25GW of distributed wind on the UK electricity system

7th Dec 2006

An engineering assessment carried out for the
Renewable Energy Foundation, London

Oswald Consultancy Ltd

Weather data has been kindly provided by the Met Office and the British Atmospheric Data Centre which is Crown Copyright.

This analysis is based in part on data obtained from the Ofgem Renewables Obligation Certificate Register (http://www.rocregister.ofgem.gov.uk/main.asp). Further information, such as the installed capacities of the generators has also been obtained from Ofgem. All this information is in the public domain. Oswald Consultancy Ltd have taken all reasonable measures to ensure that this information and the subsequent analysis is correct (errors and omissions are excepted).

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Introduction

- The UK government aims to increase renewable energy provision into the into the UK national electricity grid. They have a target of 15% electrical energy by 2015 and an aspiration of 20% by 2020
- Wind is an uncontrolled energy resource, it blows when it wants.
- Integrating this level of wind into a highly controlled grid system brings new challenges
- EoN Netz in Germany and Avista Utilities in California have both declared that managing power variations from wind is problematic
- This study has assessed the impact 25 GW of wind will have on the grid. This represents 16% of energy at a Capacity Factor of 30%
- In particular the power variations of a distributed wind fleet is assessed and found to be
  - Highly volatile, combining large magnitudes of power fluctuation and high rates of change
  - To balance the grid, other generators will be required to vary output
  - Reduce the opportunity for other renewable generators to supply electricity

Wind turbine basics

- The power in the wind is given by

$$Power = 0.5 \times \rho \times v^3 \times Area$$

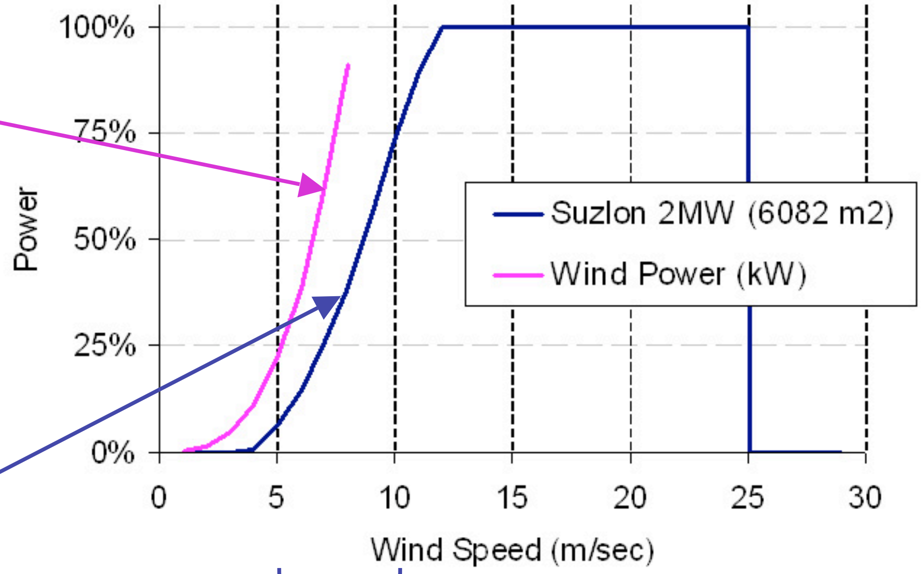
$\rho = air\,density$

$v = air\,velocity$

$Area = Swept\ area\ wind\ turbine$

  - Note that power is a cubic function of wind speed. This makes power very, very sensitive to speed

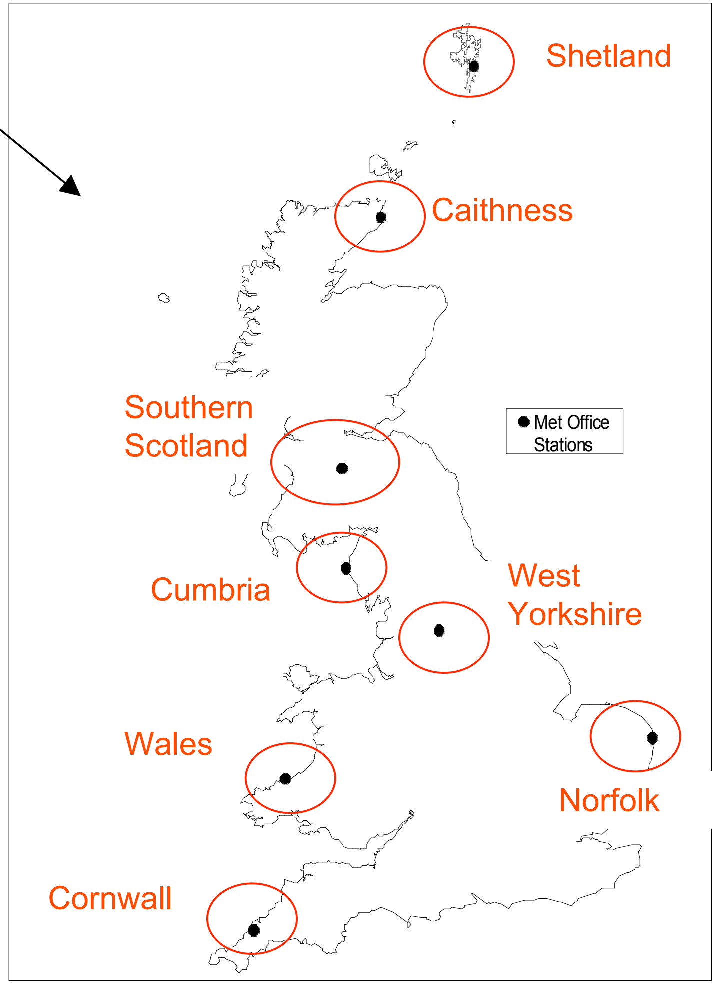
- A wind turbine deliberately spills most of this wind energy to give the power characteristic shown



Doubling wind speed from 5m/sec to 10 m/sec increases power from 6% to 73% of rated output, a 12 fold increase.
This is illustrates why wind turbine output can vary enormously within a few hours

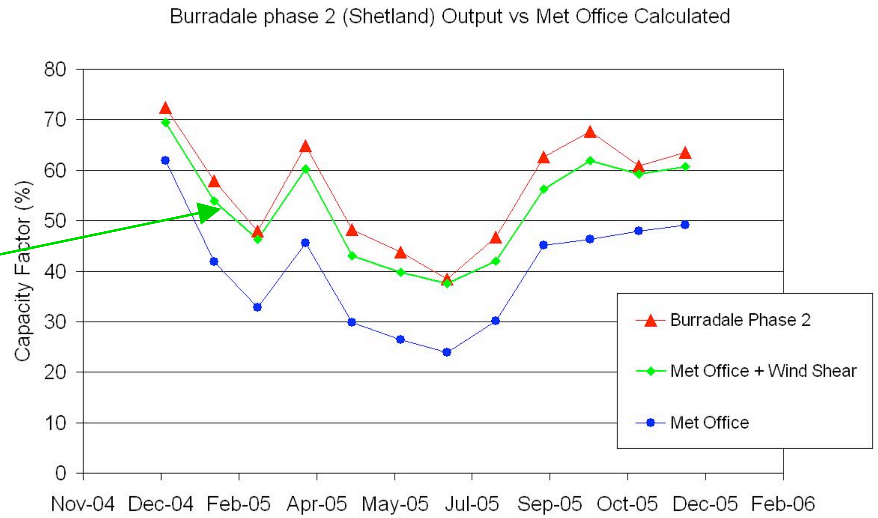
The 8 dispersed regions

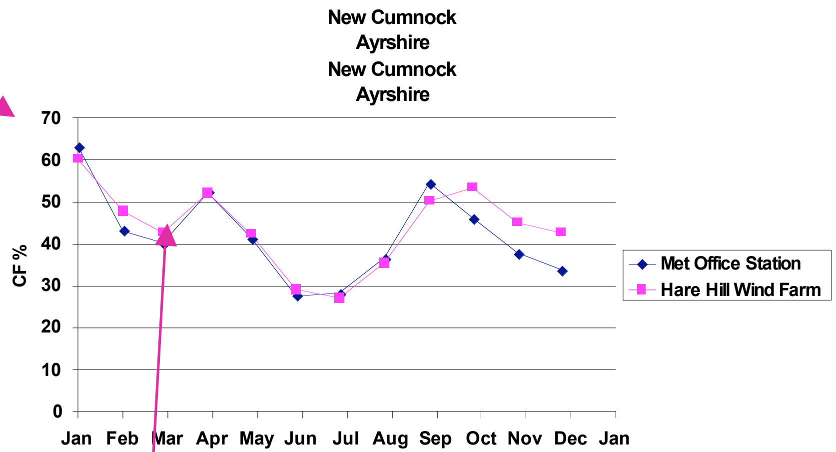
- 8 well dispersed regions were chosen
- The output of these regions has been analysed using published ROC output data from Ofgem.
  - This showed the national capacity factor for the UK to be 28.2% in 2005
- The regions currently have significant numbers of wind turbines which
  - demonstrates that the sites are windy
  - allows scale factors to calibrate Met data to Ofgem data
  - In practice, Shetland is too far for grid connection but is exceptionally windy
  - There is no region for central England as this has little wind



Using Met Office wind speed data

- Two wind speed scale factors were employed to adjust for
  - Hub height differences
  - Location effects
- Hub height scale factor yields the green curve from the basic Met Office data
- Location scale factors were chosen to align with Ofgem data and give a best case scenario for UK wind
  - This gives calibrated results for determining wind output from Met Station data
  - The resulting Capacity Factor from the UK model was 1.26 times higher than achieved in 2005 i.e. 35.5% versus 28.2% which is at the high end of expectation





South Scotland with location scale factor 1.2

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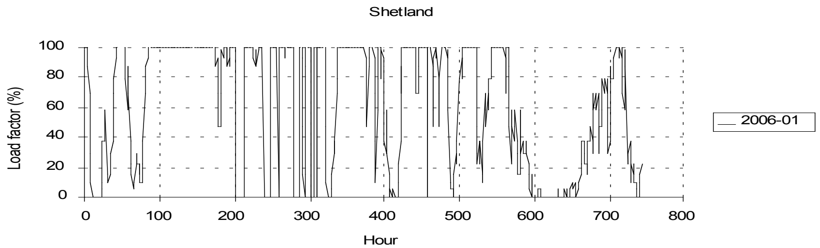
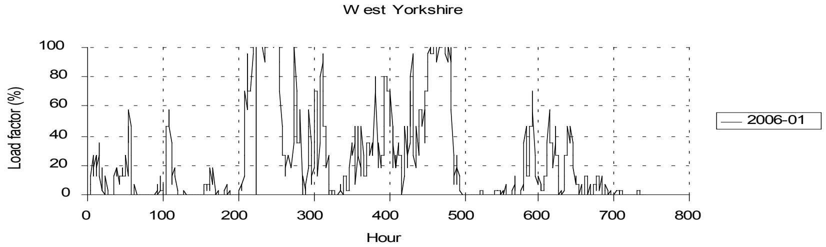
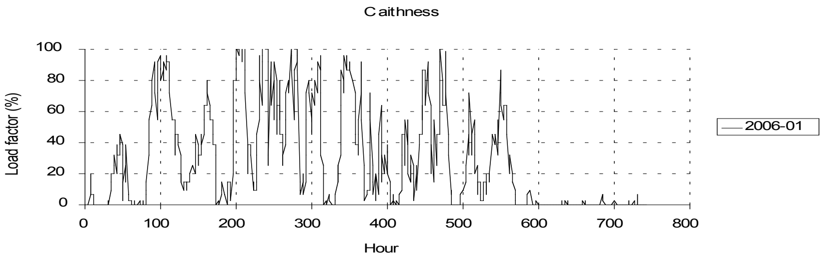
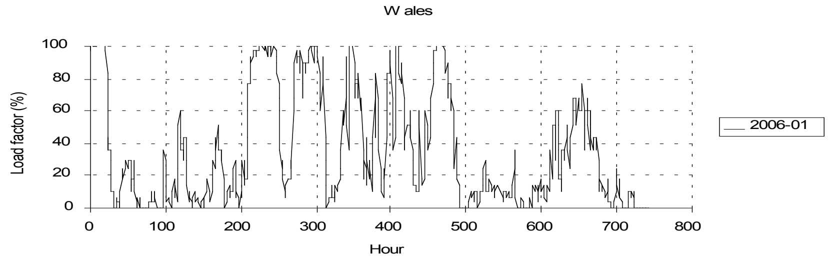
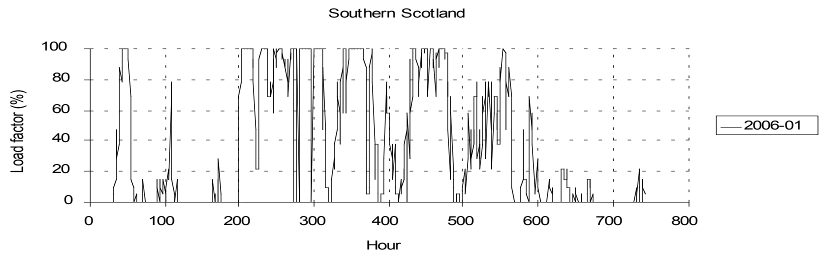
Results 8 Individual Regions, Jan 2006

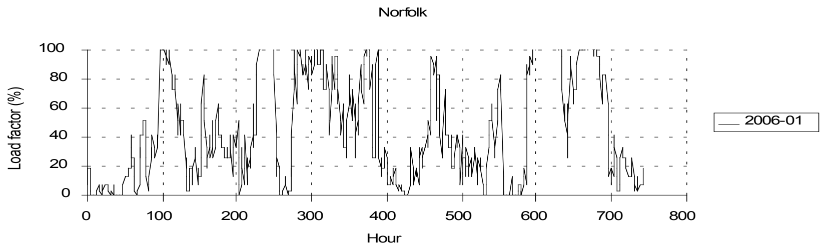


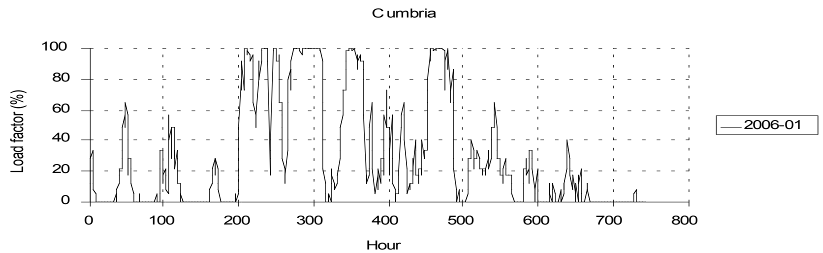


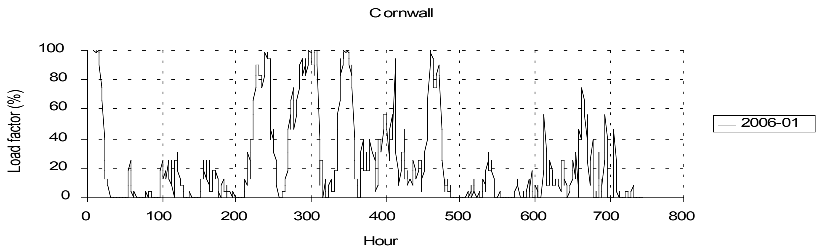




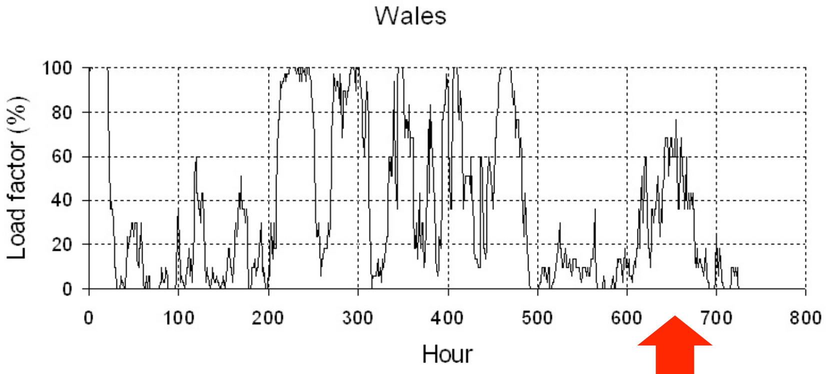




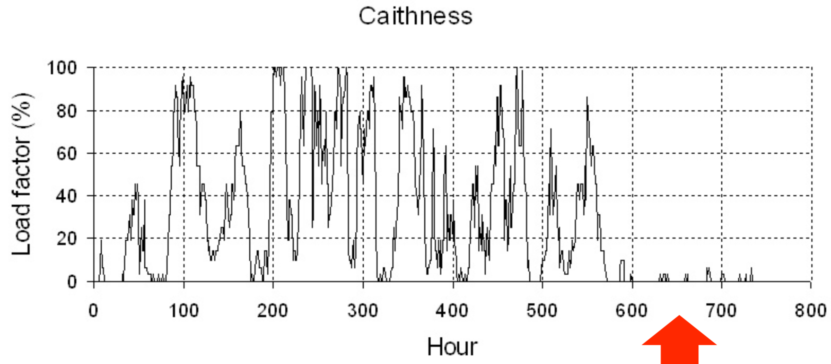




Aggregating does smooth output

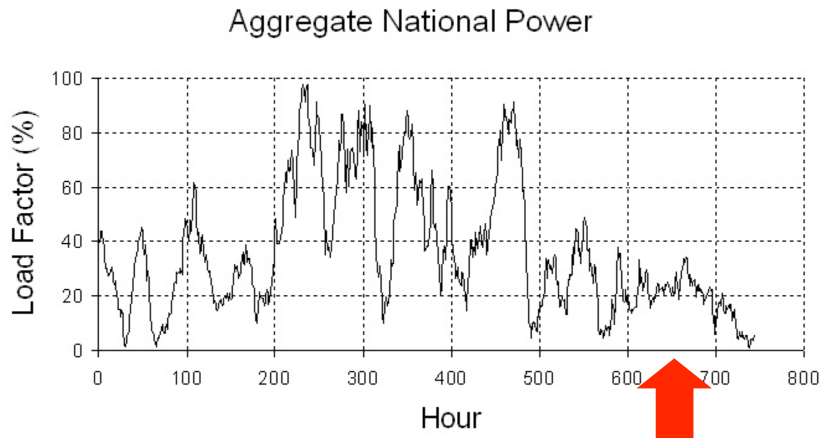


Ramping



Zero

- Some have argued that distributing wind turbines will smooth output
- This is correct, the aggregated output is smoother than the individuals
- However, overall power output is far from smooth



Smooth

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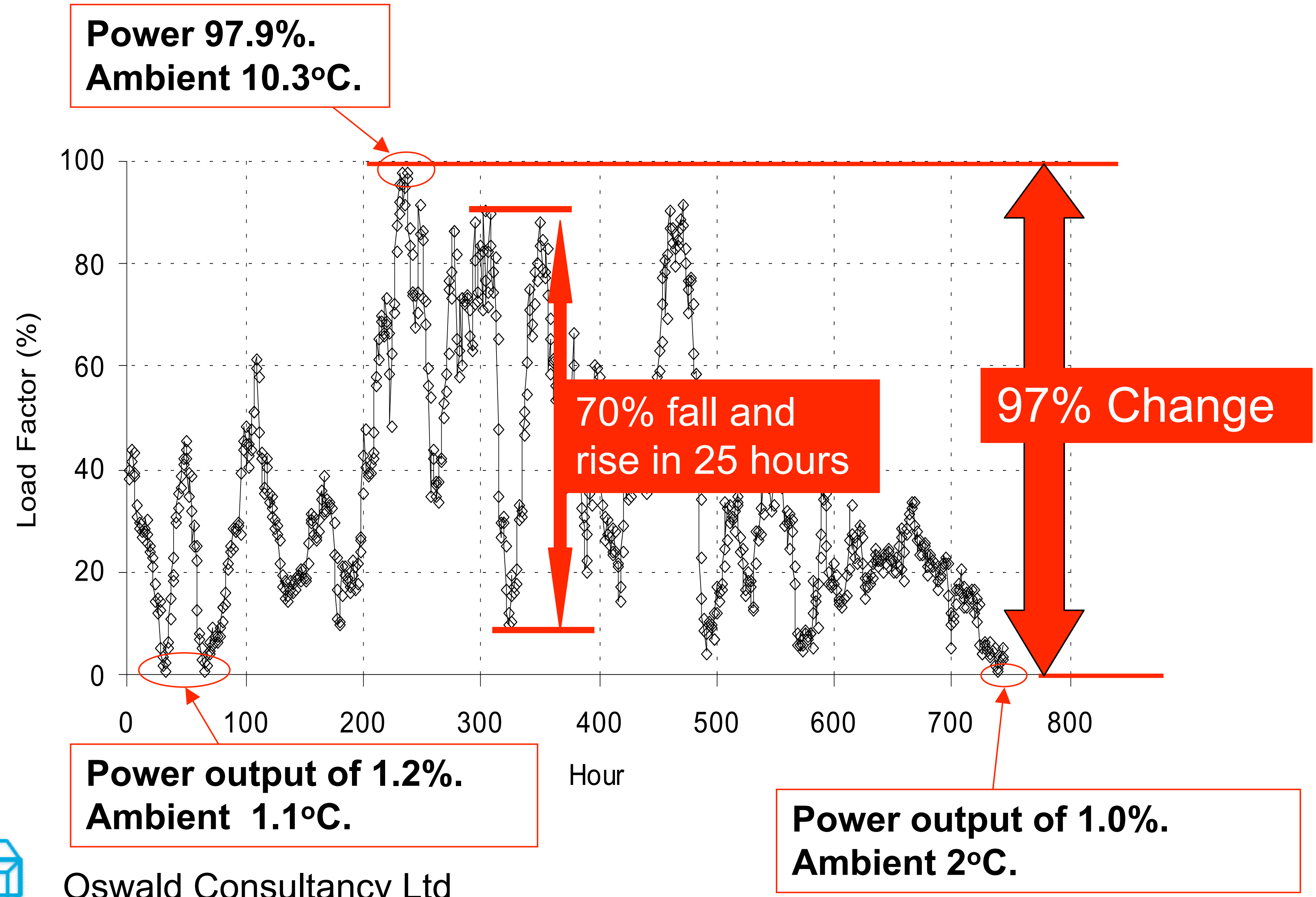
Aggregated UK output, Jan 2006



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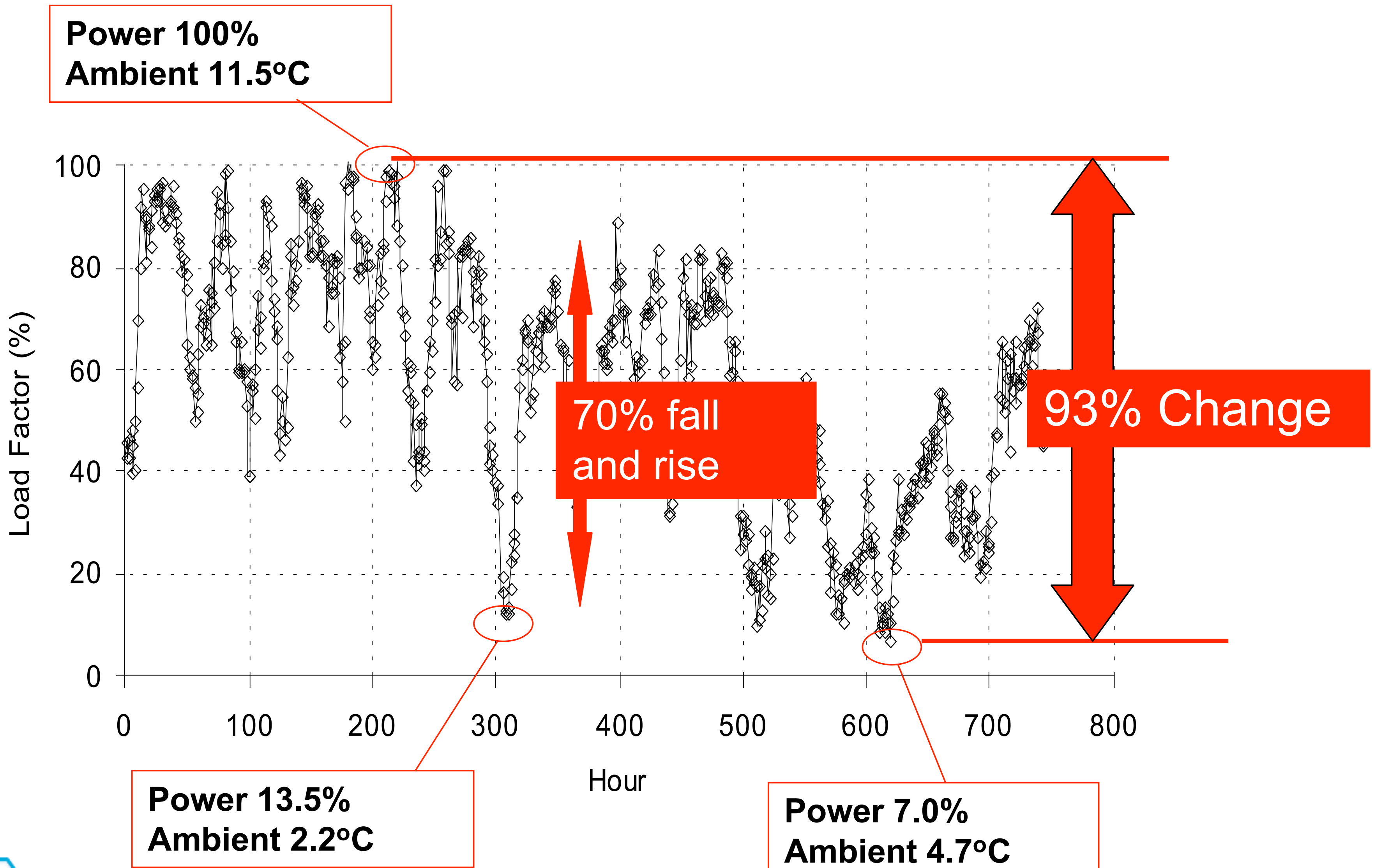
Aggregated UK output, Jan 2005



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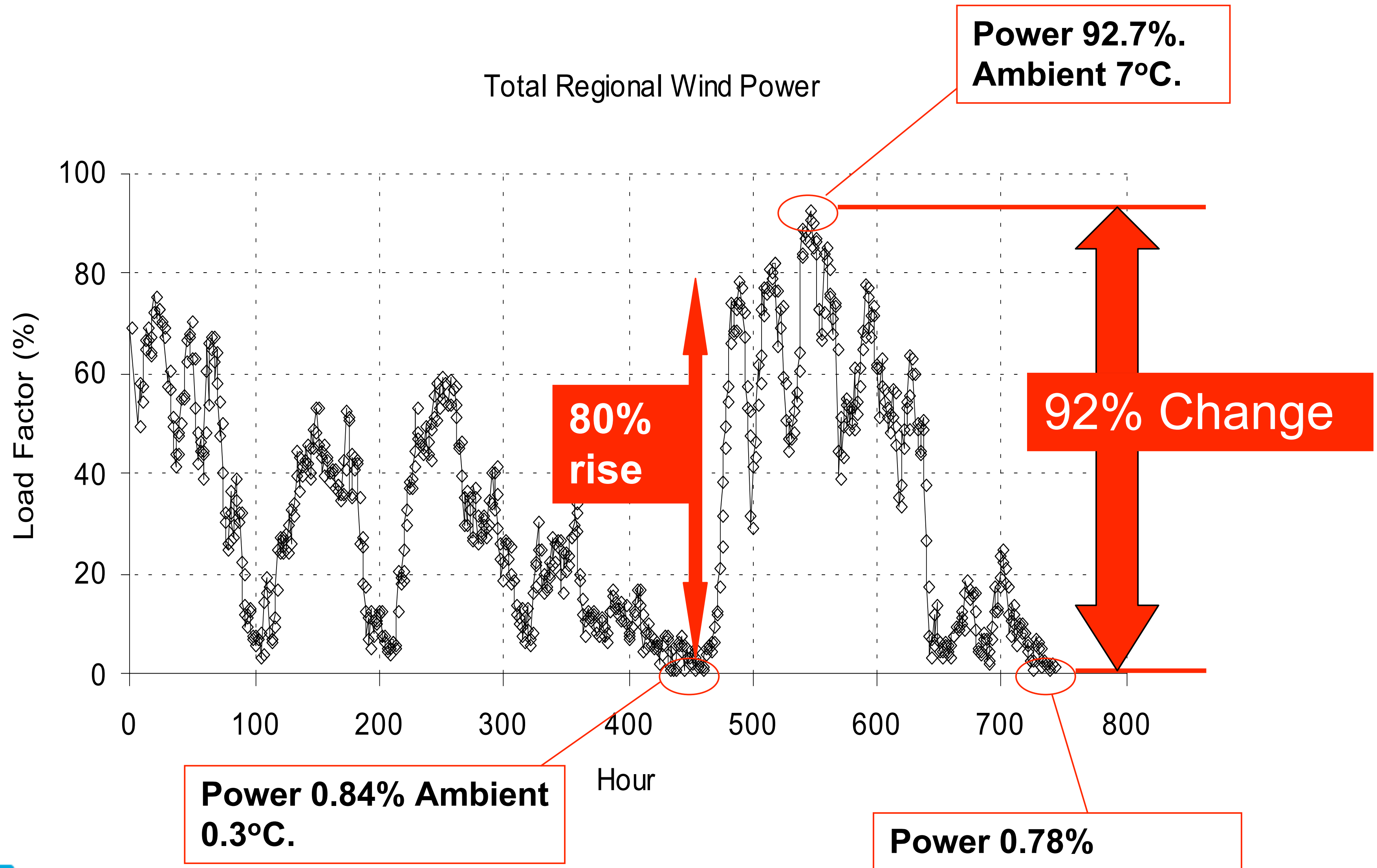
Aggregated UK output, Jan 2001



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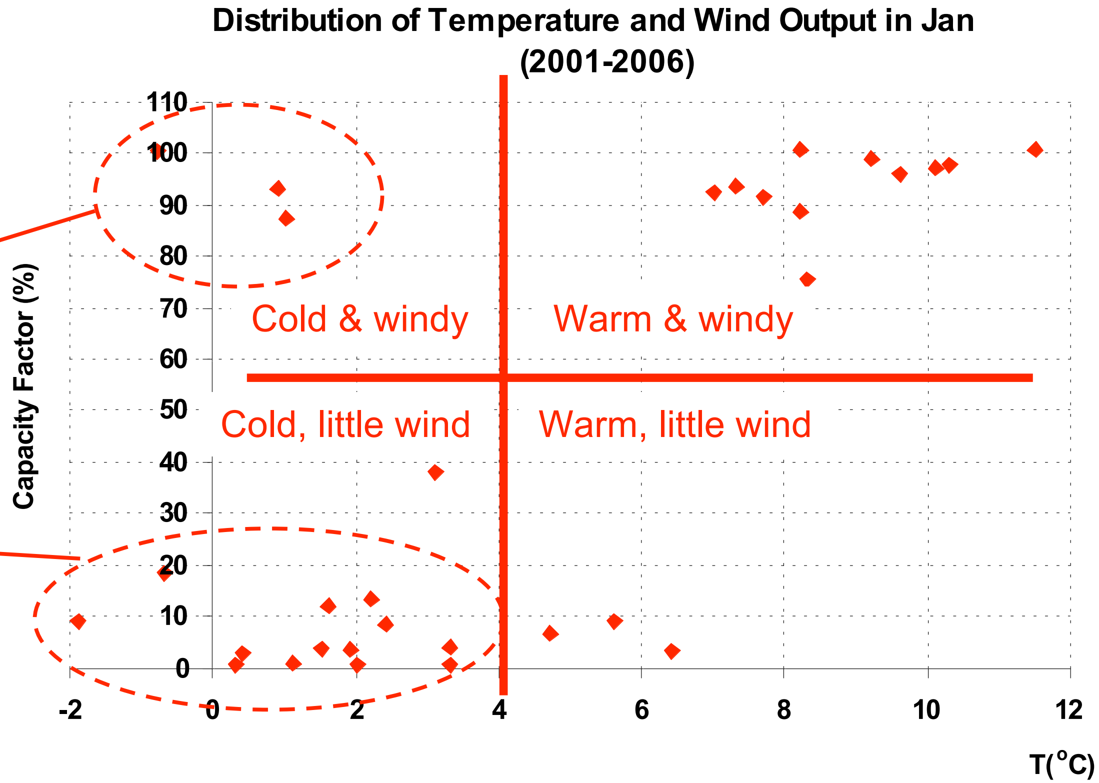
Summary of January output variations

- Over the last 12 years, on average, January wind power varies by 94% of installed capacity.
  - This variation is decided by the weather
- On average, the minimum output is only 3.7%
- Power swings of 70% in 30 hours are commonplace in January
- Other generators must vary output to ensure the grid remains balanced

Date	Max Power Change	Minimum power
Jan 2006	97%	1%
Jan 2005	93%	7%
Jan 2004	93%	3.2%
Jan 2003	96%	3.9%
Jan 2002	92%	8.7%
Jan 2001	92%	0.8%
Jan 2000	98%	1.7%
Jan 1999	99%	0.6%
Jan 1998	99%	1.1%
Jan 1997	80%	2.8%
Jan 1996	89%	10.2%
Jan 1995	96%	3.7%
Average	94%	3.7%

Wind fails to deliver when it is cold

- This shows the peaks and troughs of wind output for Januaries 2001 - 2006 vs ambient temperature
- It has been argued that maximum electricity demand occurs when it is cold and windy. This can be true, but it is more likely to be cold and still
  - Although average output is higher in January, it often occurs at the wrong times



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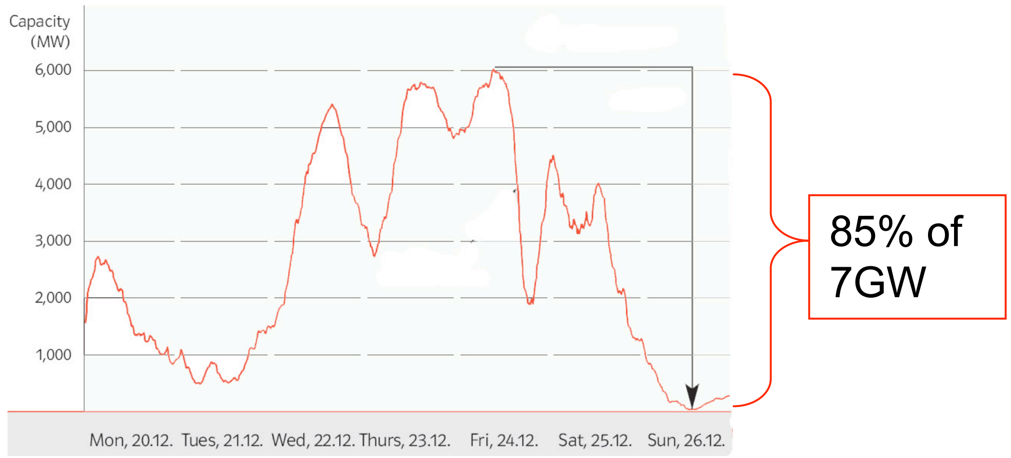
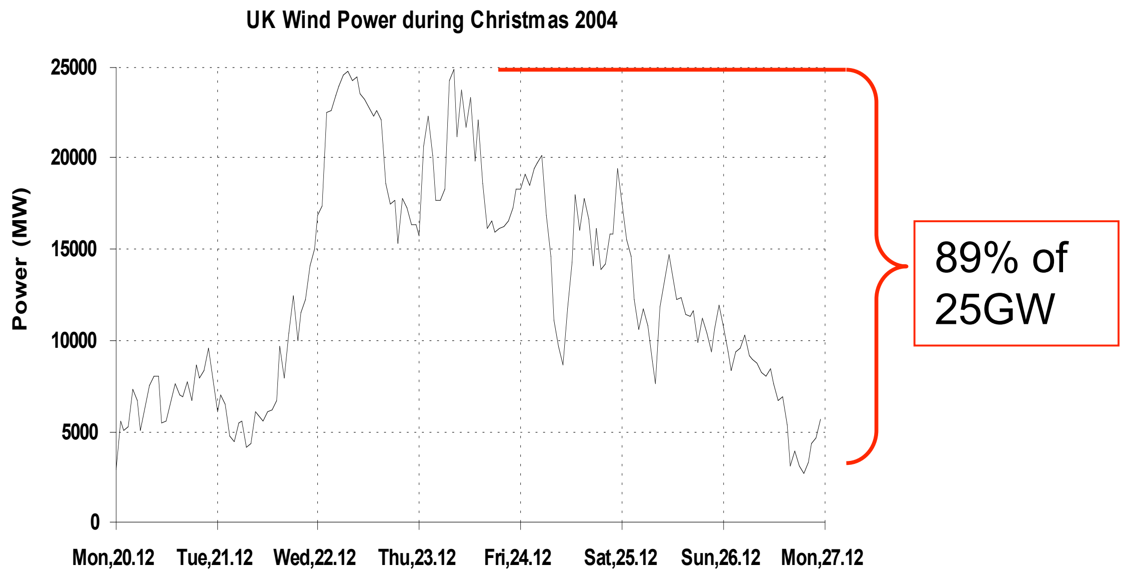
Comparing to German experience

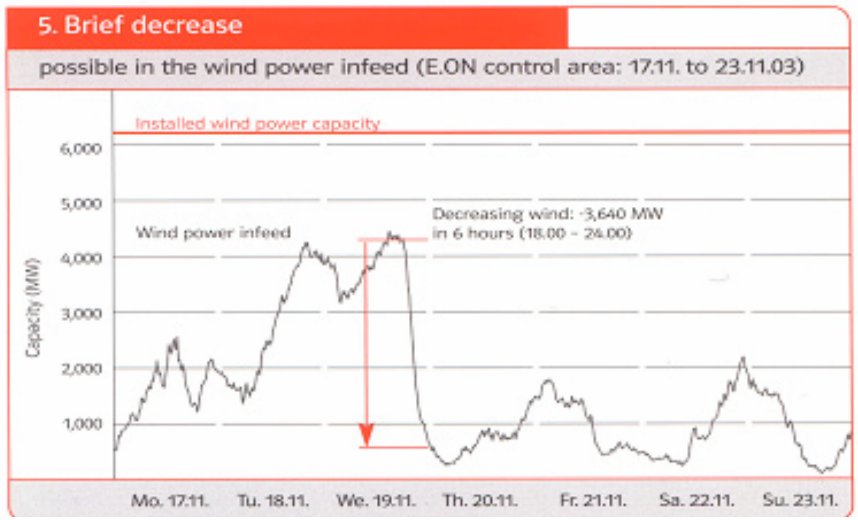
- In the week of Christmas 2004 E.ON Netz in Germany reported a major rise and fall in power from their wind fleet.



- For the same time, the UK model predicts the same occurring in the UK

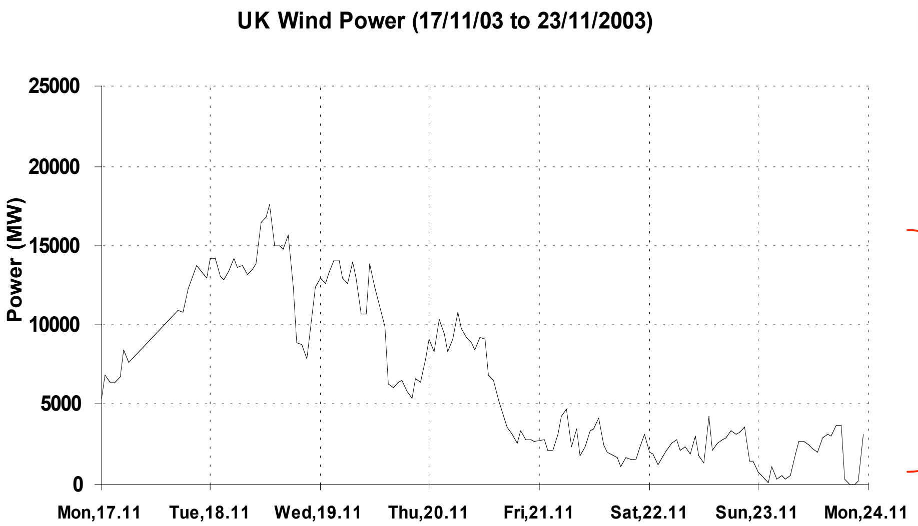


And in Nov 2003



59% of 6.2GW

- E.ON in Germany experienced a 59% fall in wind output over 6 hours on 19th Nov 2003



70% of 25GW

- At the same time the UK model predicts a similar rise and fall of output in the UK, but at a slower rate

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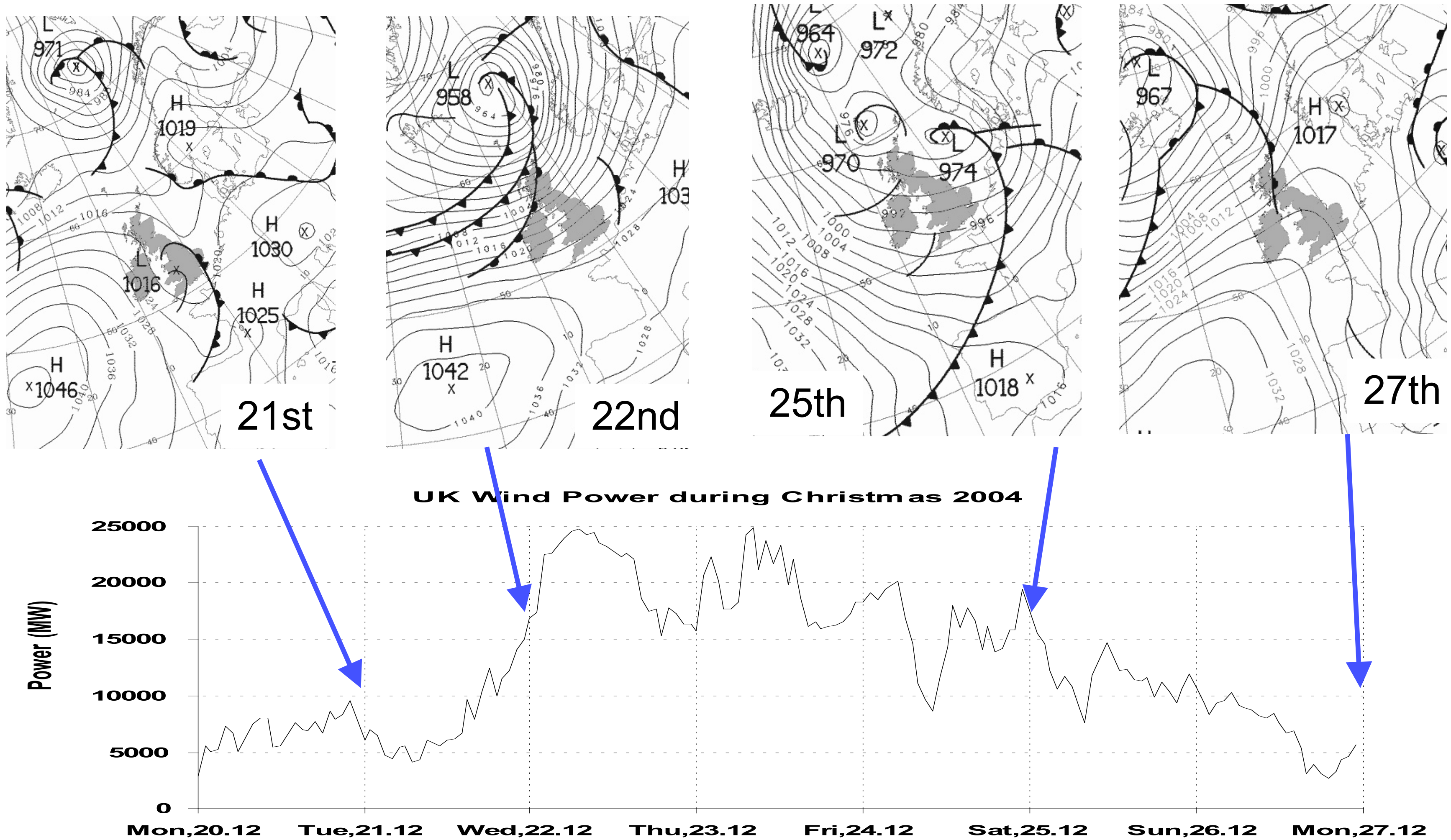
Meteorological pressure charts explain it



- The closer the isobars the stronger the winds
- Weather systems are bigger than countries

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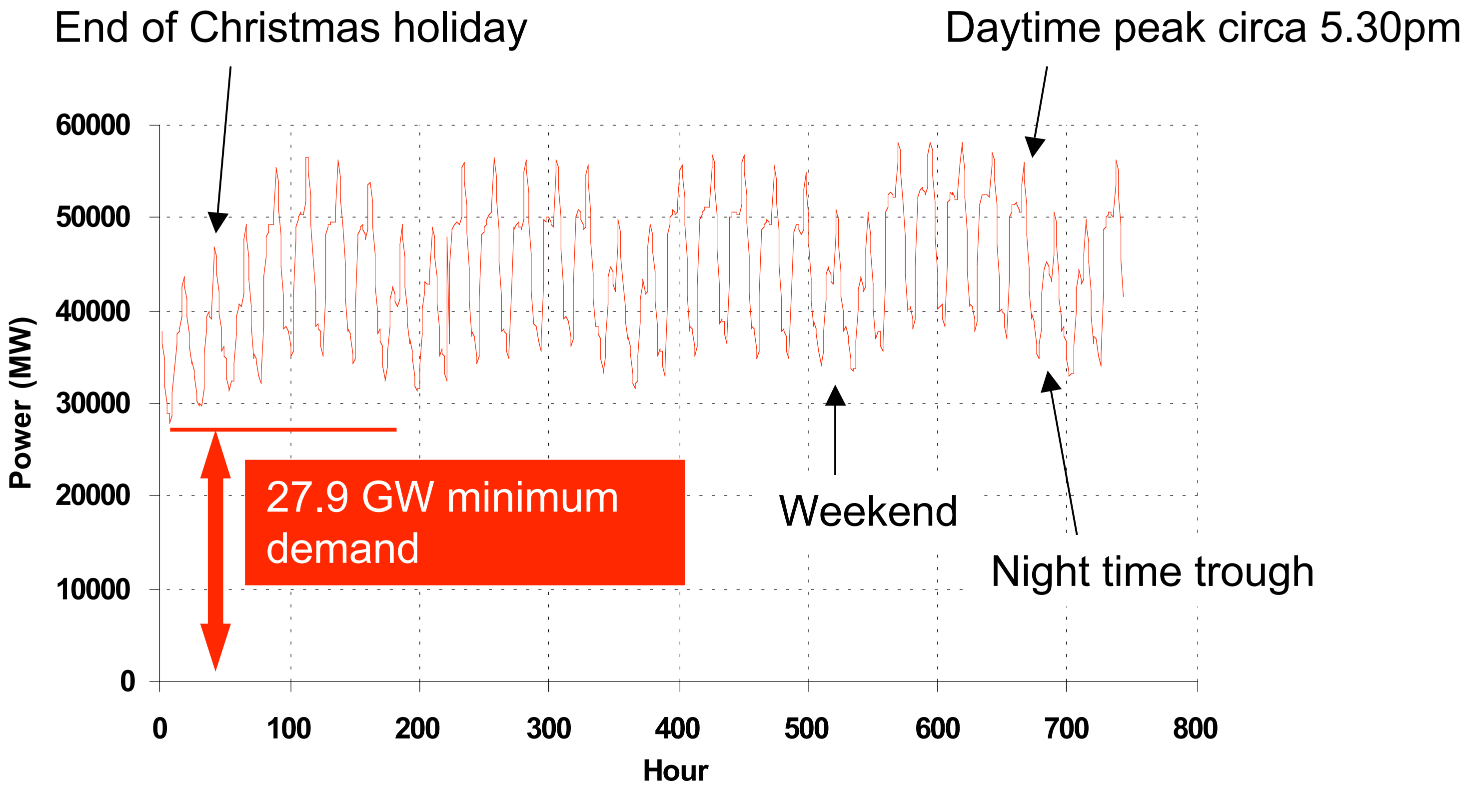
Effect on other generators

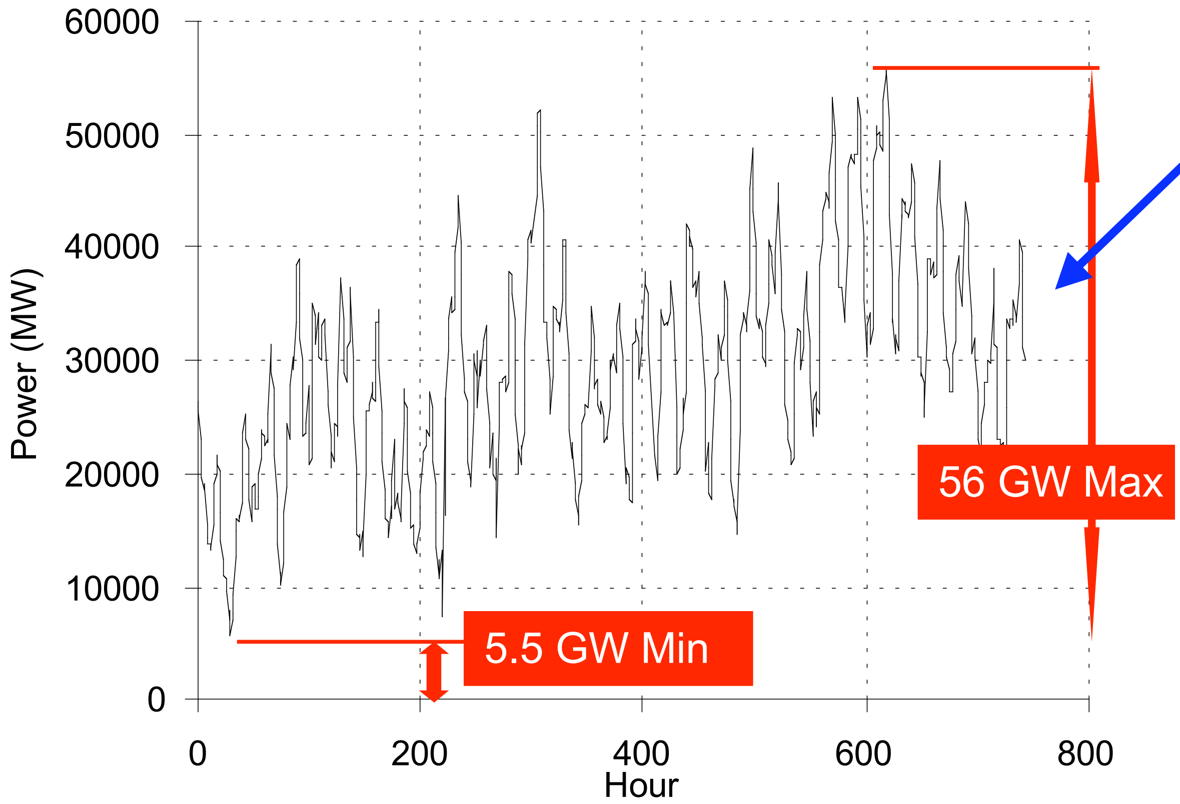
The remaining plant on the grid must compensate to balance the grid

UK consumer demand, Jan 05



- Demand is predictable and familiar
- Adding on wind power leaves the ‘Residual demand on other generators’

Residual demand on other generators (Jan 05)



- Unpredictable, random
- Large variation (5.5GW to 56GW)
- Increased thermal cycling of base load plant.
- Opportunities for operator mistakes in plant & grid control
- Reduced opportunities for other low carbon technologies

Issues

- Chose which low carbon technologies get precedence on grid
- Thermal cycles will damage conventional plant and reduce availability

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Conclusions

- Distributed wind is smoother than local wind but output is still highly volatile and uncontrolled
- Weather systems are much bigger than countries. This
  - Limits the smoothing that can be achieved
  - Weather systems last for days and long periods of little wind can occur
  - UK can expect fluctuations to follow German experience
- Wind delivers energy in short intense bursts which requires other plants to cycle up and down. This
  - Reduces availability of balancing thermal plant
  - Reduces opportunities for other renewables to generate
- Statistically, minimum wind occurs on colder days
- Too much wind capacity causes problems with
  - Control and balancing of the system
  - Balancing plant operates less reliably as a consequence of cycling

Recommendations

- 25GW of wind may be excessive which may lead to curtailment for operational reasons, as has occurred in Germany
  - A more balanced mix of renewable and low carbon technologies would be preferable with priority given to controllable technologies
- A Government shift to other low carbon technologies is justified
  - The RO would be better if it rewarded load following for the benefit of the system
- Government needs to ensure wind is distributed across the country or offshore and not simply concentrated where winds and returns are highest