

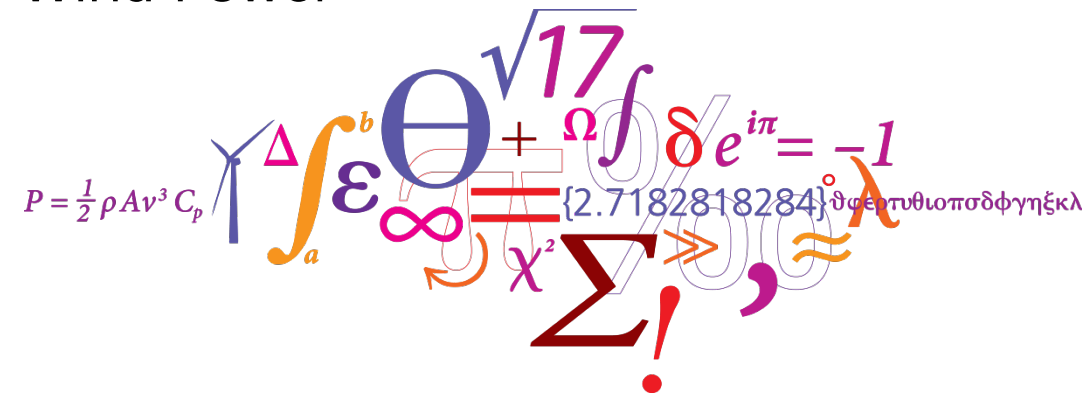
Integration of wind power - variability

a module of the

Grid Connection and Integration of Wind Power

part of the

DTU Online Master's Programme



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Learning objectives

After this lecture you will be able to:

- List the main challenges in integration of wind power
- Describe the root cause for variability
- Calculate cumulative distribution functions for wind power variability (ramping)

Integration – what does it mean?

Integrate*:

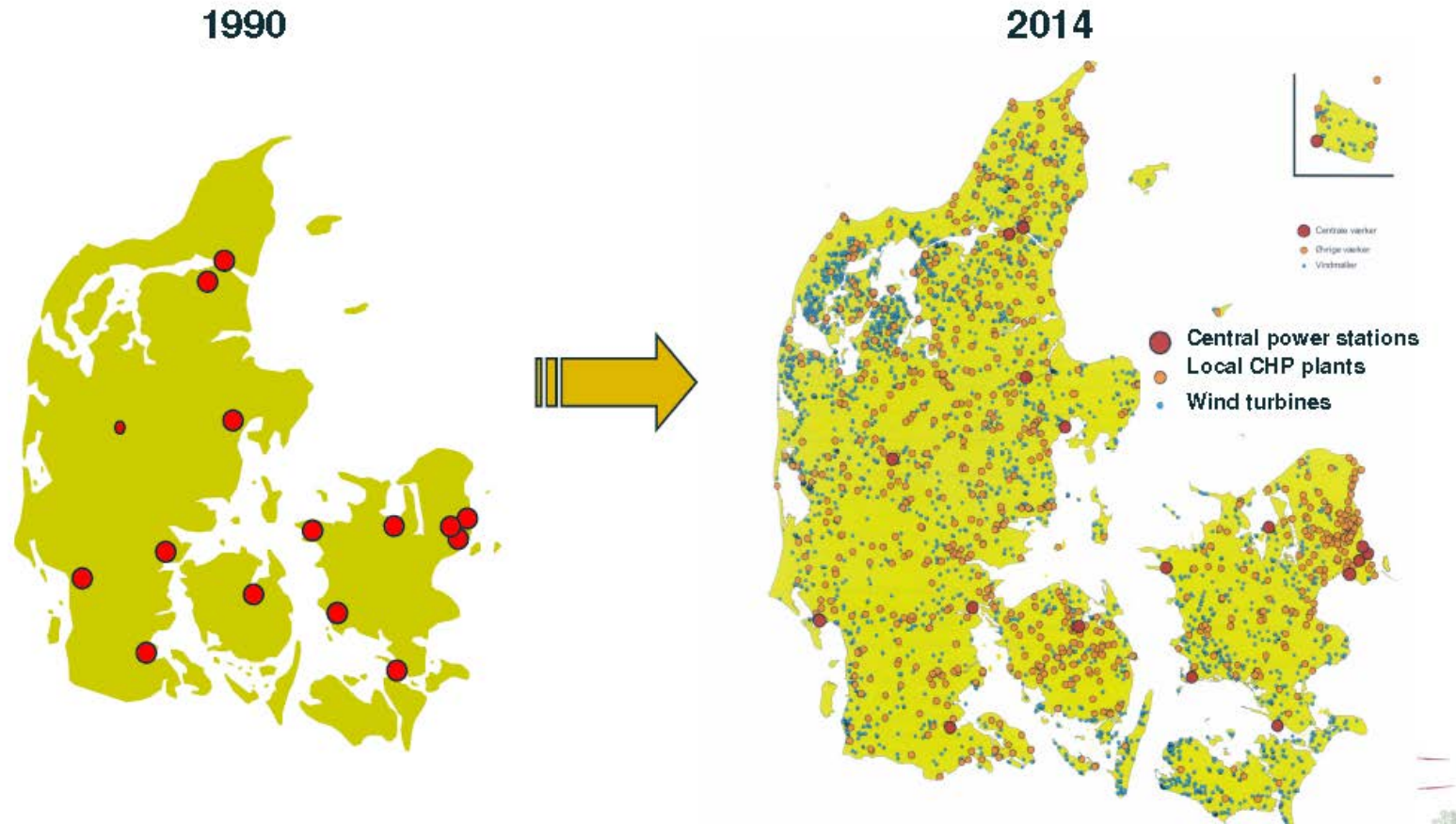
- *to form, coordinate, or blend into a functioning or unified whole*
- *to unite with something else*
- *to incorporate into a larger unit*

Integration of wind (and renewable sources in general) with respect to power systems:

- Consider them as “normal” sources like all the others with “honors” and duties (i.e. provision of ancillary services) needed in order to properly control system voltages and frequency
- Adapt the power system operation to accommodate the characteristics of weather driven generators (wind and PV)

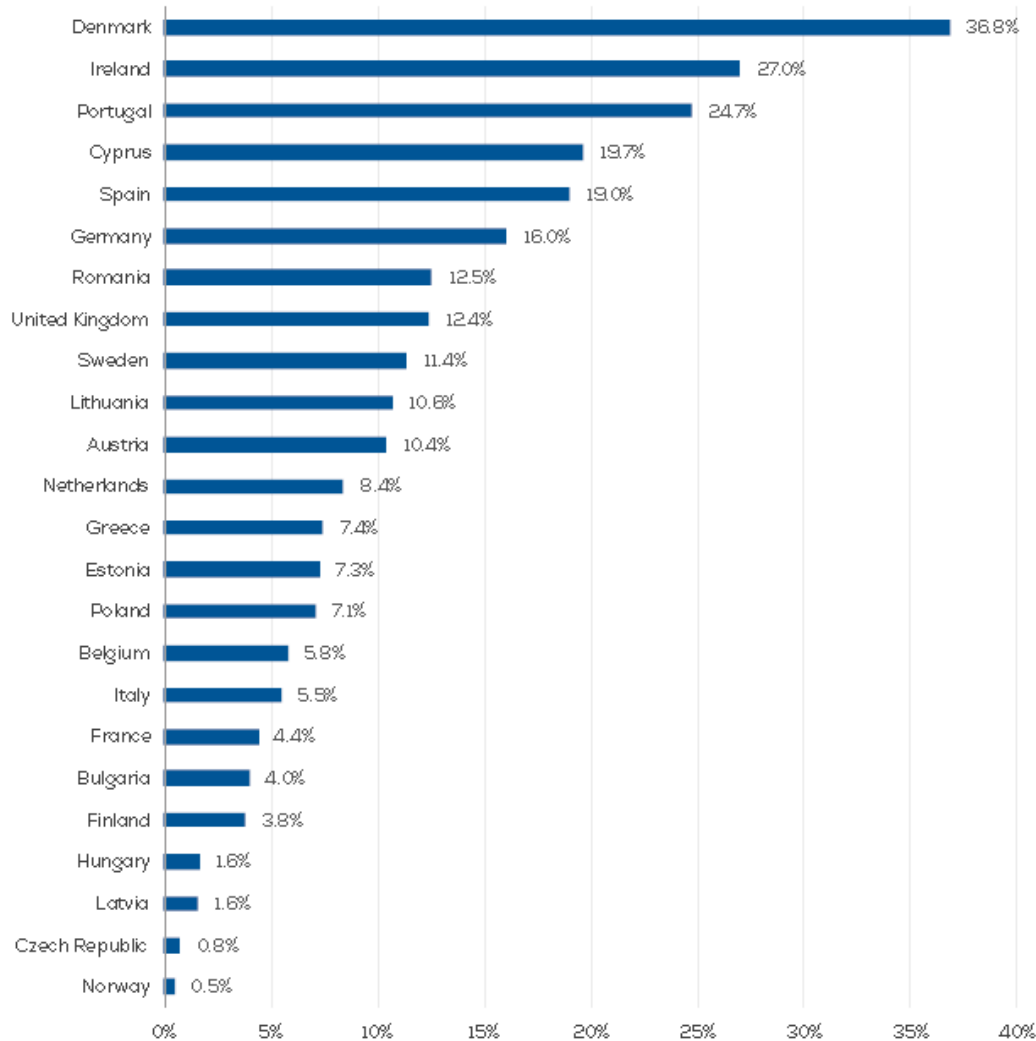
**Miriam-Webster online dictionary*

Danish Power System



Source: Energinet.dk

Wind power share in 2016



Note:

The share is calculated as energy share over the entire year:

$$\text{wind energy share (\%)} = \frac{\text{wind energy produced (TWh)}}{\text{gross electricity demand (TWh)}}$$

There are several instances when the instantaneous share of wind power in a power system exceeds 100%

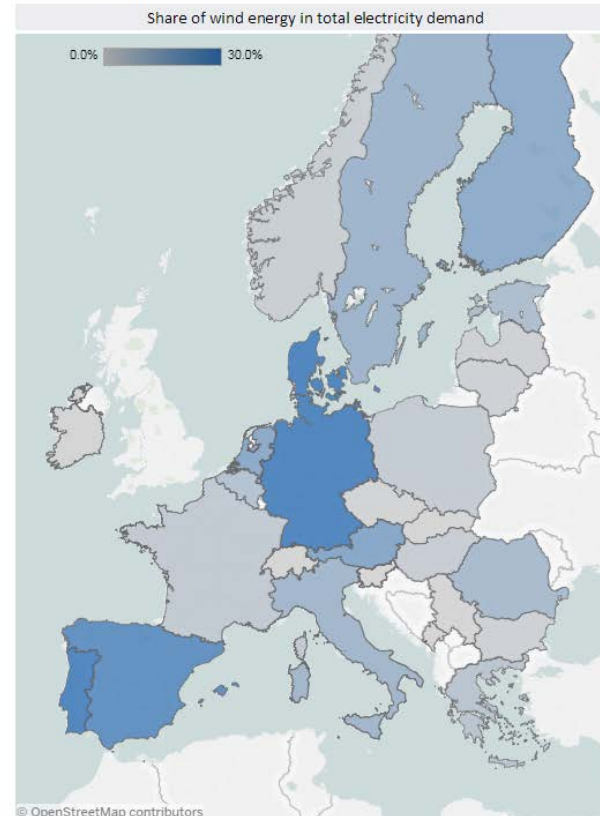
Wind Power in Europe

How much wind was in Europe's electricity yesterday?

Share these figures [f](#) [t](#) [in](#) [G+](#)

Click on countries for national details
Ctrl + click for selecting various countries

20 August 2017



* Elaborated on the electricity demand of an average EU28 household in 2015, Eurostats
** Elaborated on the industrial electricity consumption of each EU28 country in 2015, Eurostats

Share of wind energy in electricity demand

14.0%



Onshore Wind (GWh)
716
Offshore Wind (GWh)
131

WHICH COULD POWER



Equivalent EU households*
85 million

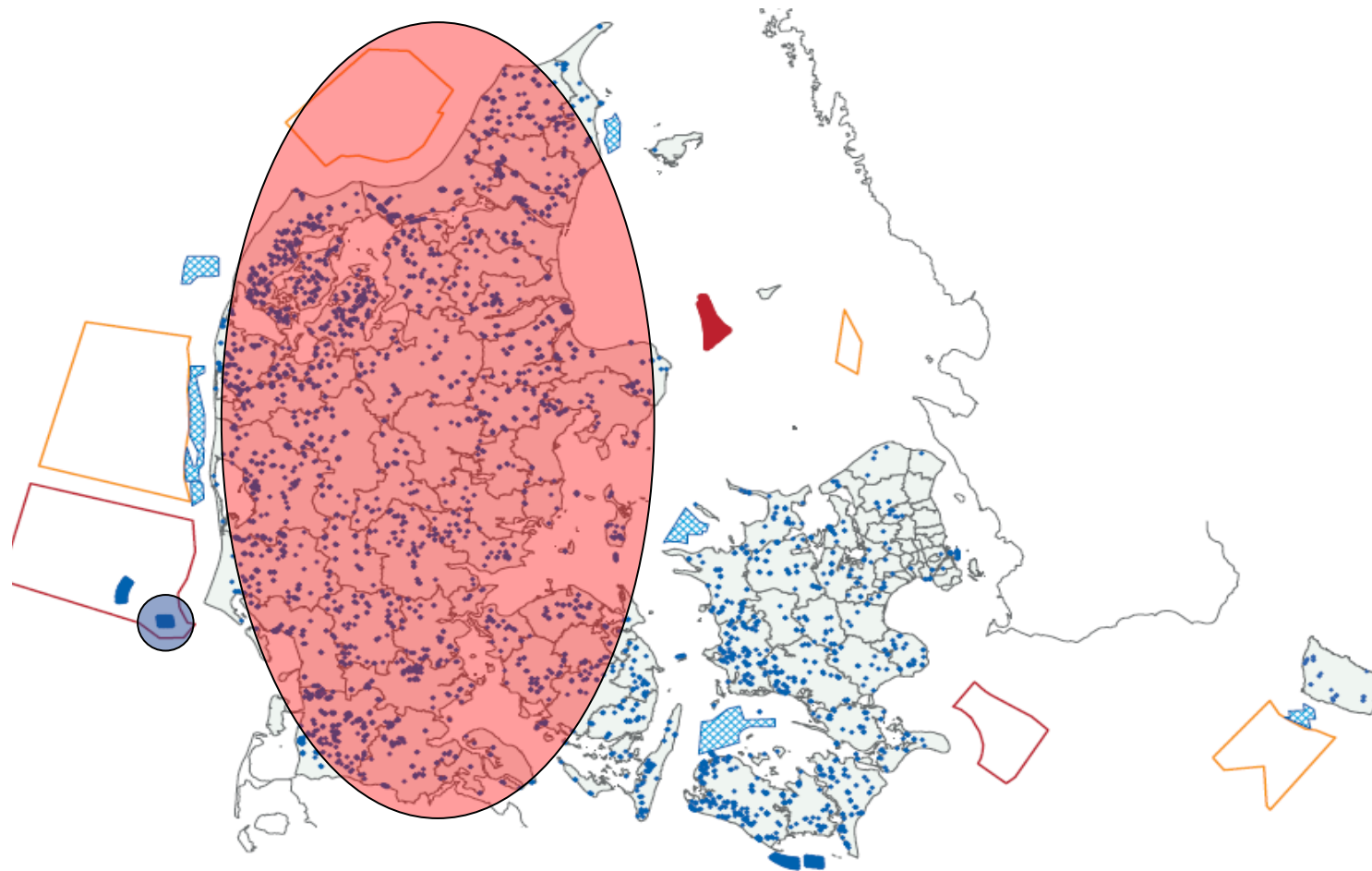
OR



Average industrial electricity demand **
33%

<https://windeurope.org/about-wind/daily-wind/>

Wind power variability – offshore vs onshore



Wind power variability – offshore vs onshore

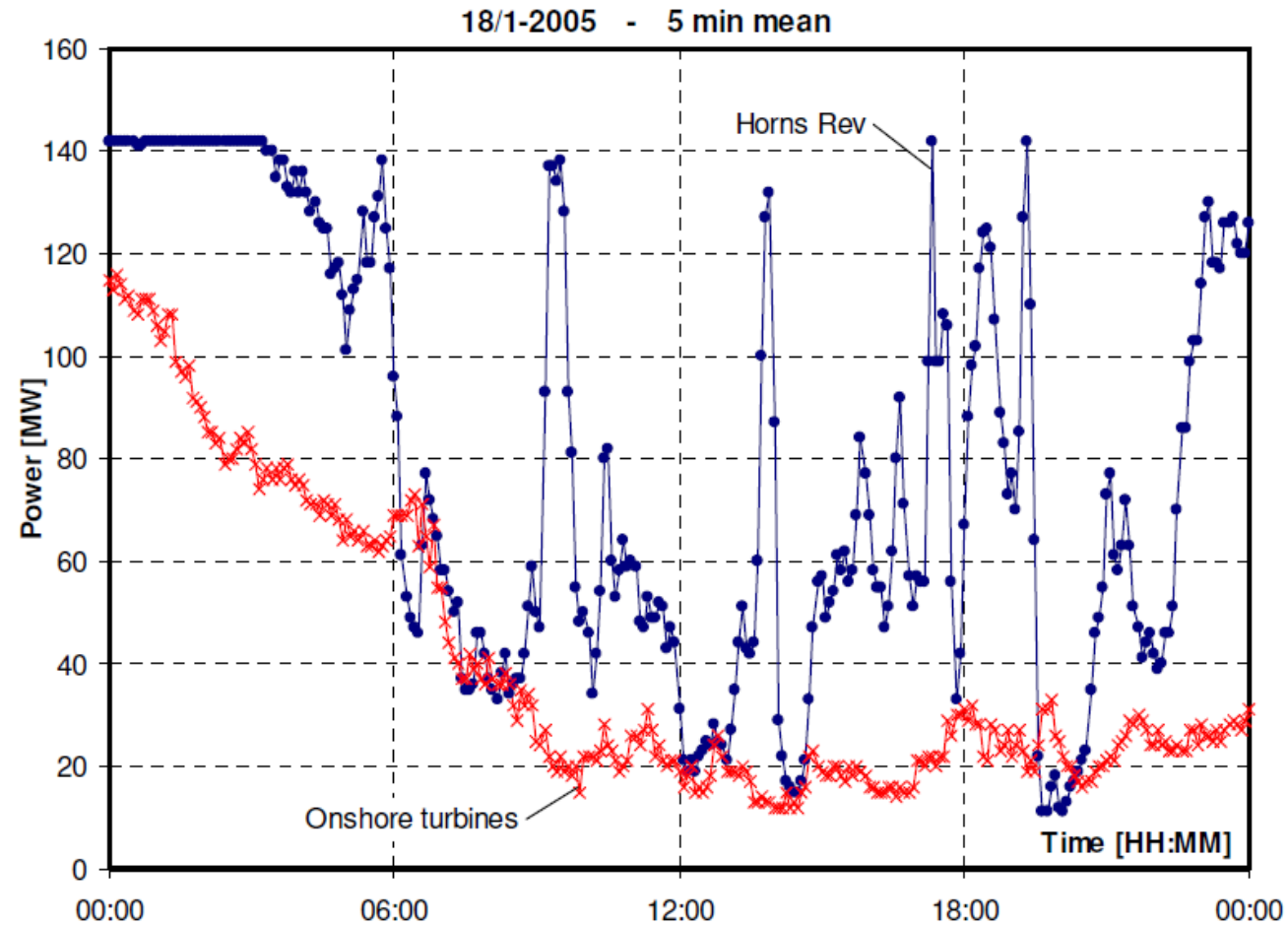
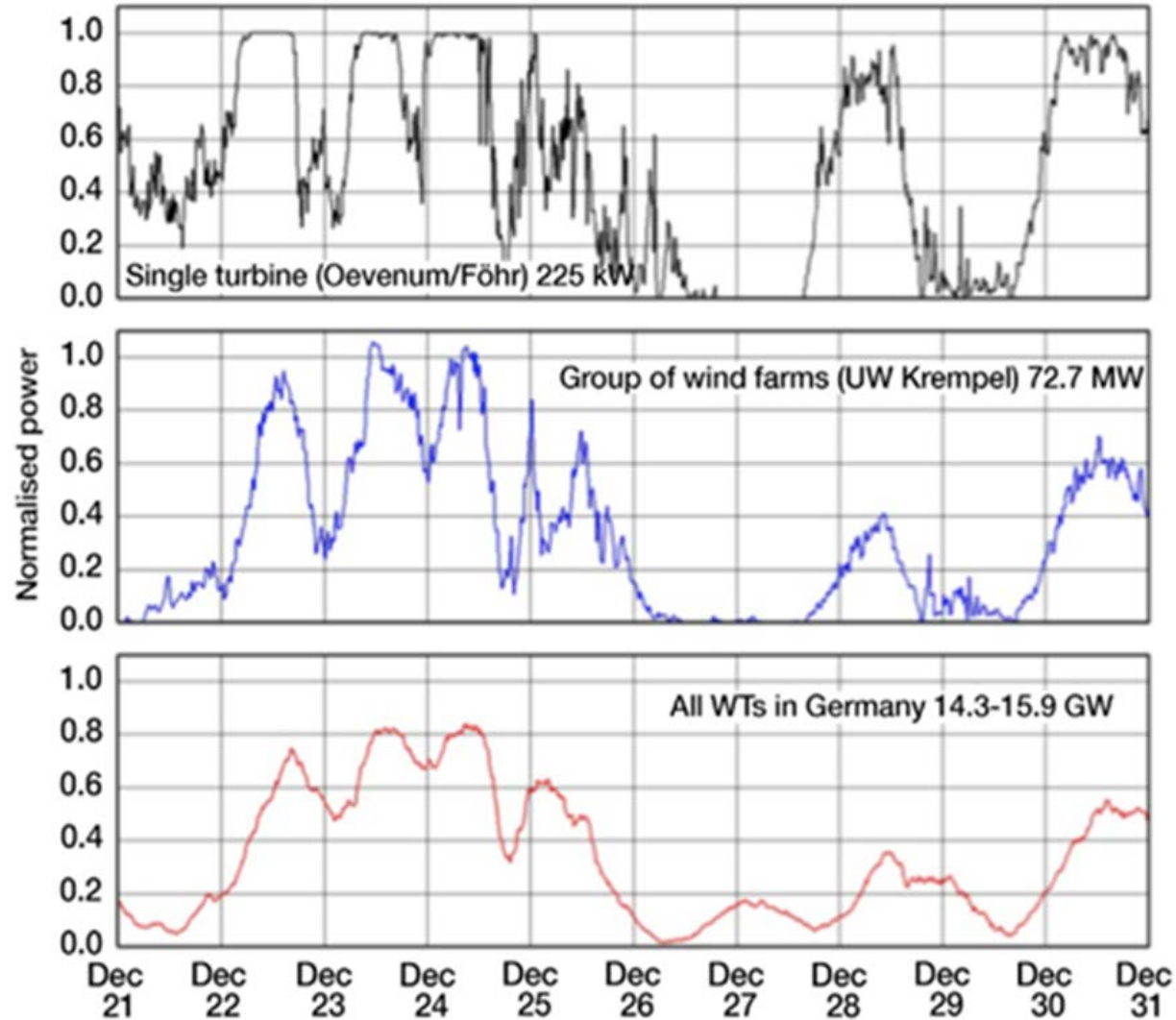


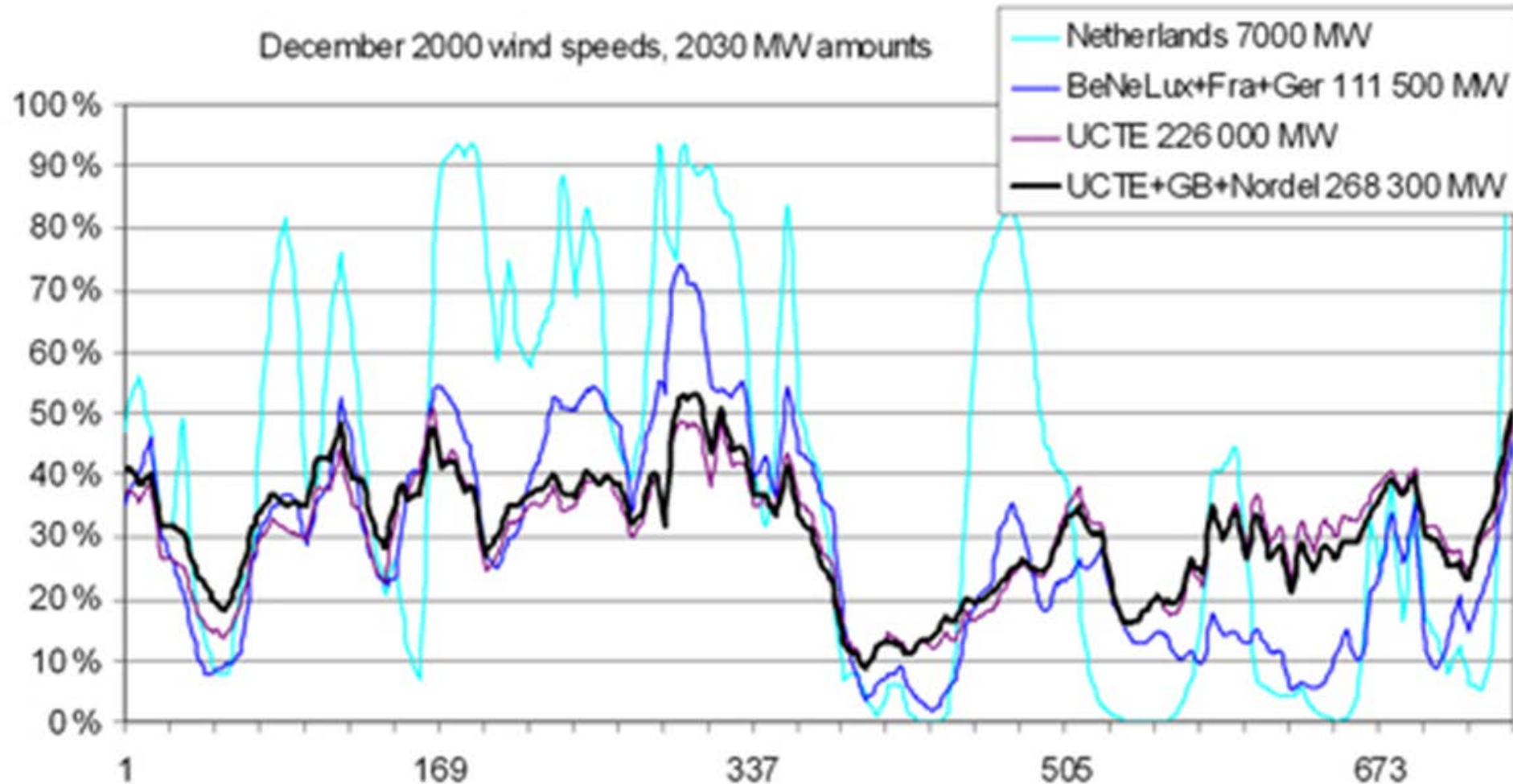
Figure 9. Power fluctuations during a day with many rain showers

J. Kristoffersen, The Horns Rev Wind Farm and the Operational Experience with the Wind Farm Main Controller, Copenhagen Offshore Wind 2005

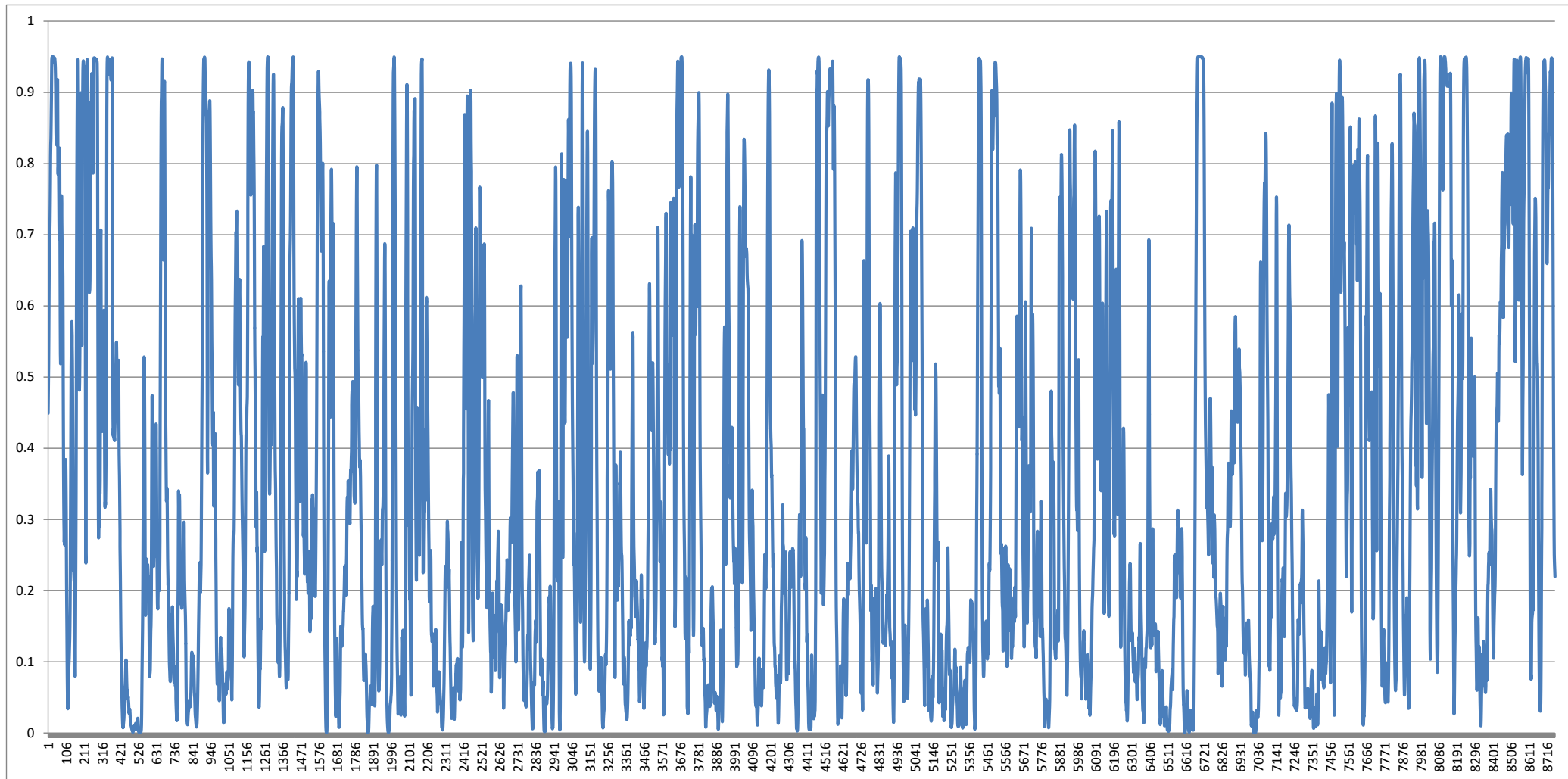
Wind power variability - smoothing



Wind power variability – smoothing



Wind Generation Profile - DK



Variability – ramp rates

A different measure of variability often used, is the ramp rate, defined as the difference in the power produced in two different time steps:

$$P_{\text{ramp}}(t) = P(t+1) - P(t)$$

Ramp rates can be calculated for different time periods, most used ones are 5 and 15 min or 1 hour

Calculating the ramp rates

Depending on the resolution of the data, calculating the ramp rates may require a preliminary step in calculating the mean value:

$$P_{\text{ramp}}(t) = P_{\text{mean}}(t+1) - P_{\text{mean}}(t)$$

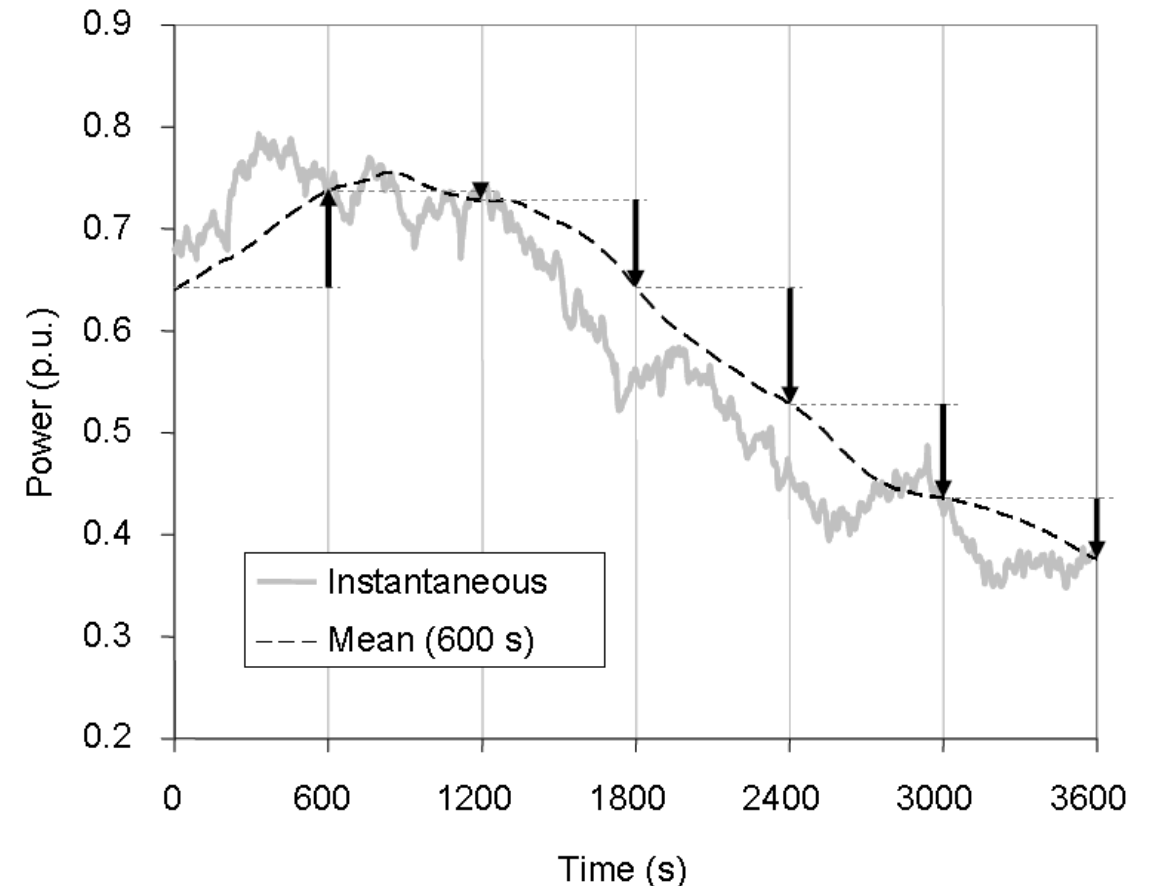
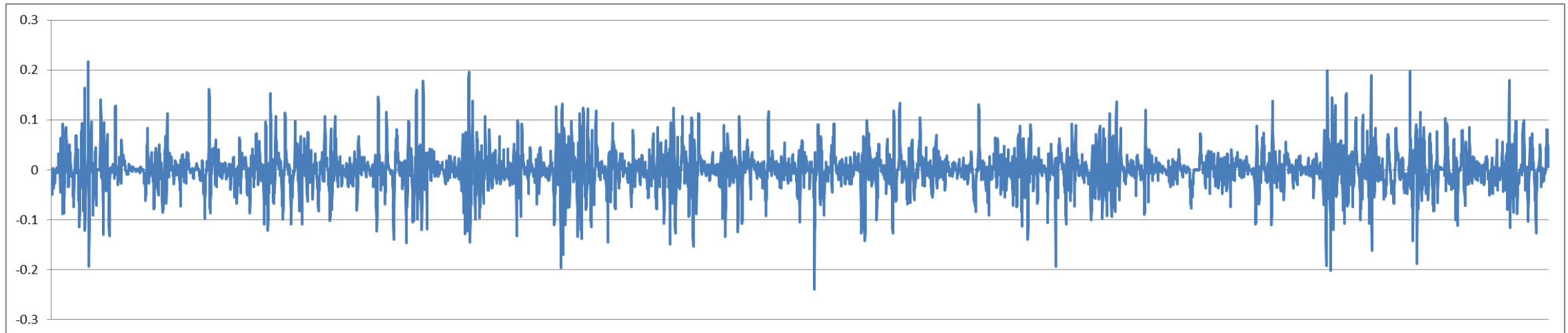


Fig. 4. Definition of ramp rate for period time $T_{\text{per}} = 10$ min. The ramp rates are indicated with arrows.

Ramp rates – DK profile

Once we have the ramp rates, there are several ways of plotting the results:

- time series

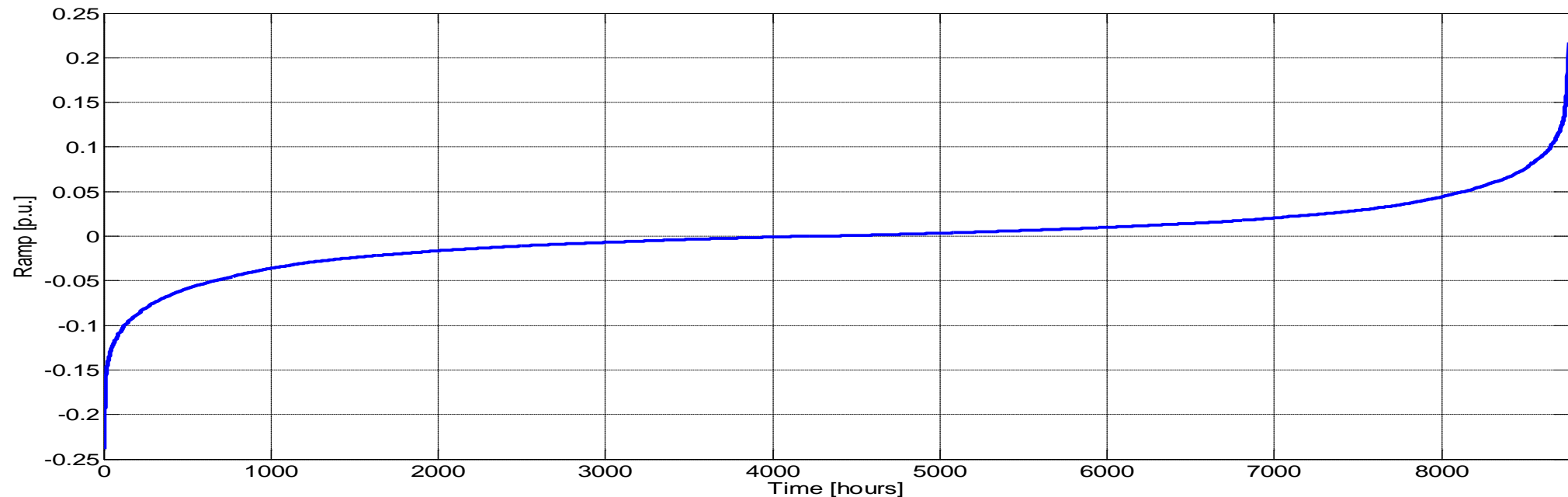


...not really useful!

Ramp rates

Duration curves

Plotting the results in a sorted manner, e.g. based on the value, rather than chronologically



Ramp rates

Cumulative distribution function:

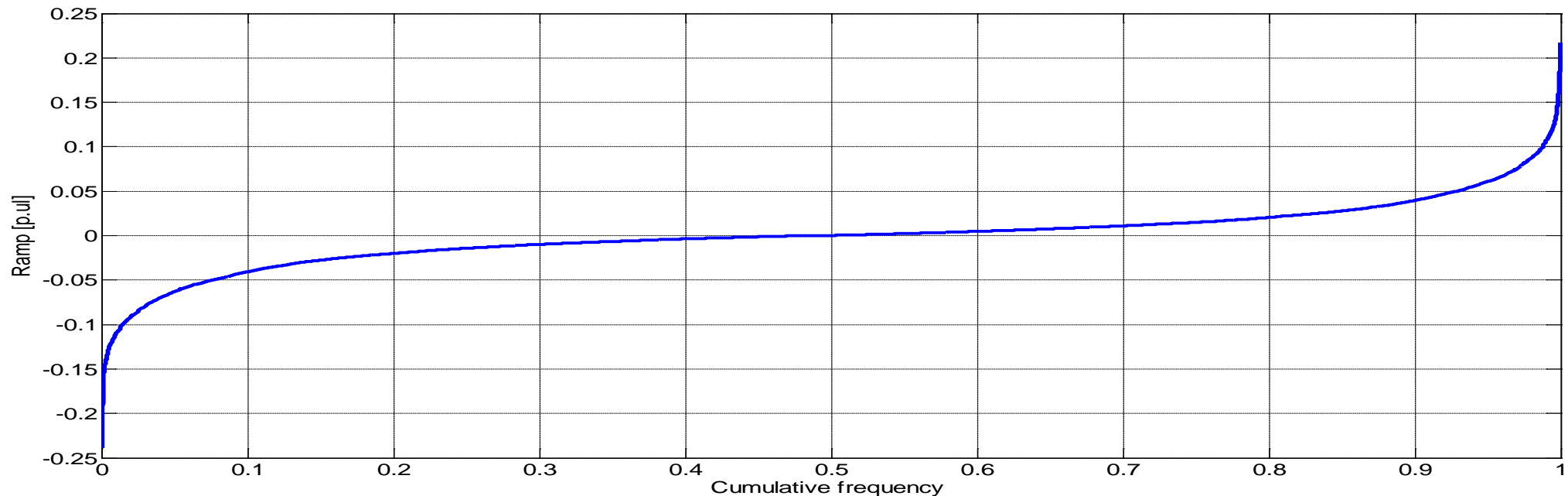
"a function whose value is the probability that a corresponding continuous random variable has a value less than or equal to the argument of the function"

Cumulative frequency distribution:

"a cumulative frequency distribution is the sum of the class and all classes below it in a frequency distribution"

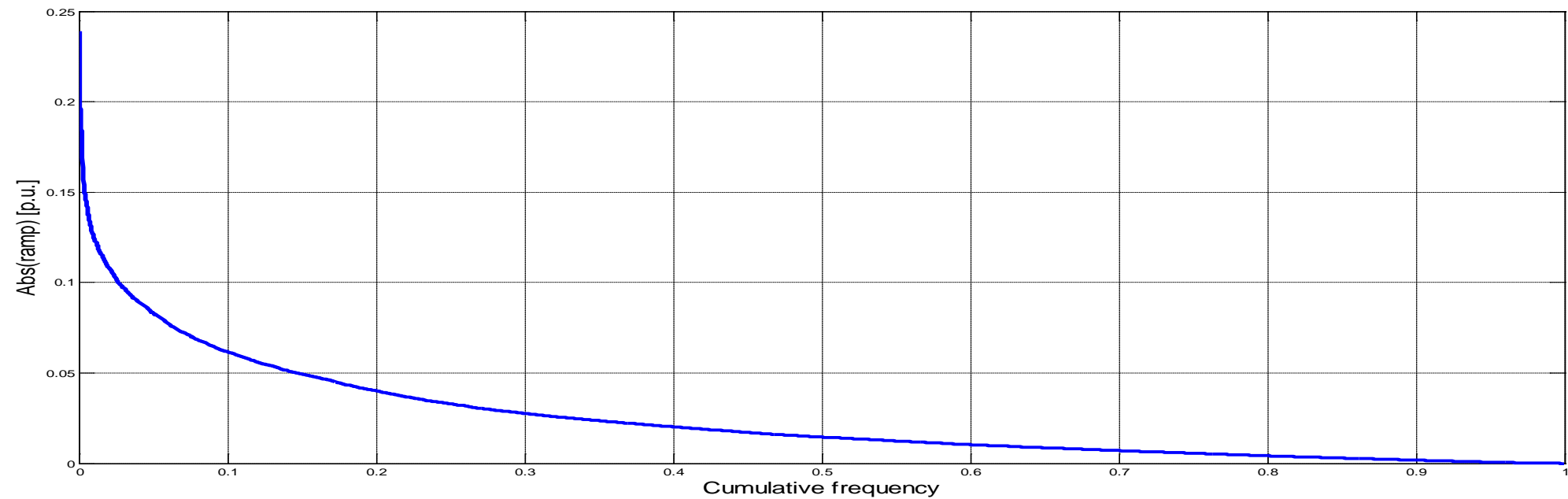
Ramp rates

The same as previous, but the x-axis is the cumulative frequency, i.e. how many times the ramp rate has a certain value



Ramp rates

The same as previous, but the ramp magnitude is in absolute value



Summary

- Variability induced by wind power
- Definition of ramp rates
- Calculation of ramp rates duration curves and cumulative frequency