European experience in wind power grid integration

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Introduction

Aims:

1. Technical issues for wind farm connections:
   - Focus on connection of offshore wind farms

2. Problems of operation of electricity systems with large amounts of wind generation

1. Technical issues for wind farm connections

Offshore wind farm electrical systems consist of four key elements:

Offshore

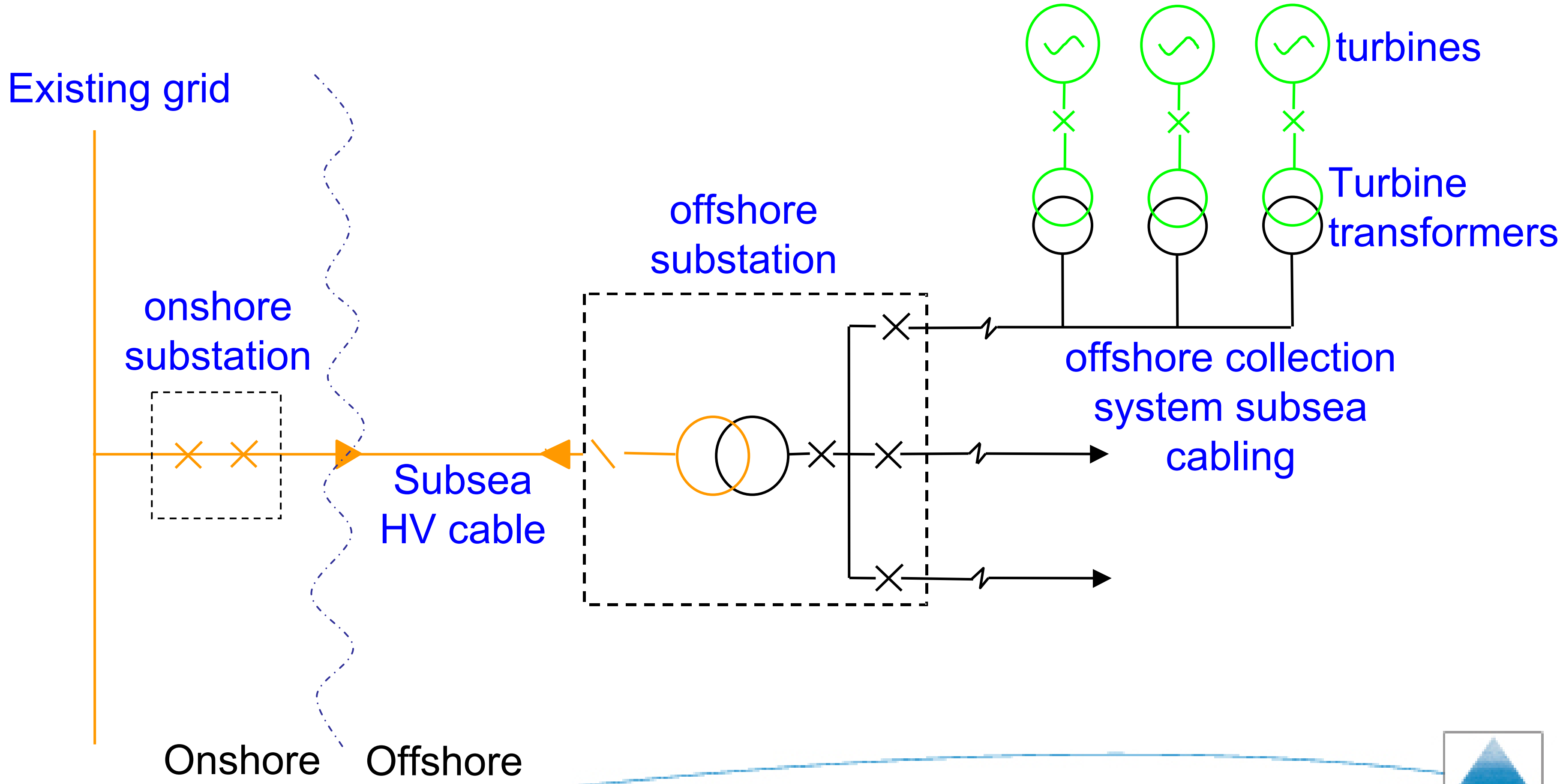
1. Inter-turbine cables (not discussed here)
2. Offshore substation, if necessary
3. Transmission cables to shore

Onshore

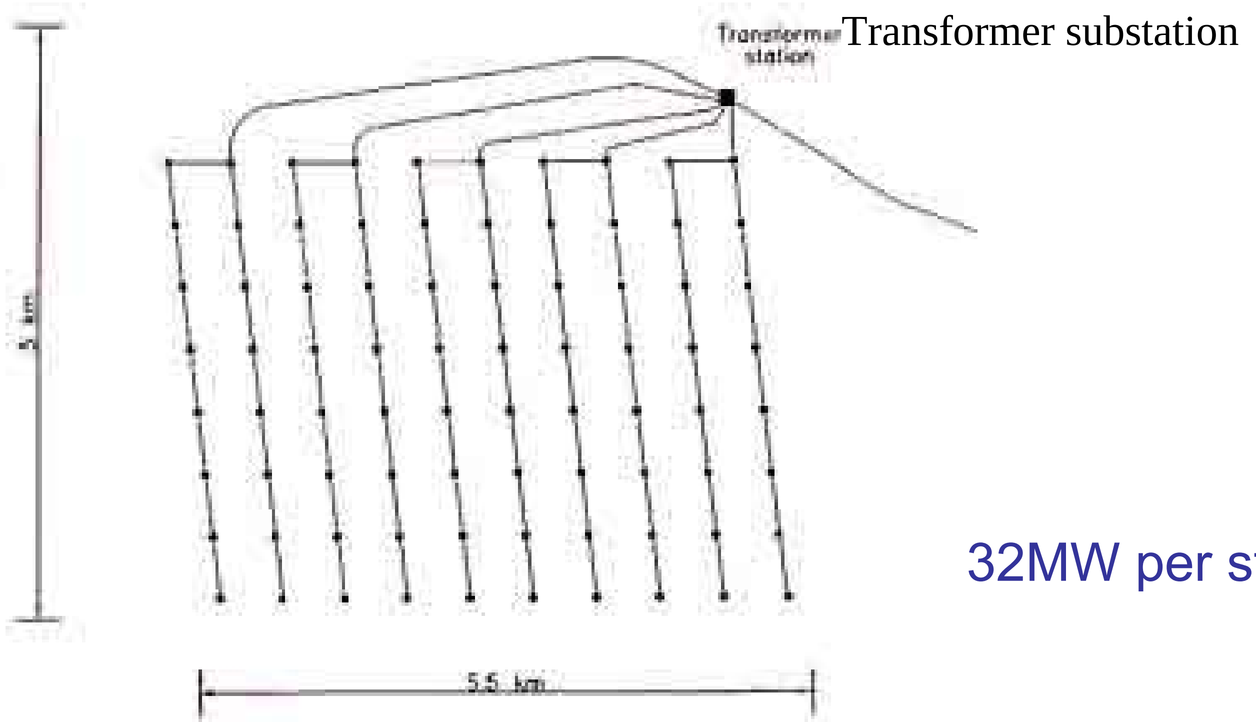
4. Onshore substation (and onshore cables)

Offshore wind farm electrical system

Typical Single Line Diagram (SLD)



Electrical collection system - layouts



32MW per string

➡ Trend is for radial circuits without additional links

Cable protection

Approximately 70% + of cable failures are due to human activity, e.g. fishing gear, anchors.

Burial is the best protection.

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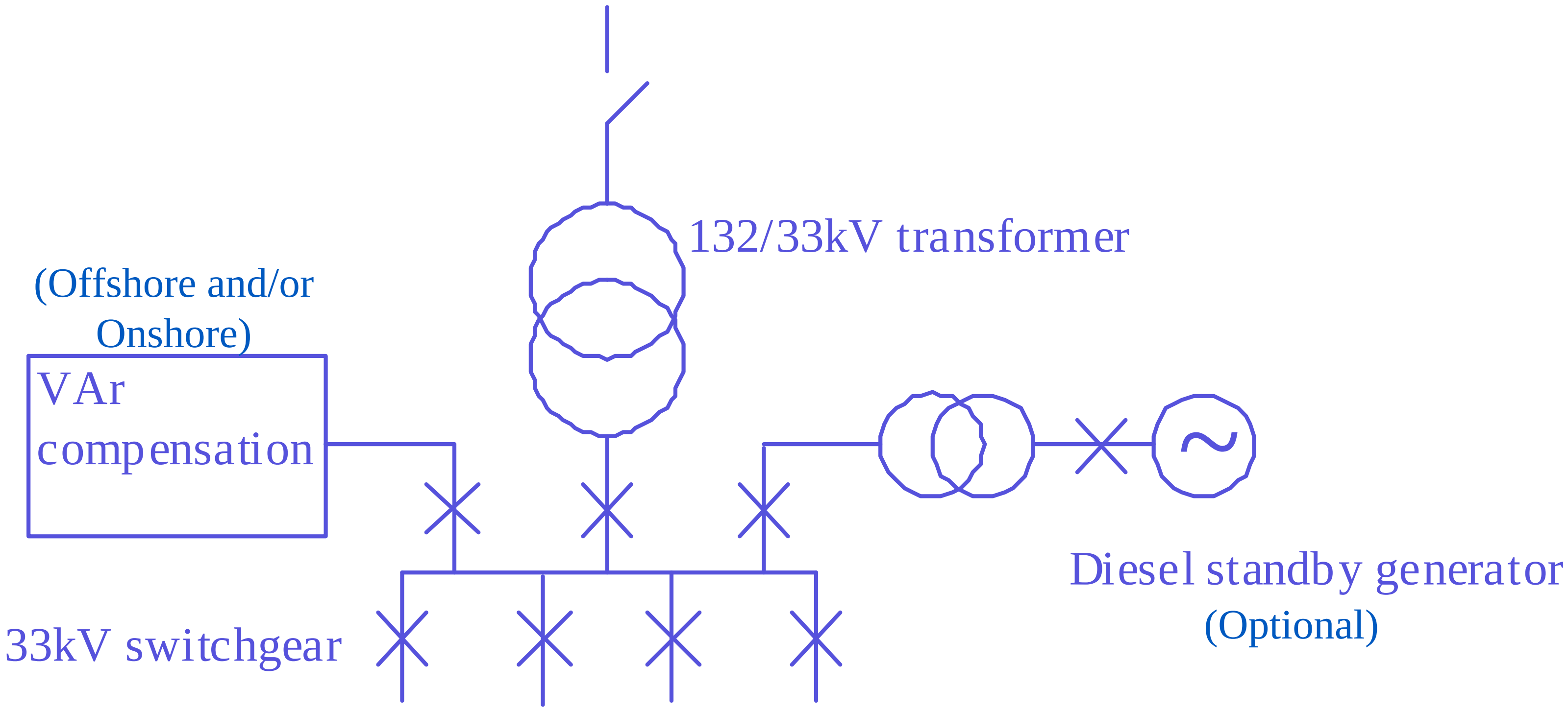
Offshore substations – single line diagram



Offshore substations

Barrow (UK)

Horns Rev (Denmark)

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Offshore substations - summary

- Expensive: try to avoid offshore substations
- Probably necessary for projects above ~100MW and ~15km offshore, particularly if grid connected above 36kV: but the decision will depend upon the details of the project
- Costs typically €7-12M installed for around 100MW
- Main plant is switchgear (36kV and HV) and transformers
- Back-up supplies and other items also possible, e.g. reactive compensation equipment

NB - DC converter substation not considered above.

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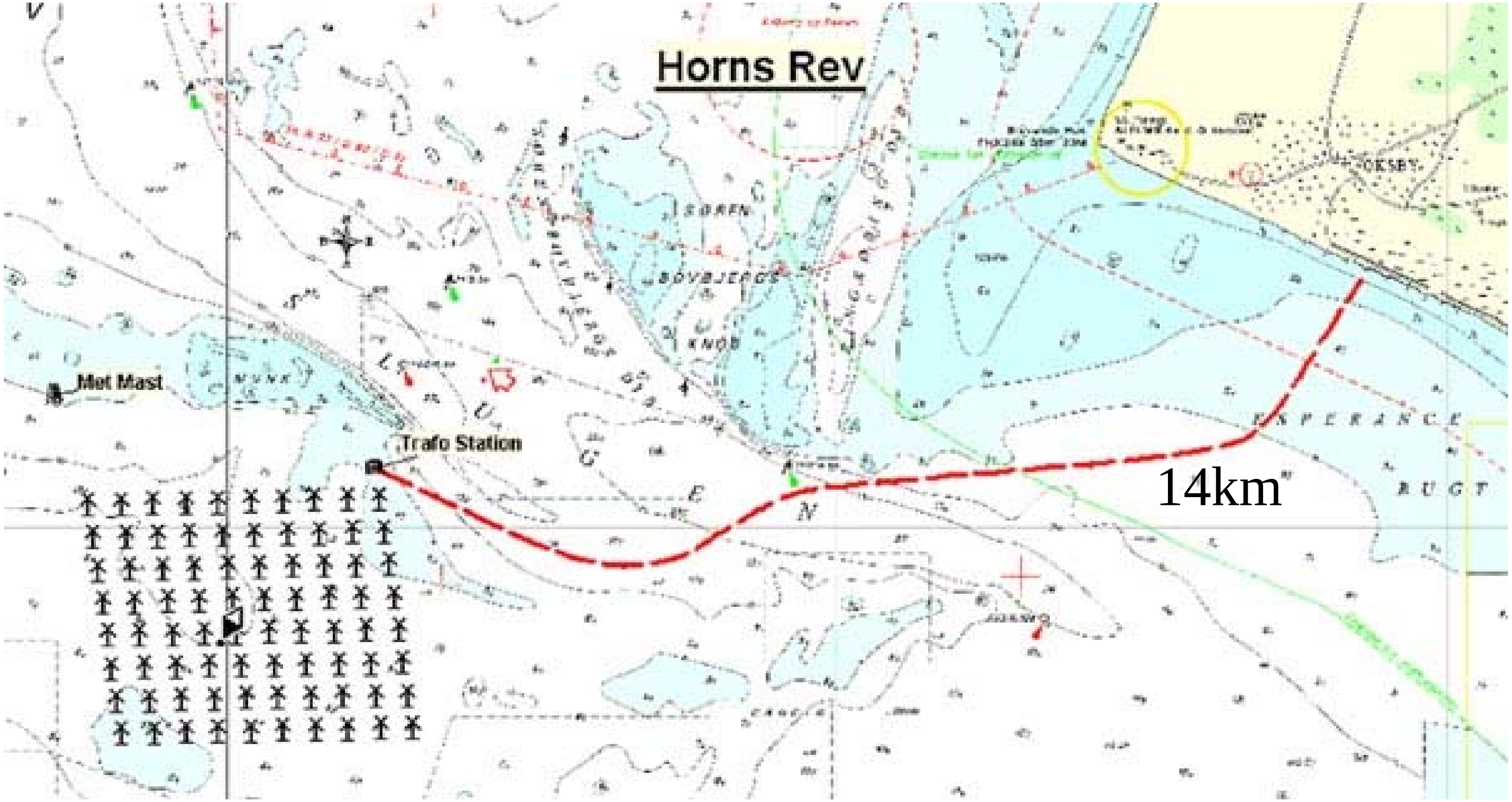
Transmission cables to shore

- Projects grid connecting at higher voltages, i.e. >36kV will probably opt for cable at the grid voltage
  - e.g. Horns Rev @ 150kV
  - Barrow @ 132kV

- A major cost item: detailed design and detailed knowledge of the seabed conditions are very important

- The cable size should be optimised by including the value of electrical losses: usually this results in a cable larger than the minimum size

Transmission cables - Horns Rev



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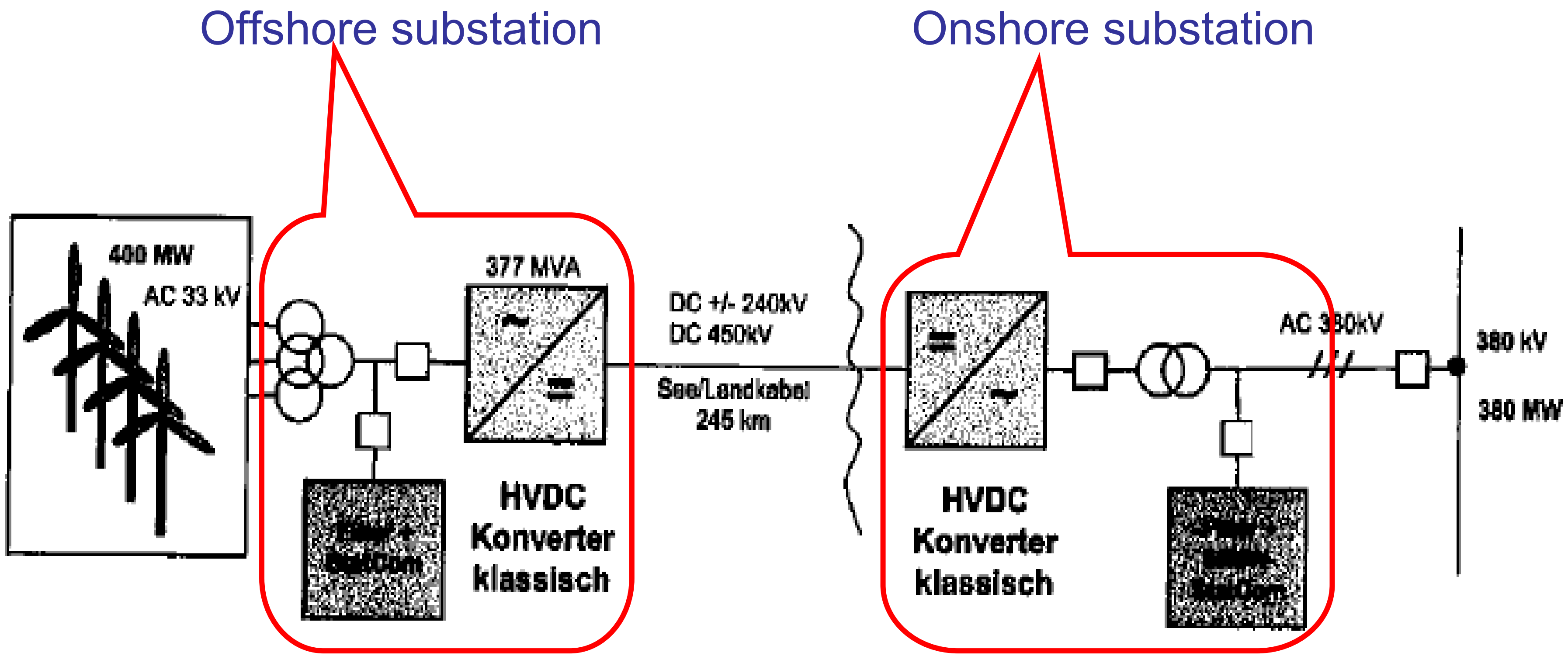
Transmission cables – DC options

Converter stations are big, expensive and unavoidable. One of them must be located offshore, which may affect reliability



Transmission cables – AC v DC

- AC:
  - Maximum cable length is limited by charging current (usually ~ 100 km)
- HVDC:
  - cheaper cable, lower cable losses
  - converter cost, converter losses, reliability
  - therefore beats AC at longer distances (e.g. Germany)
  - offshore AC/DC converter station will be large and expensive
  - the onshore DC/AC converter can provide other benefits to the electricity system: reactive power control
  - very little previous experience with offshore converter stations: will it be reliable?

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Onshore works

- Cable landing is important
- Onshore substation is relatively standard design
- Reactive compensation is important – long HV cables produce significant reactive power (MVAr)
- Grid Operator requirements are important:
  - reactive power control
  - voltage control
  - ability to limit power output, or rate-of-change of power
  - power quality:
    - voltage steps
    - voltage flicker
    - harmonics

2. Problems of operation of electricity systems with large amounts of wind generation

- This presentation is relevant for regional, national and international electricity systems, not small or island systems

The Problems

As total wind capacity increases, eventually its effects on large electricity systems become too big to ignore.

- Where will it be built?
- When will it be built?
- What will it produce in *N* hours?
- How certain is that forecast?
- How fast could the wind output change?

Conventional generation will be ‘displaced’, so wind generation has to provide similar functions: it may have to ‘look like’ large thermal power plant with synchronous generators.

A few large wind farms can cause more severe problems than several smaller wind farms.

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How can electricity systems operate with high wind penetration?

Denmark:

Strong interconnections to other countries, especially Norway and Sweden, with large hydro generation capacity.

Crete (small island system, 300 MW):

'Curtailment': reduce the wind generation output during critical periods.

Interconnections (transmission reinforcement) may be cheaper than curtailment, but may take a long time to build.

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Issues:

- Technical requirements for wind generation (‘Grid Codes’)
- Transmission system reinforcement
- Variability, predictability and forecasting
- Wind curtailment

Not covered here:

- Contribution of wind generation to reliability: ’capacity credit’ or ‘generation adequacy’
- Increased costs for system operation (many studies show the costs are small)

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‘Grid Codes’ for wind generation

Grid codes state the technical requirements on generators, to provide functions that allow the system to work.

Grid codes were initially written for conventional generation; now modified to include wind.

Grid codes for wind generation have been implemented in many countries, and are under discussion in all other major wind markets.

Often, **slow development of grid codes is an impediment to rapid growth of wind generation**.

Common grid code requirements for wind

- Limit on power output: ‘power cap’
- Limit on rate-of-change of output power (‘ramp rate’): positive, negative
- Frequency regulation
- Reactive power and voltage control
- Operating range: voltage and frequency
- Transient stability (‘fault ride-through’)
- Provision of information to electricity system operator in real-time

Transmission system reinforcement

Transmission reinforcement may be necessary to connect areas of wind generation to areas of high electricity demand, or to other electricity systems.

But there are problems:

- In the West, it takes much longer to build transmission systems than it does to build wind generation; maybe 10 years.
- Risky: will transmission reinforcement get permission at all?
- Design to cope with failures ('N-1 contingencies'), but is this justified for wind generation?
- It may be economic to build transmission capacity that is less than the wind generation capacity: a study for offshore wind generation in the UK concluded that ~90% was optimum (see next slide).

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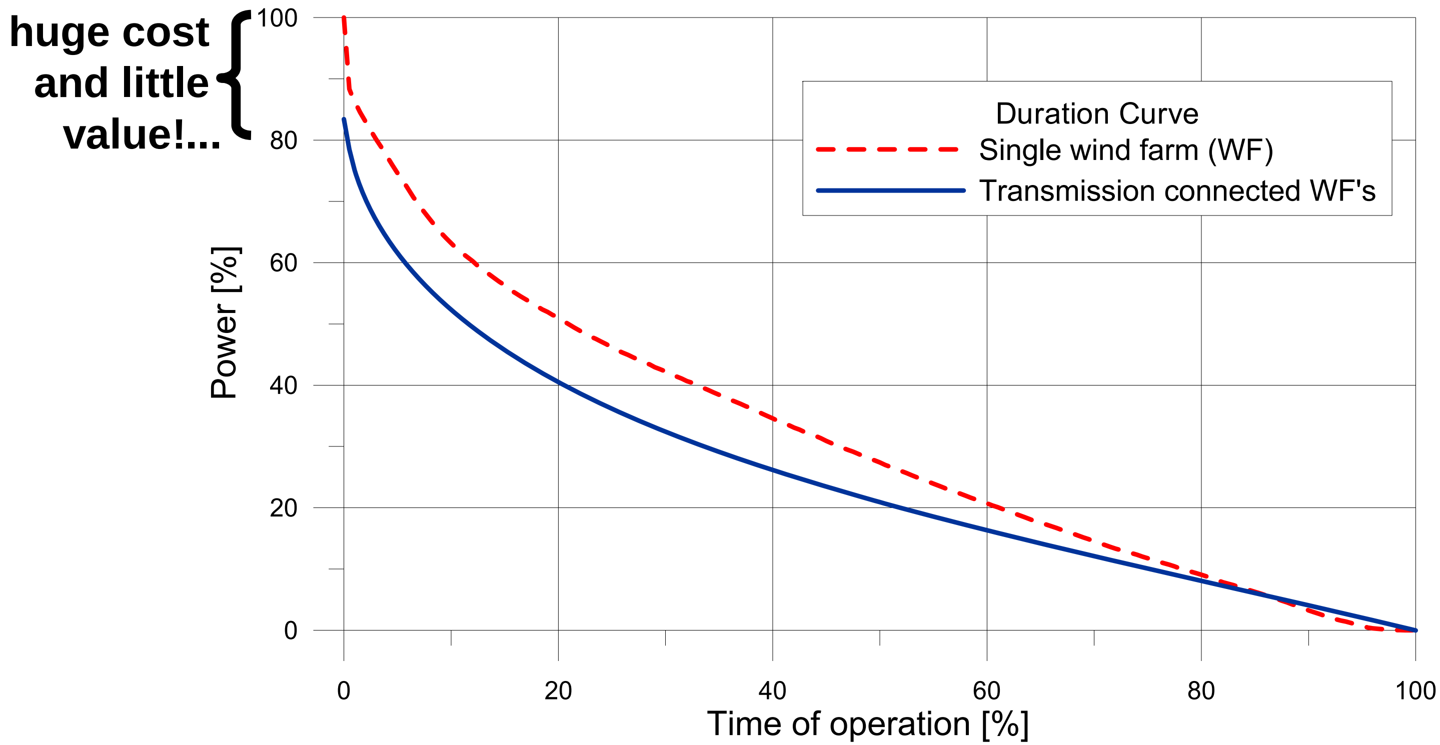
How much transmission capacity do you need for wind generation?



Source: Ana Estanqueiro, INETI, Portugal
Measured data, transmission-connected wind farms

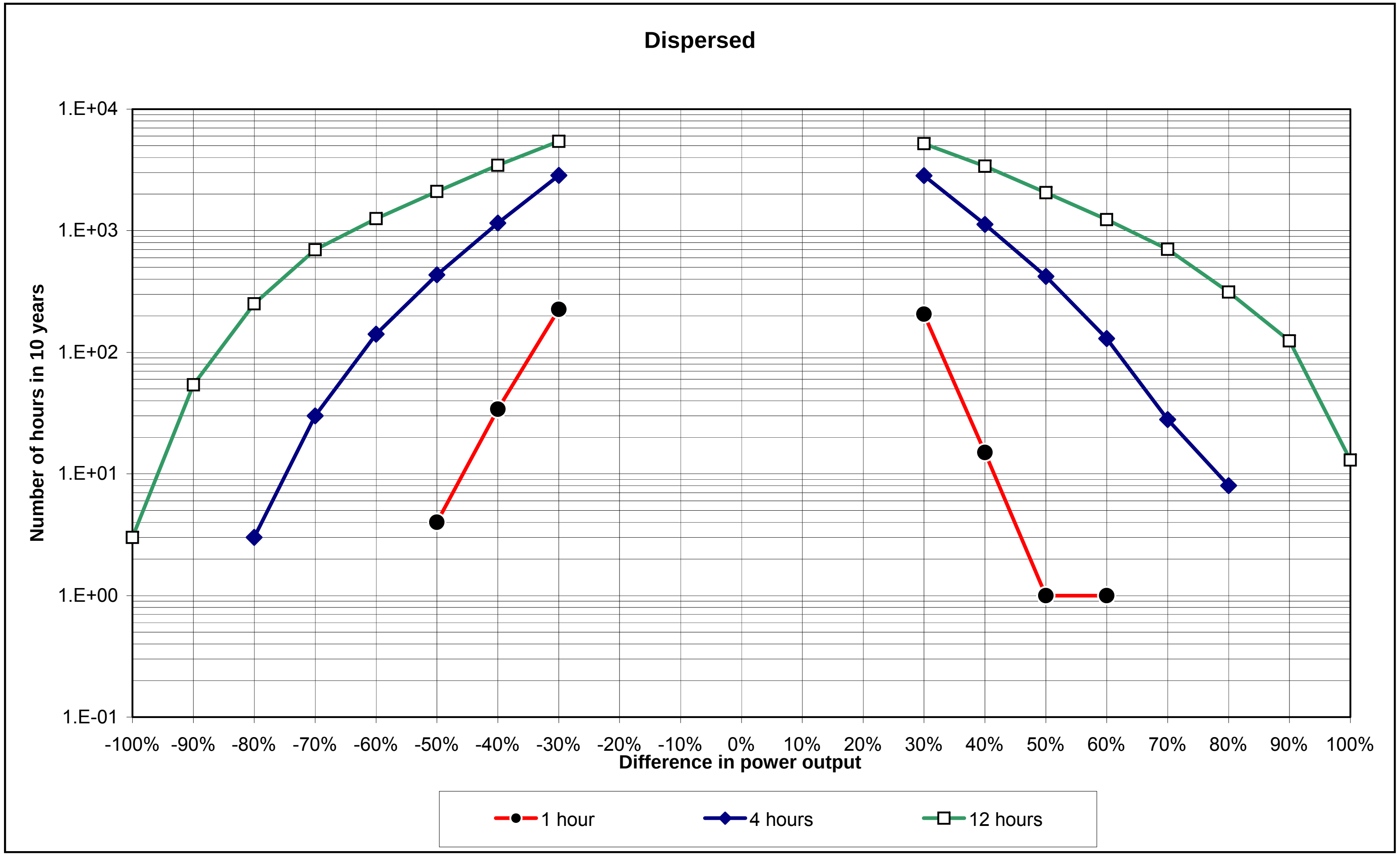
Variability, predictability and forecasting

Variability is not the same as *unpredictability*.

Wind generation is variable, but to some extent predictable.

The worst case is a storm front, which can cause many wind turbines to shut down from full output in a short time

Variability of dispersed wind farms: 5 wind farms



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Variability, predictability and forecasting

Variations in output power on timescales of >30 minutes are important for power system operators.

Fortunately, there is substantial ‘geographic averaging’ for areas the size of transmission systems. This effectively removes variability on timescales of minutes, and significantly reduces variability on timescales of 30 minutes to a few hours.

The previous slide (for five meteorological stations, ~200 km maximum spacing) showed the most extreme event was a change of 60% over 1 hour. This happened once in 10 years.

Similar analysis by GH for all wind farms in Germany for 2000 to 2003 shows the largest change over 1 hour was 16%. Worst-case figures of 20% over one hour are typically reported elsewhere.

Variability and predictability: what can you do about it?

1. Build enough transmission capacity to take advantage of 'geographic averaging', to reduce the magnitude of changes in wind production.

2. Forecasting techniques:
   - are good, and improving;
   - recent work is concentrating on forecasting periods of uncertainty, so the electricity system operator can be more cautious during those periods

Forecasting allows the electricity system operator to reduce the output of wind generation in advance of critical periods. This solves many possible problems, but:

- the electricity system operator must have the legal ability to do this;
- who pays for the 'lost' production from the wind generation?

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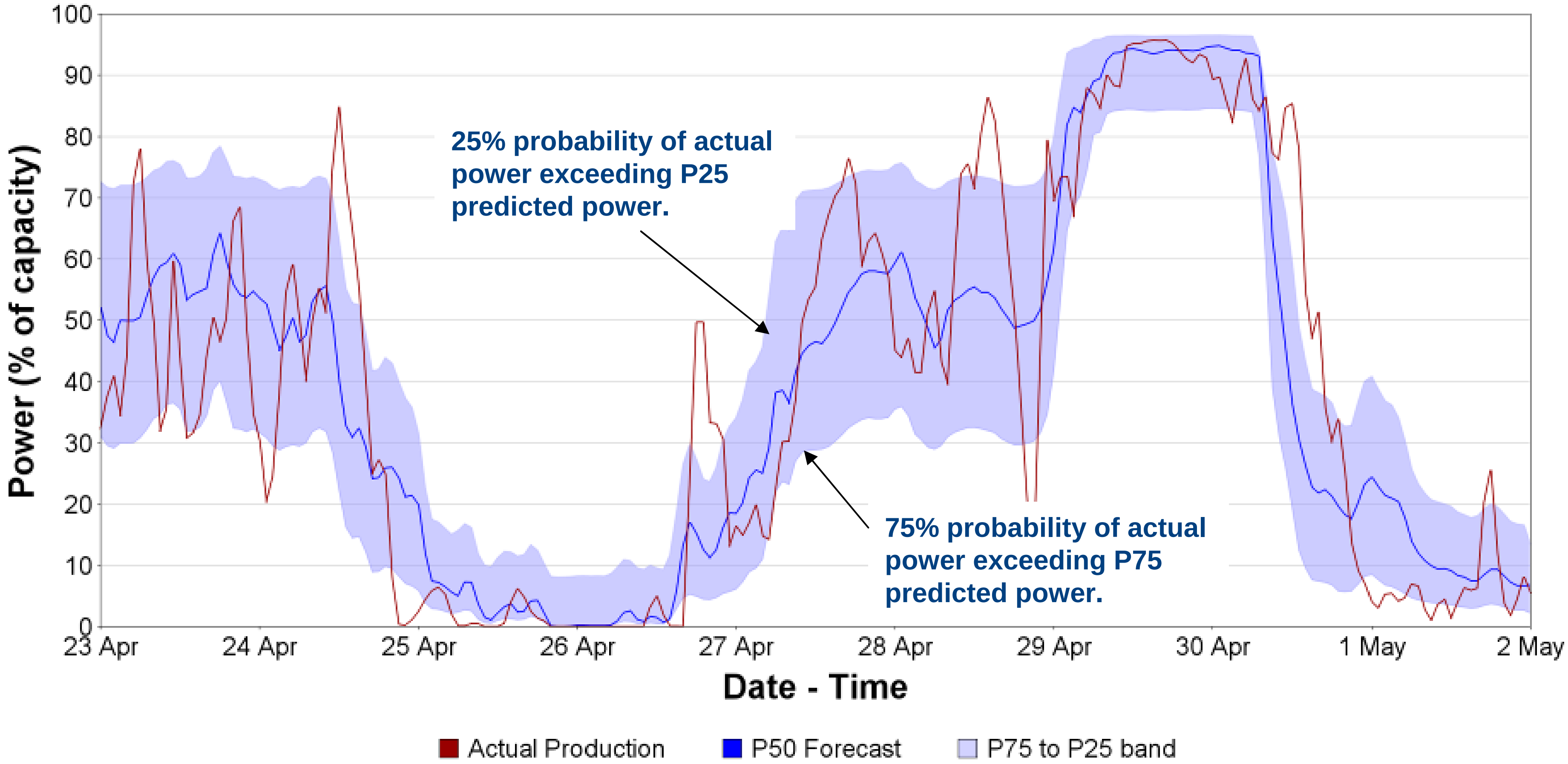
Forecast Certainty

Hourly data 12 hours in advance



Integration issues: summary

• New problems, not encountered before.

• None of the problems are insoluble, i.e. there are no absolute limits on wind generation capacity on any electricity system.

• However, as wind penetration increases, unit costs also increase, which may eventually make wind less attractive than alternatives

• In the West, expansion of wind generation often occurs at the same time as deregulation or re-organisation of the electricity supply industry, which adds to the difficulties

• Some issues can seriously impede progress towards national targets:
  • Getting Grid Code modifications agreed
  • Getting network operators to understand the technical issues
  • Building transmission capacity

Extra slides (in case of questions)

Definitions

The following concepts are useful, for understanding the effect of wind generation on an electricity system, and comparing systems:

Wind energy penetration:

Annual production from wind generation as a fraction of total electricity consumption.

Wind capacity penetration:

Wind capacity as a fraction of total generating capacity.

Curtailment of wind generation

Curtailment: instruct the wind generation to reduce output (also called ‘constraining off’)

Because:

- part of the transmission system is becoming overloaded (perhaps due to a failure);
- a rapid reduction in wind output is expected, and the TSO wants to reduce the rate-of-change;
- the wind generation is displacing conventional generation, which is needed to provide:
  - Inertia
  - Frequency response

Wind has zero fuel cost, so is only constrained as a last resort.

Who pays?

Increased costs for system operation

Wind saves fuel costs, and will reduce the need for new conventional power stations, but against this must be set:

- Transmission reinforcement capital cost
- Possible increased electricity losses (because the wind generation may be located further from the main load centres)
- Increased ‘balancing costs’ to cope with the increased variability of wind generation
- Increased ‘balancing costs’ to cope with the increased uncertainty

Many national-level studies have quantified these factors, and concluded that for wind capacity penetration levels of 10 to 20%, the effect on final consumer price is very small. Costs will rise for higher wind penetrations.

Energy storage

In principle, energy storage can solve:

- Variability and unpredictability of wind generation
- Need for transmission reinforcement

Possible technologies

- Batteries (various forms)
- Pumped hydro
- Compressed air
- Hydrogen
- Heat
- …. many others

But: so far too expensive, and too inefficient (~70-80% in/out efficiency)

"The cheapest short-term electricity store is steam in a boiler, and the cheapest long-term electricity store is a pile of coal."

The End

Thank You!

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