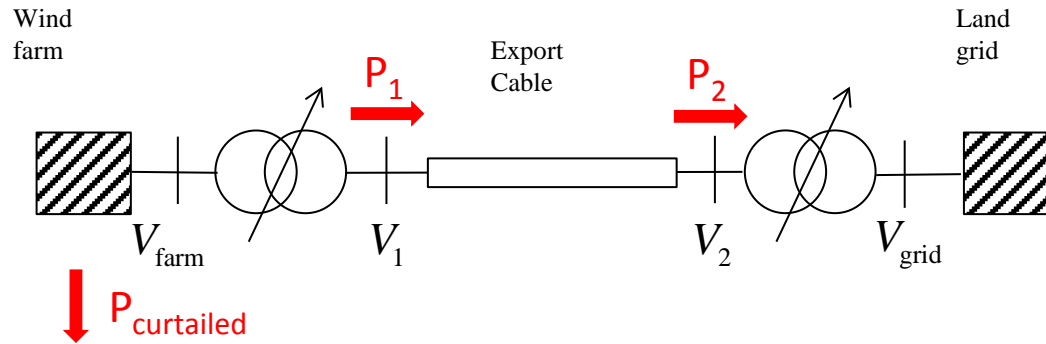**200km** 220 kV cable, 1000mm2

Wind farm production variability (example)

Representative for NOWITECH reference wind farm at Doggerbank.
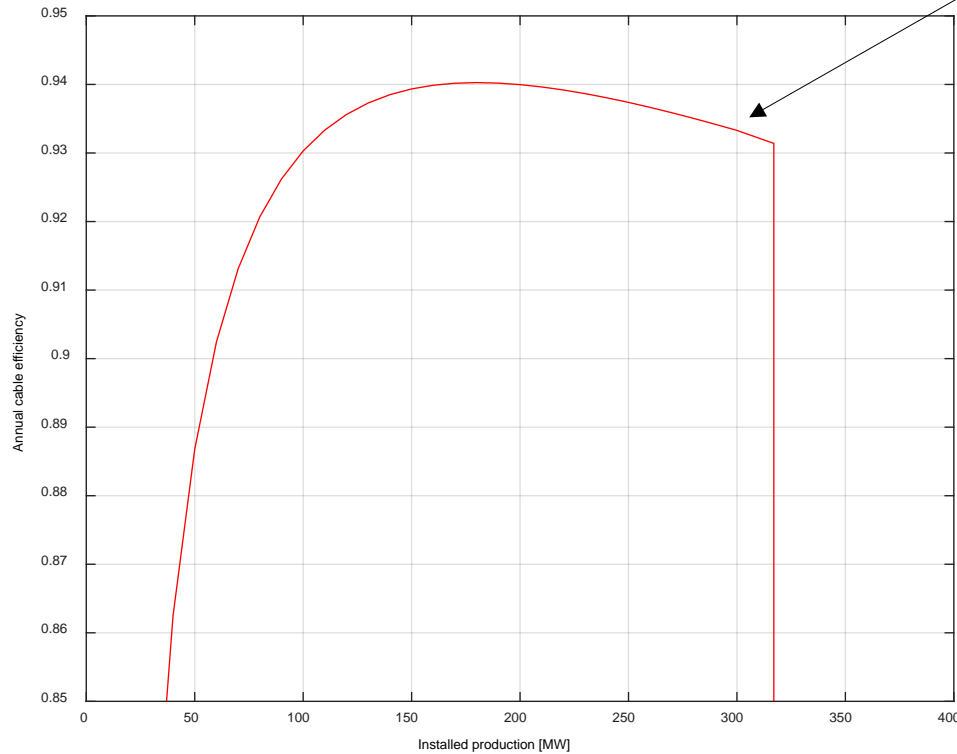Average wind speed 9.4 m/s
Utilization factor is 46.

Annual cable efficiency

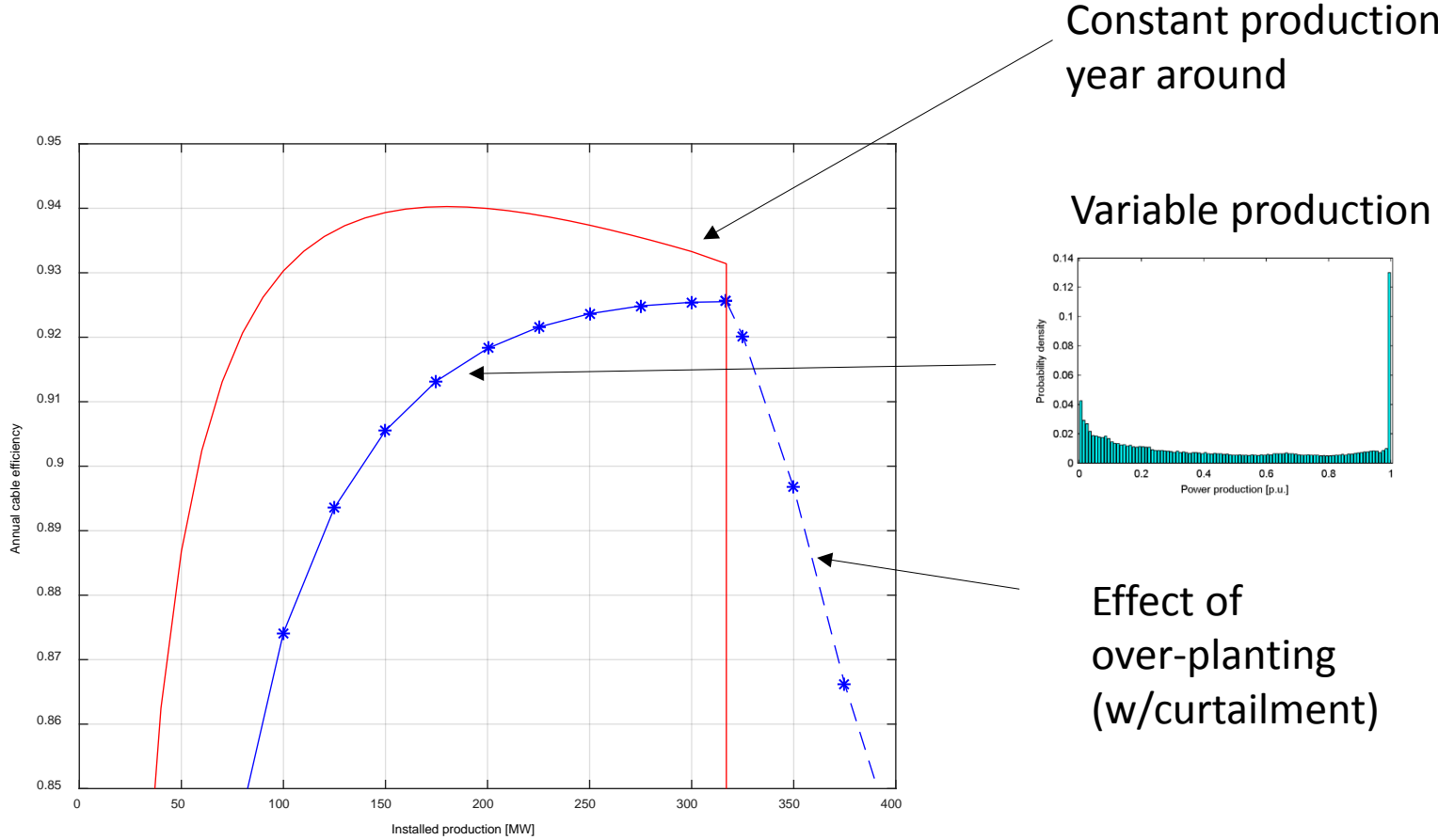$$\eta_{annual} = \frac{\int P_2 \, dt}{\int (P_1 + P_{curtailed}) dt}$$

Efficiency for **constant** production

Constant production year around

200km 220 kV cable, 1000mm2

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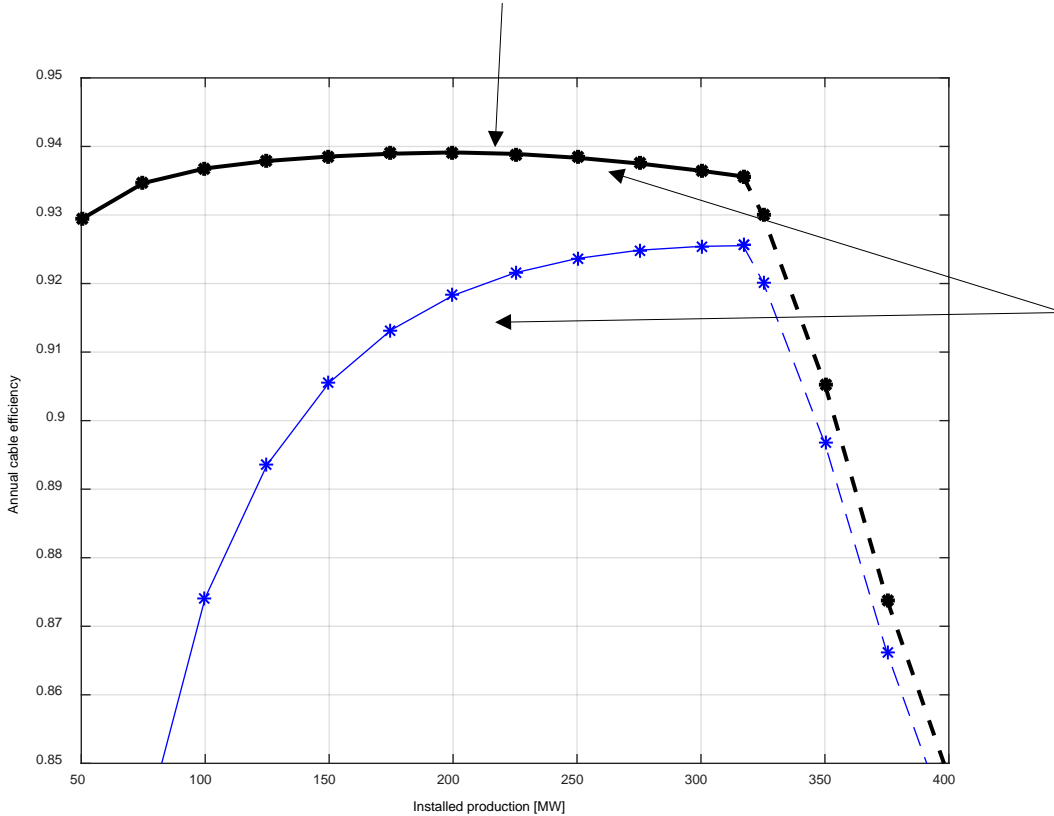# Annual efficieny for realistic production variability

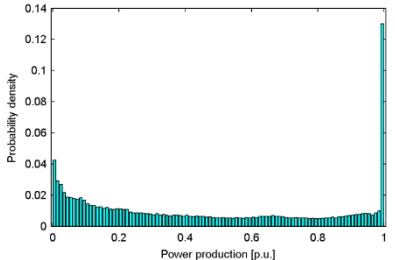Constant production year around

Variable production

Effect of over-planting (w/curtailment)

Annual efficiency as function of **installed** production
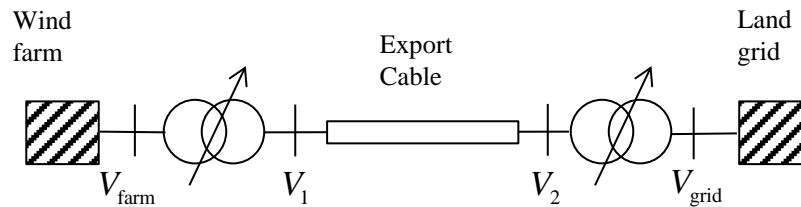

Will now show how to get to this level

Variable production

200km 220 kV cable, 1000mm2

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Hypothesis:

- Total losses over one year of operation can be reduced by operating the cable at an optimal, **variable voltage**.

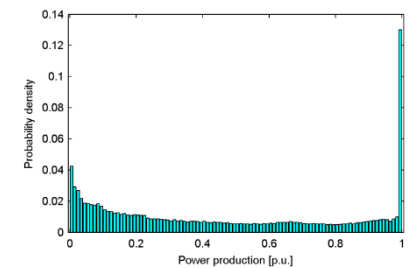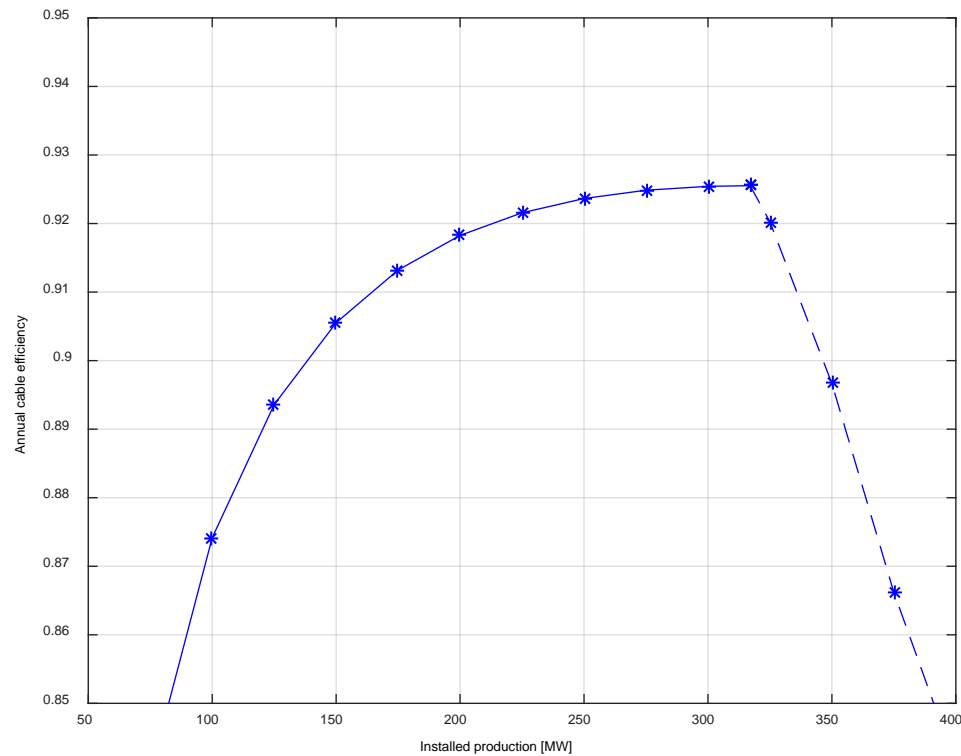Wind farm — V_{farm} — V_1 — Export Cable — V_2 — V_{grid} — Land grid

or, if you do not like the idea of tap-changer:

- Total losses over one year of operation can be reduced by operating the cable at a **fixed voltage** optimized for the given wind farm and the given power duration curve.
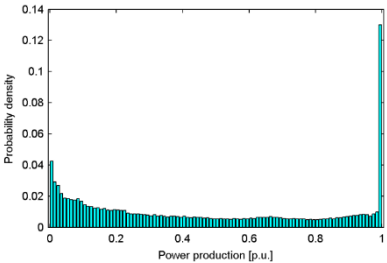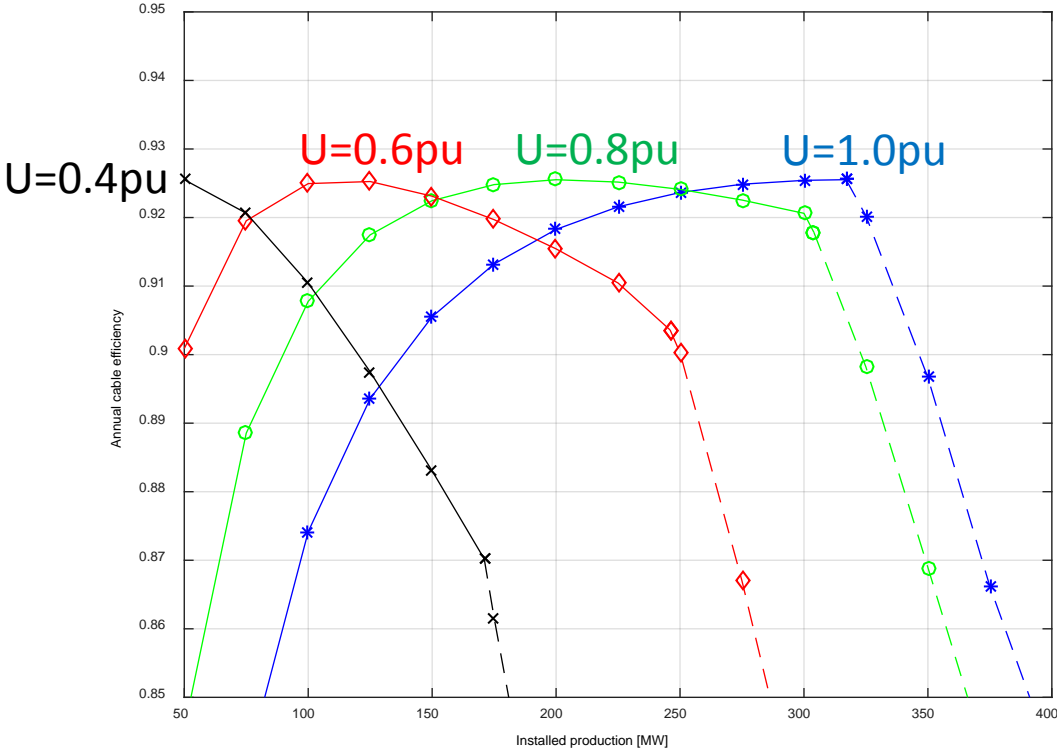
Wind farm — ? : ? — V_{farm} — V_1 — Export Cable — ? : ? — V_2 — V_{grid} — Land grid
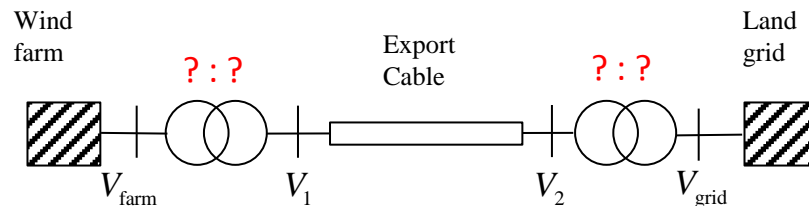
Annual efficiency as function of **installed** production
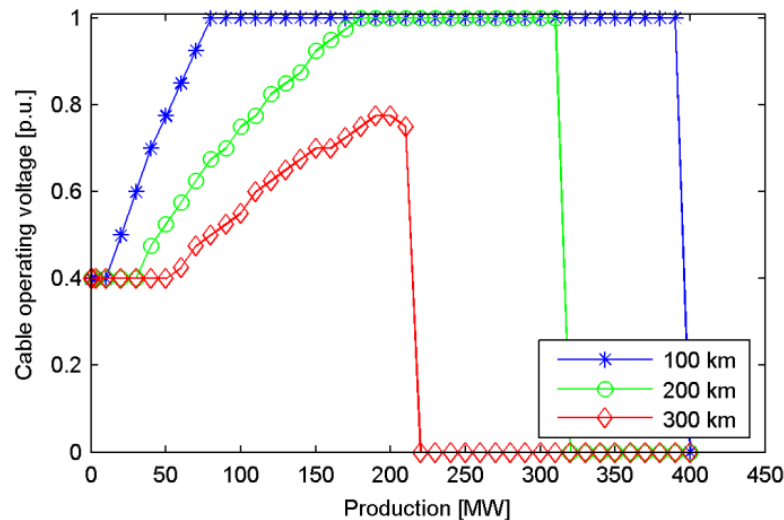

200km 220 kV cable, 1000mm2

Annual efficiency as function of **<u>installed</u>** production for different constant operating voltages

200km 220 kV cable, 1000mm2

Optimal voltage for maximum efficiency

- First step: Find optimal voltage as function of power transfer

- Next step: Find the annual efficiency when operating at a voltage continuously adapted to the variable wind power production (shown on next slide)

100km, 200km and 300km 220 kV cable, 1000mm2
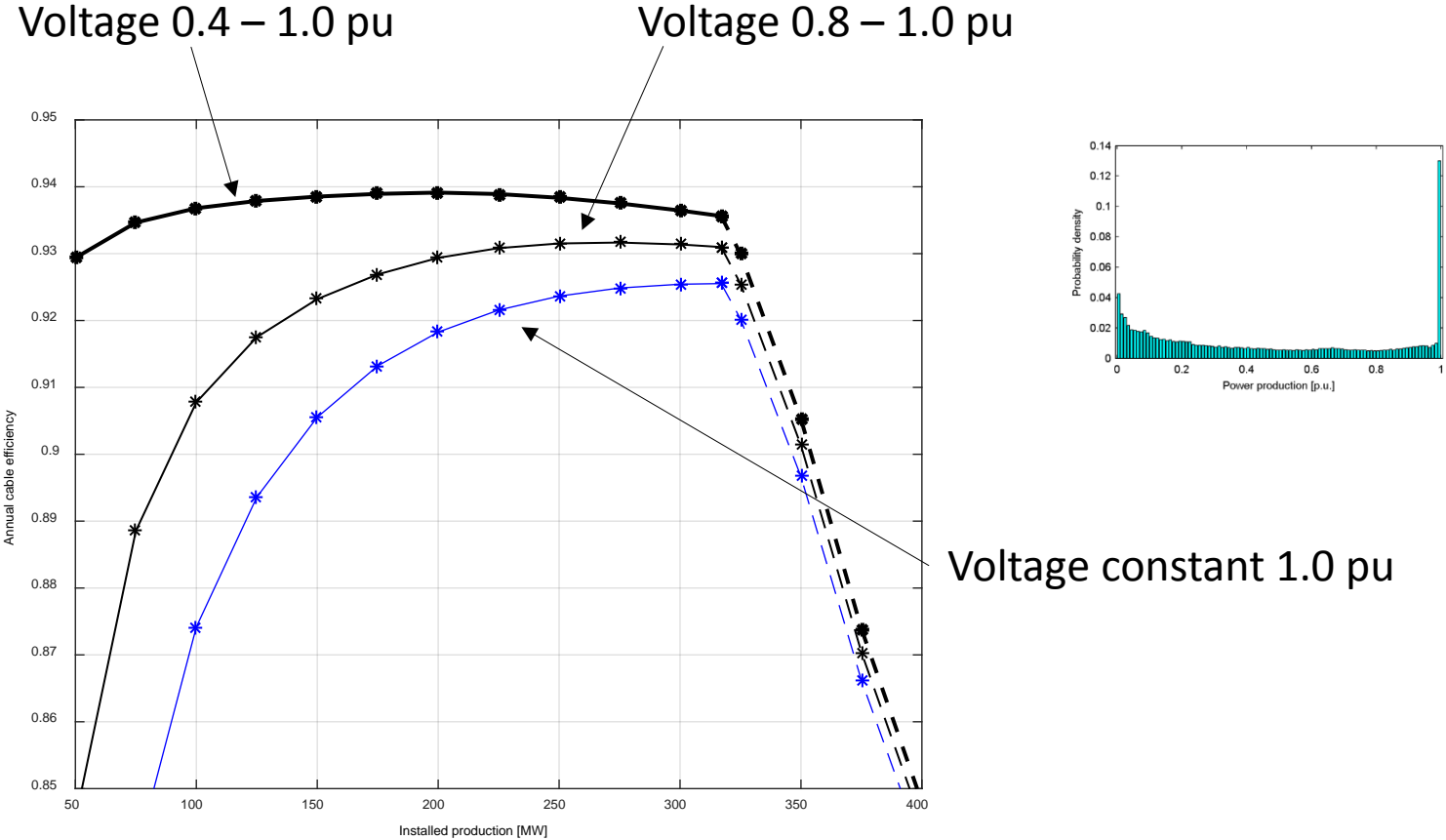
Annual efficiency as function of **<u>installed</u>** production

Voltage 0.4 – 1.0 pu

Voltage constant 1.0 pu

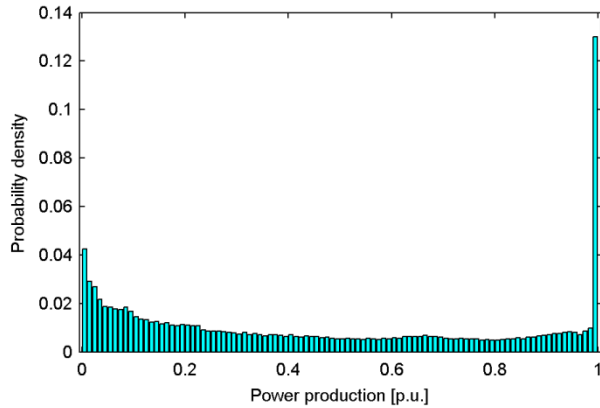**200km** 220 kV cable, 1000mm2

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Annual efficiency as function of **installed** production

Voltage 0.4 – 1.0 pu

Voltage 0.8 – 1.0 pu

Voltage constant 1.0 pu

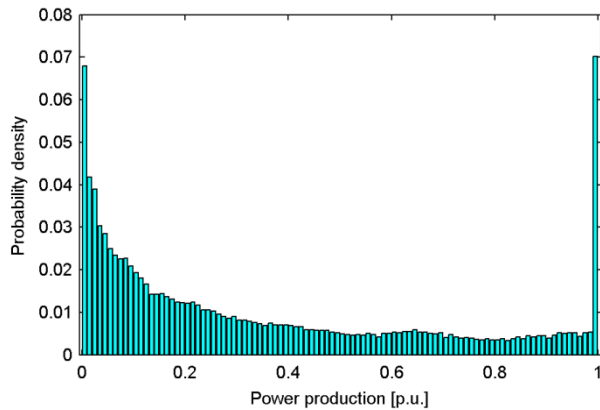**200km** 220 kV cable, 1000mm2

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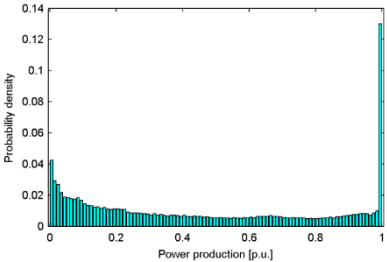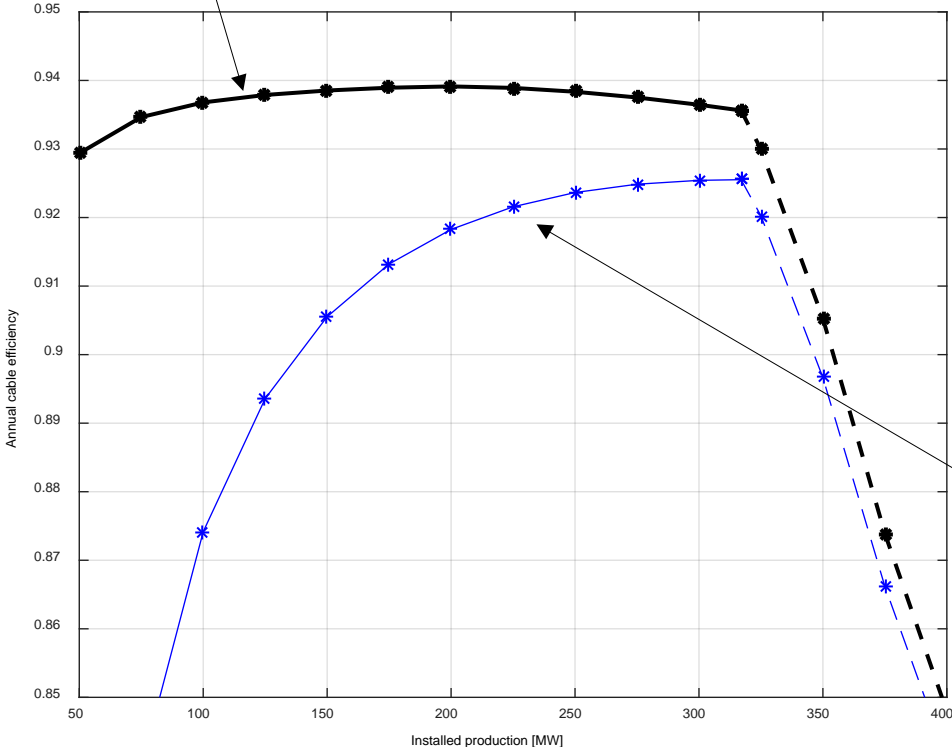
Dependency of power production distribution
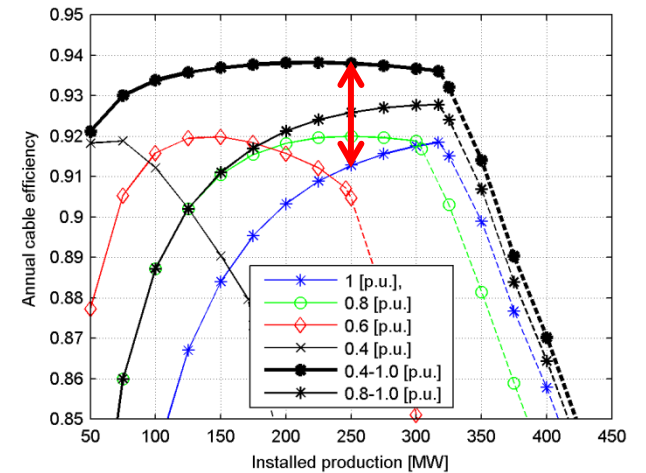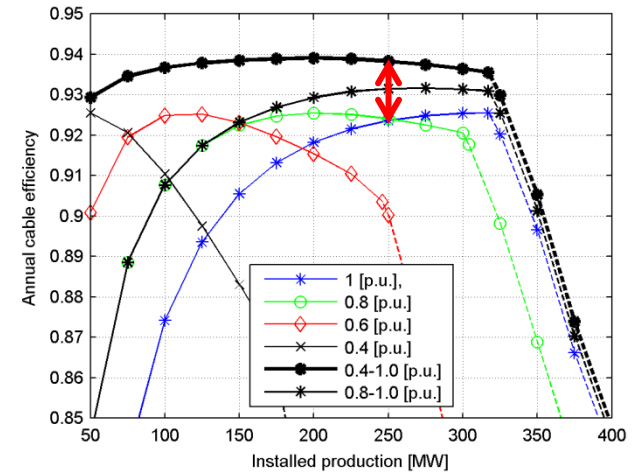
Power production distribution

46% Utilization factor

Efficiency

35 % Utilization factor

Remains to look into:

- Map the potential loss saving for different cables, distances and wind production profiles

- Look into the practical issues of utilizing the observations:
  - Technology assessment
  - Control methods
  - Stability and transient issues

- Impact of losses in other components (transformers, VAr compensation)
  - Increases or decreases ?

- **Cost-benefit ?**

- Grid codes / regulations challenges

Conclusion

- The Annual efficiency of a long export cable can be improved by operating at variable voltage or in some cases also by operating at a fixed voltage below rated.

- Work remains before it can be concluded whether it will be economically feasible to utilize the results or if it becomes too expensive and technically complicated

- The results do show that it is important to take into consideration the **annual** efficiency when choosing operating voltage and designing the export cable. It might be that the operation below rated voltage improves annual efficiency (project dependent)

- The largest improvement can be expected for:
  - Longest distances (150km ++)
  - Low utilization factor projects (for the whole, or for part of the system life time)