



## Storm Control and Reliability Indexes of Offshore Wind Farms

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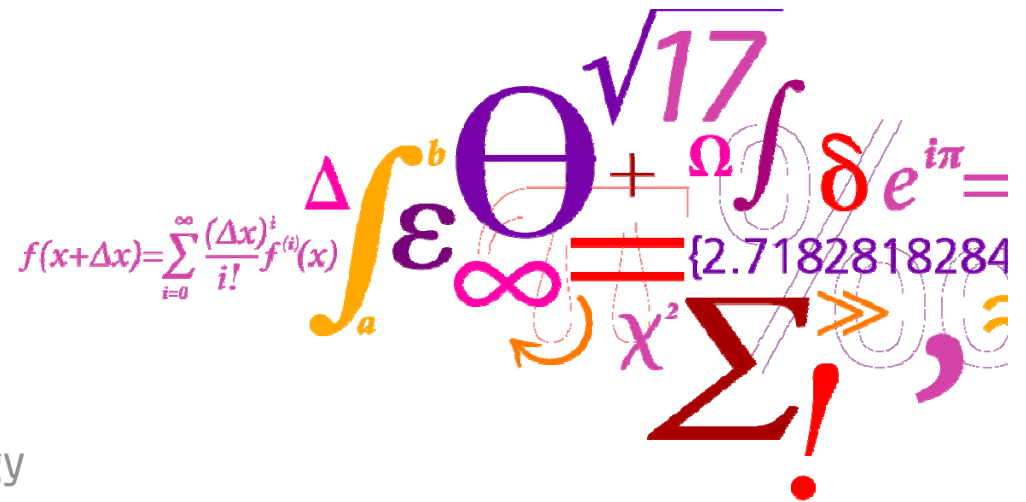
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# Storm Control and Reliability Indexes of Offshore Wind Farms

Nicolaos A. Cutululis

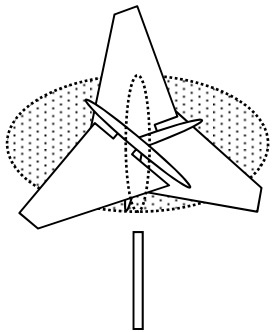


# Outline

- Wind power fluctuation model
- Storm control
- Simulation scenarios
- Simulation results
- Conclusions

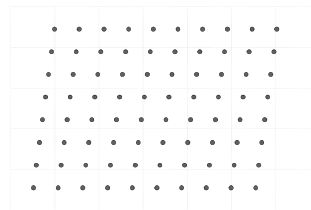
# Wind power fluctuation models

2002



Wind turbine(s)

2007



Wind farm

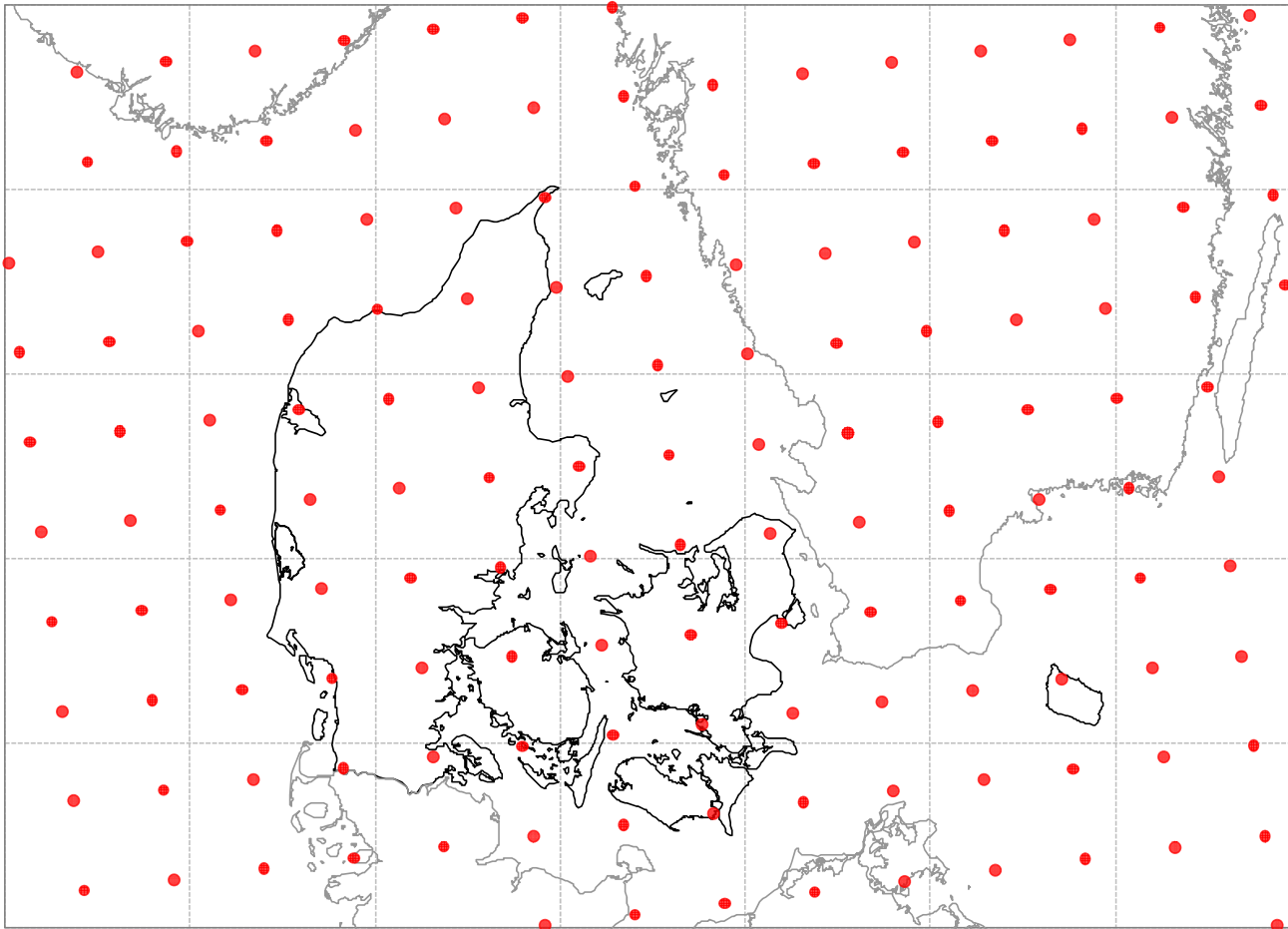
2009



Power system area

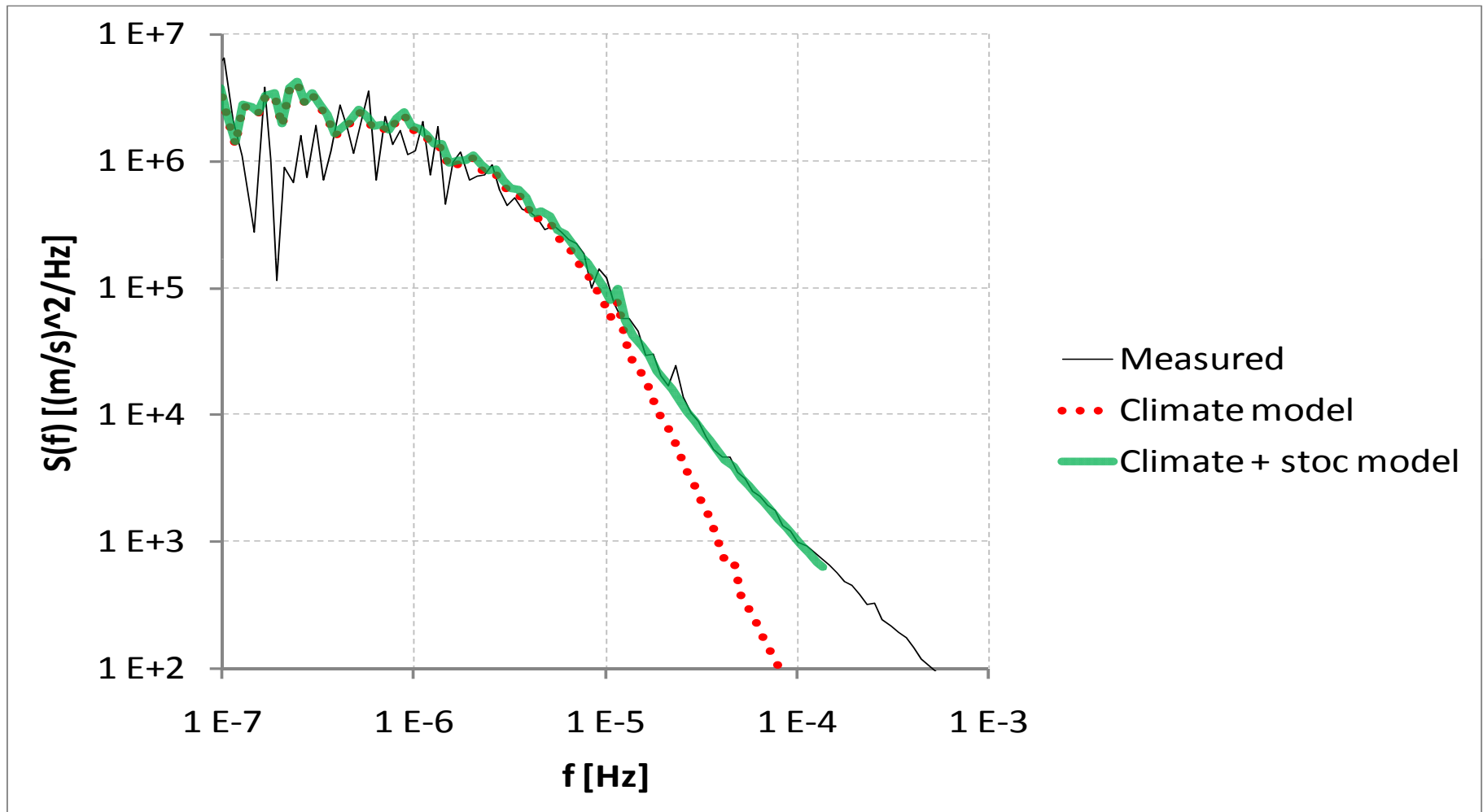
# Climate model resolution

Supplied by MaxPlank Germany  
 25 years of data  
 1 hour 50 km resolution

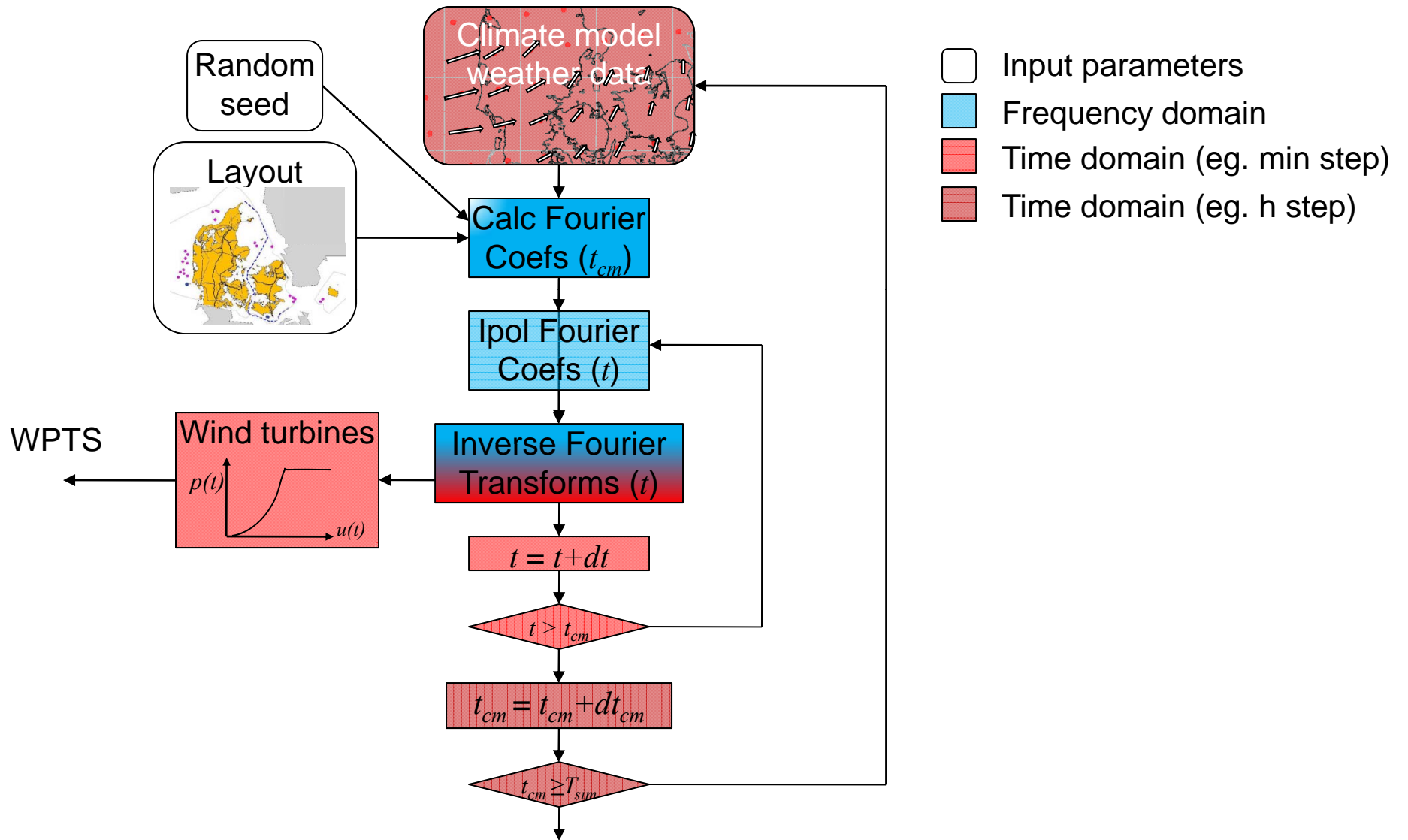


# Climate model + stochastic model

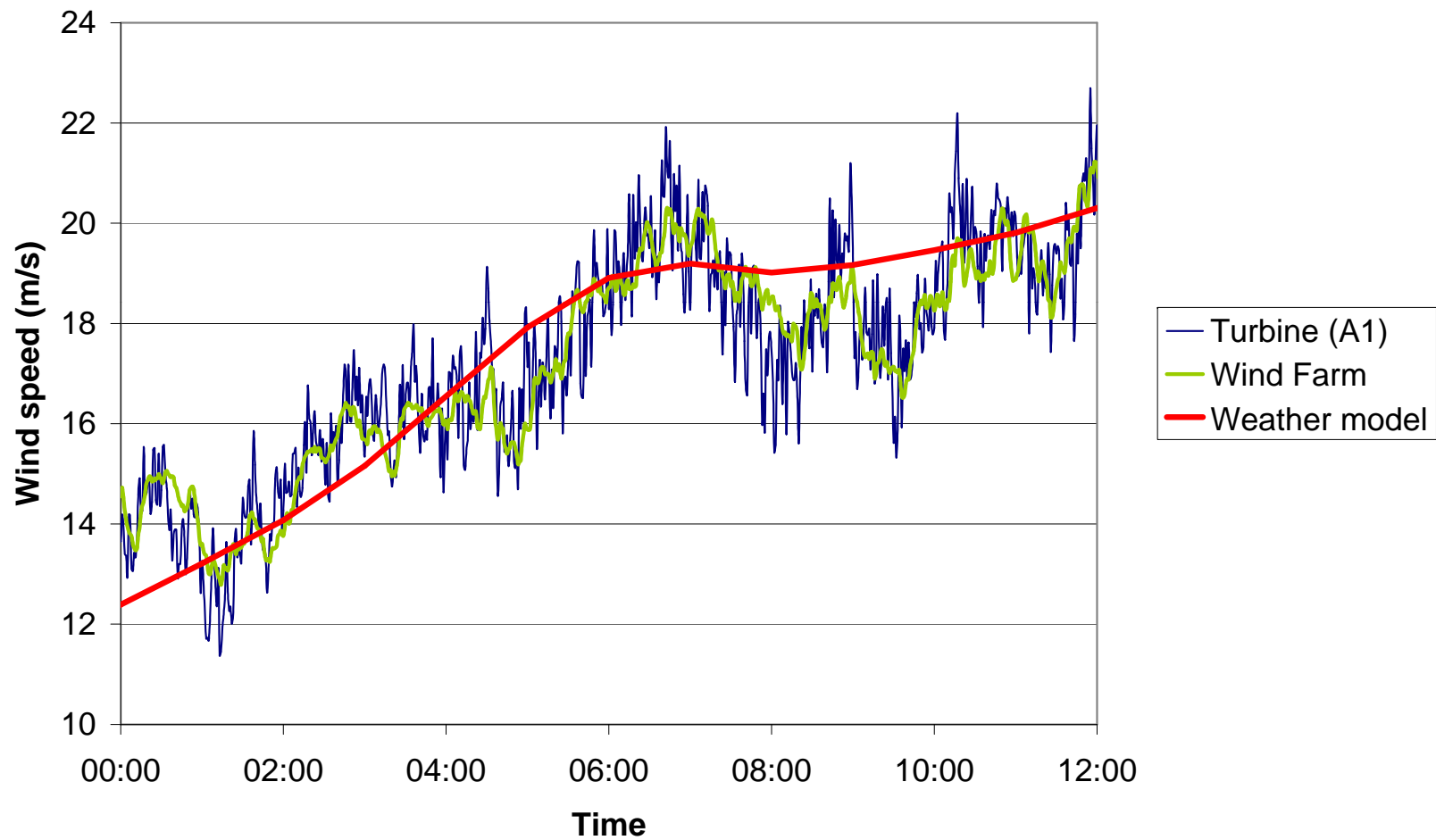
Horns Rev example



# Region wind power model - CorWind

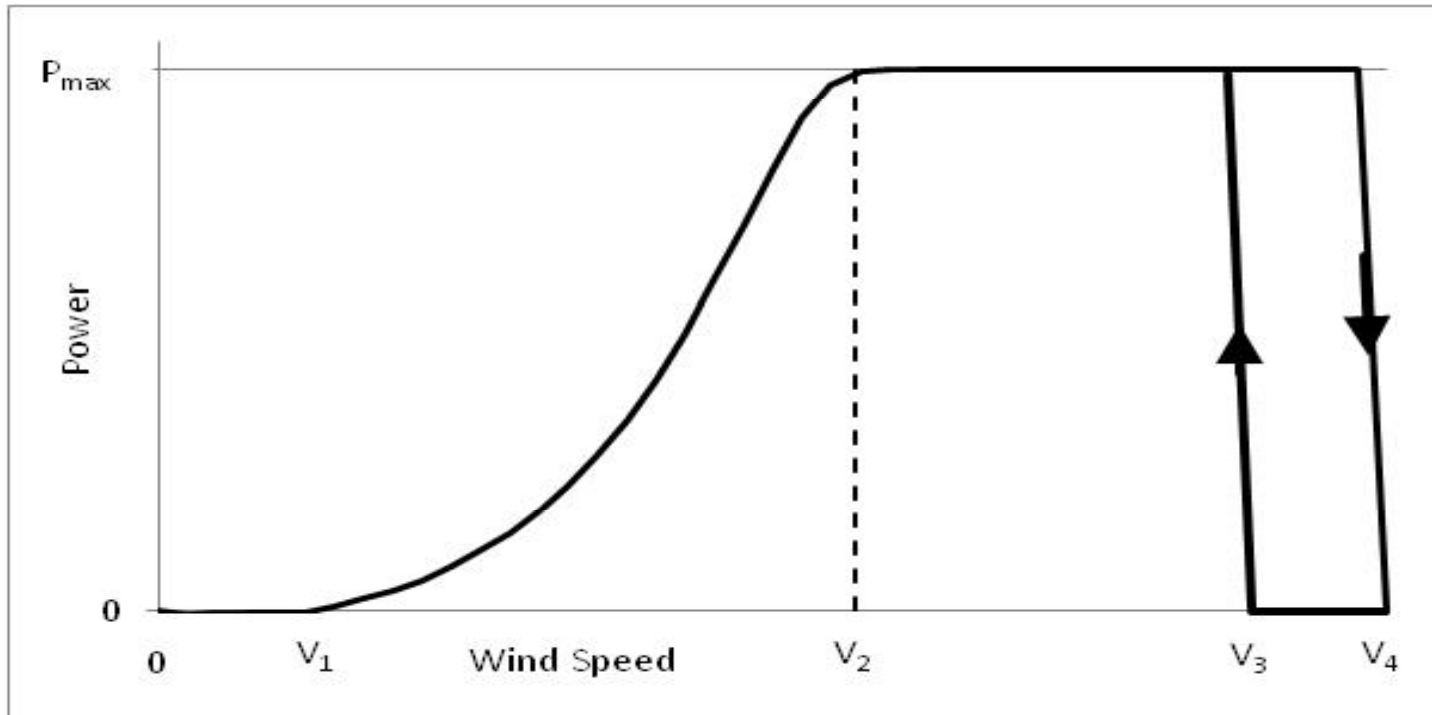


# Simulated wind speeds - smoothing



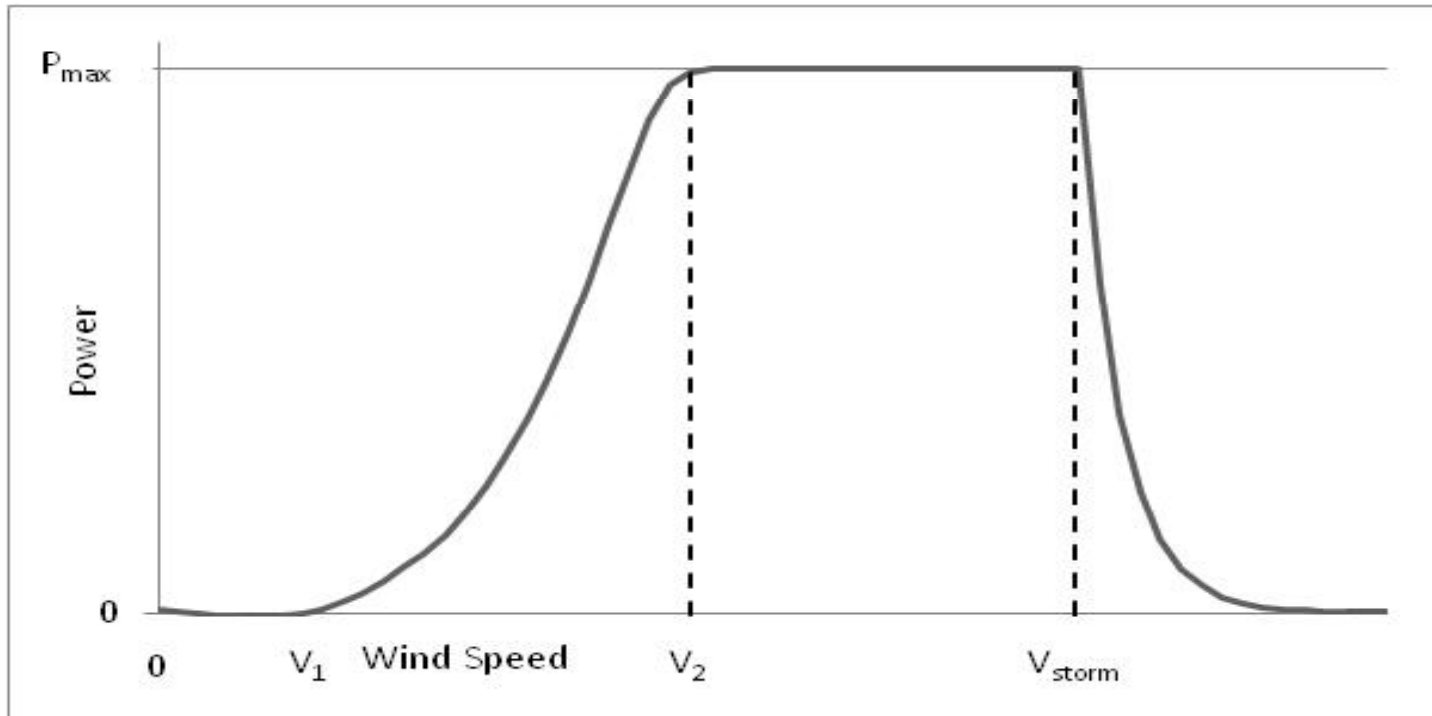


# Storm Control



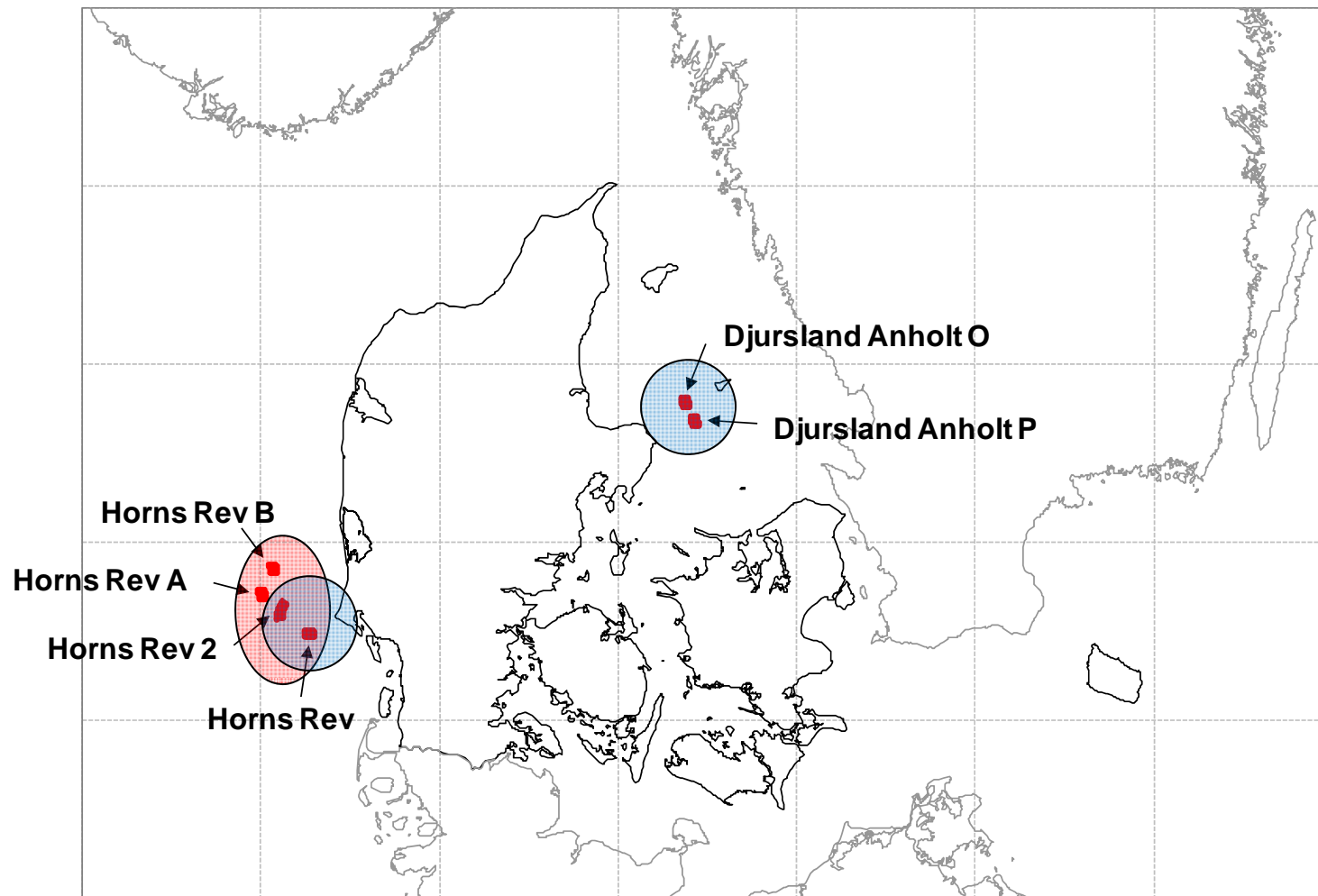
Hysteresis Storm Transition (HST)

# Storm Control



Soft Storm Transition (SST)

# Simulation cases



# Simulation cases

Name	Symbol	Wind turbine power	Total power	Annual mean wind speed
<b>Horns Rev</b>	HR1	80 X 2.0 MW	160 MW	9.6 m/s <sup>*)</sup>
<b>Horns Rev 2</b>	HR2	91 X 2.3 MW	209 MW	10.4 m/s <sup>*)</sup>
<b>Horns Rev A</b>	HRA	40 X 5.0 MW	200 MW	10.6 m/s <sup>*)</sup>
<b>Horns Rev B</b>	HRB	40 X 5.0 MW	200 MW	10.5 m/s <sup>*)</sup>
<b>Djursland Anholt O</b>	DAO	40 X 5.0 MW	200 MW	9.0 m/s <sup>*)</sup>
<b>Djursland Anholt P</b>	DAP	40 X 5.0 MW	200 MW	9.0 m/s <sup>*)</sup>

<sup>\*)</sup>the annual mean wind speeds are assumed, not measured

Simulated 5 years (1999 – 2003) with five different random seeds for the stochastic part – 25 annual wind power time series

# Simulation results

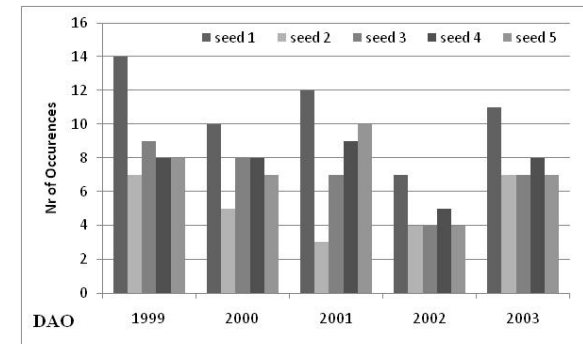
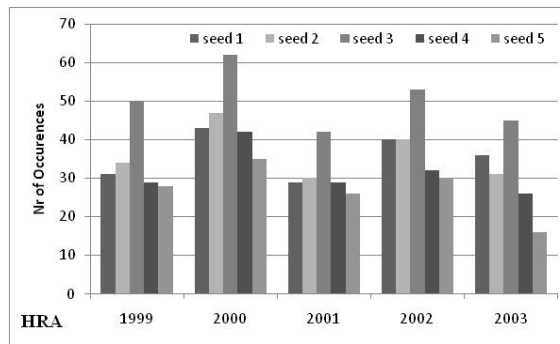
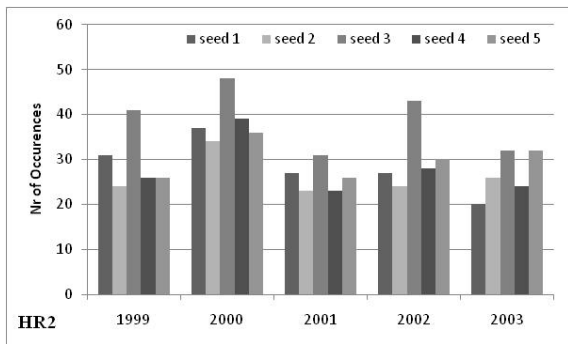
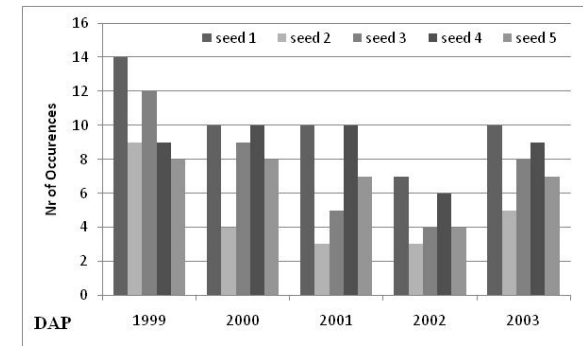
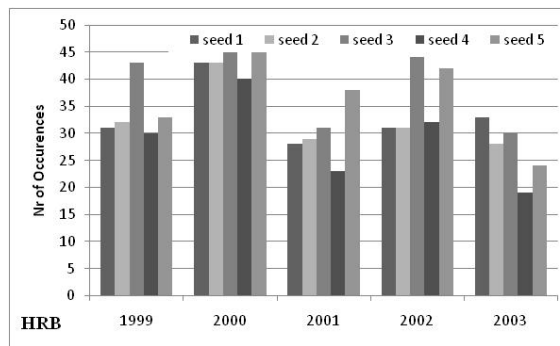
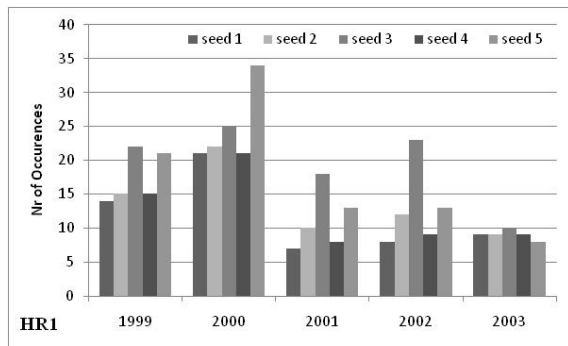
1. Frequency and Duration of Occurrence
2. Lost Energy (capacity factor)
3. Ramp Rates and Reserves Requirements

# Simulation results

1. Frequency and Duration of Occurrence
2. Lost Energy (capacity factor)
3. Ramp Rates and Reserves Requirements

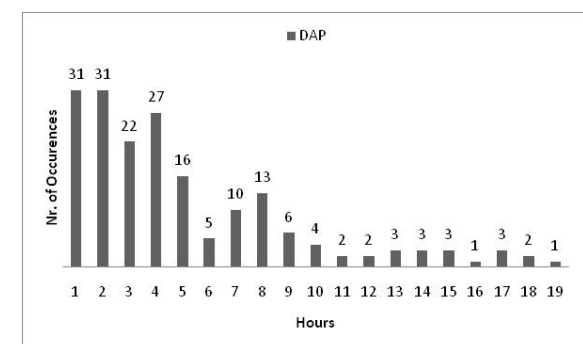
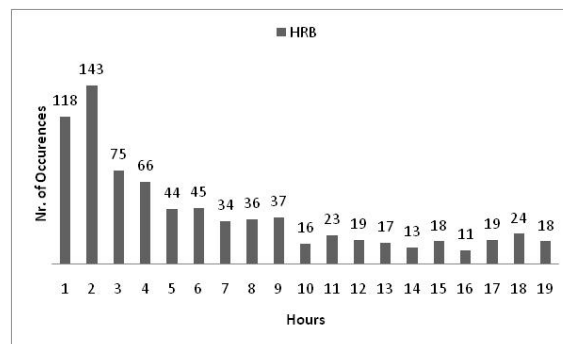
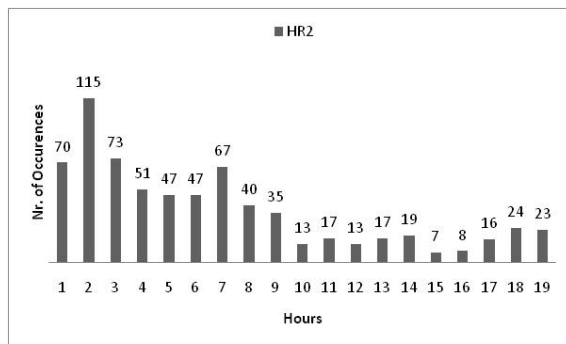
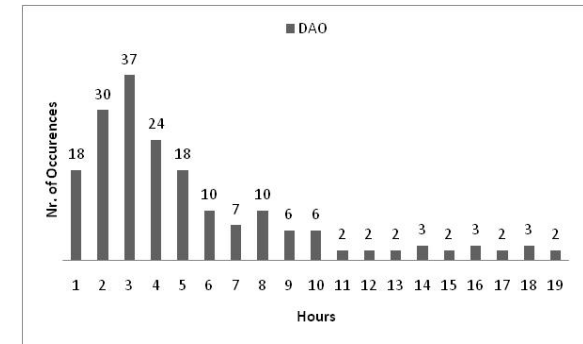
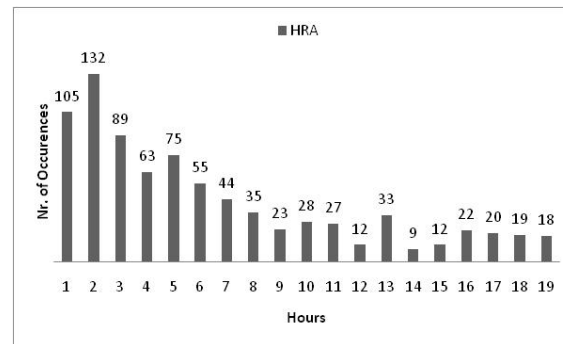
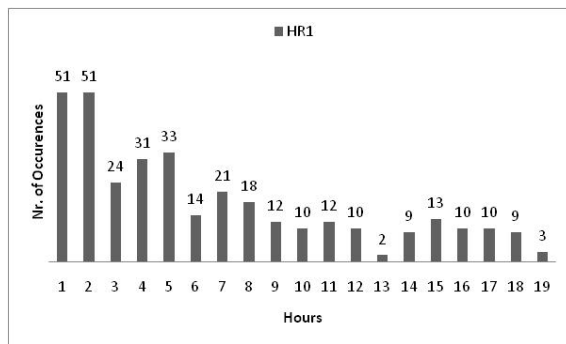
# Frequency and Duration of Occurrence

## Wind farm level



# Frequency and Duration of Occurrence

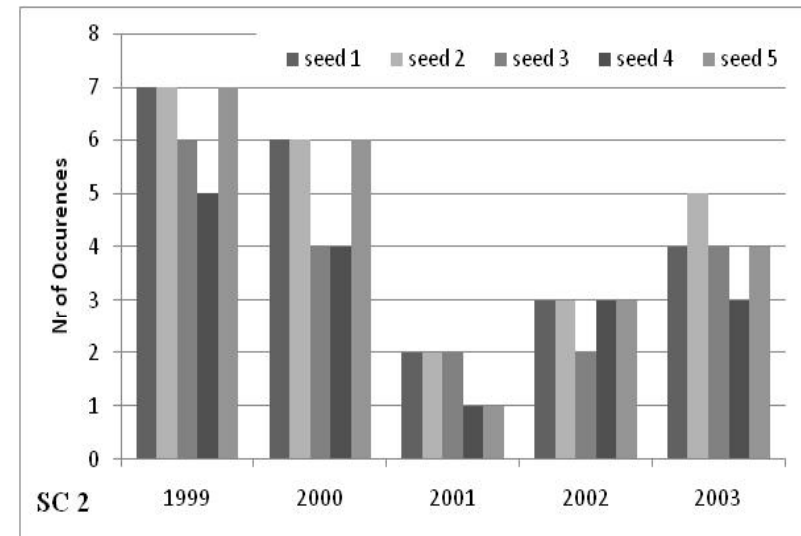
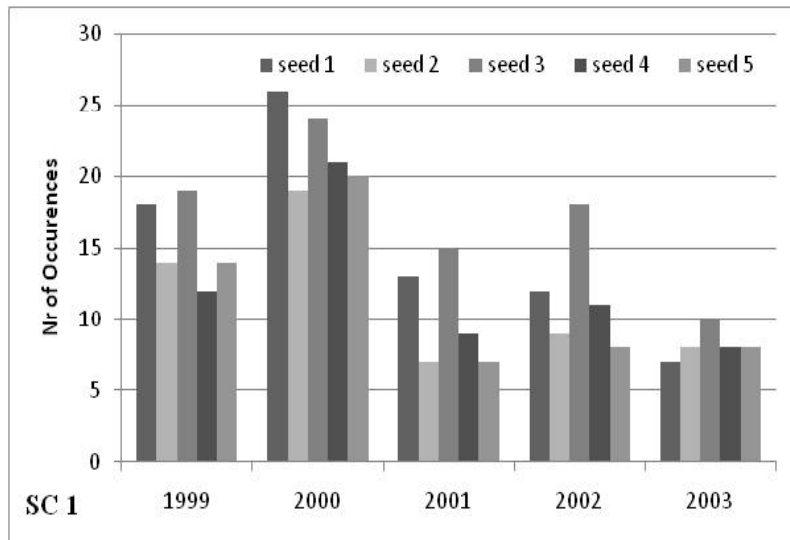
## Wind farm level





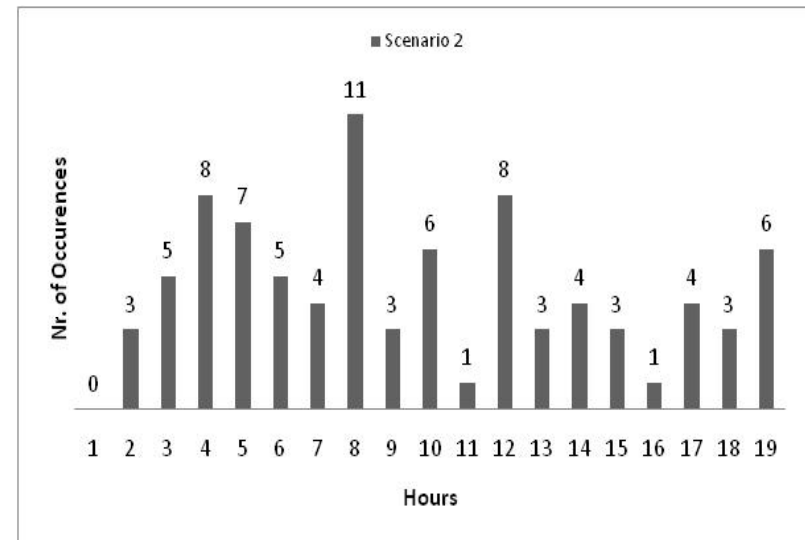
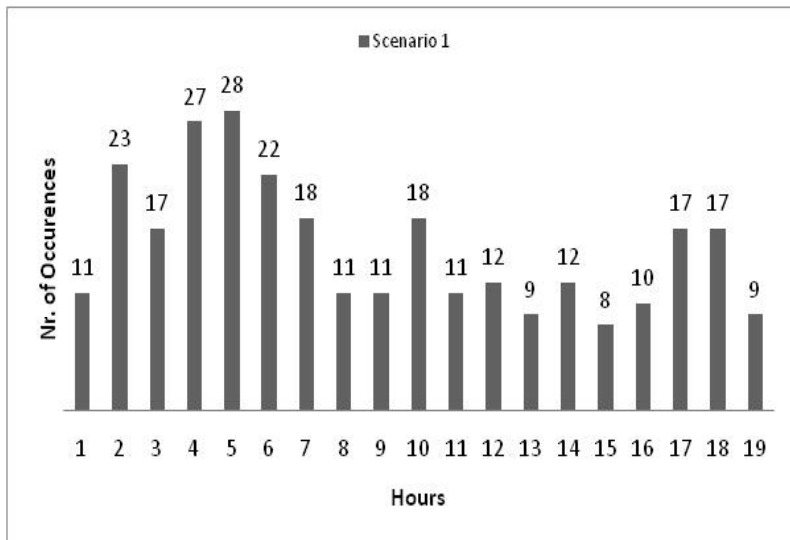
# Frequency and Duration of Occurrence

## Wind power region level



# Frequency and Duration of Occurrence

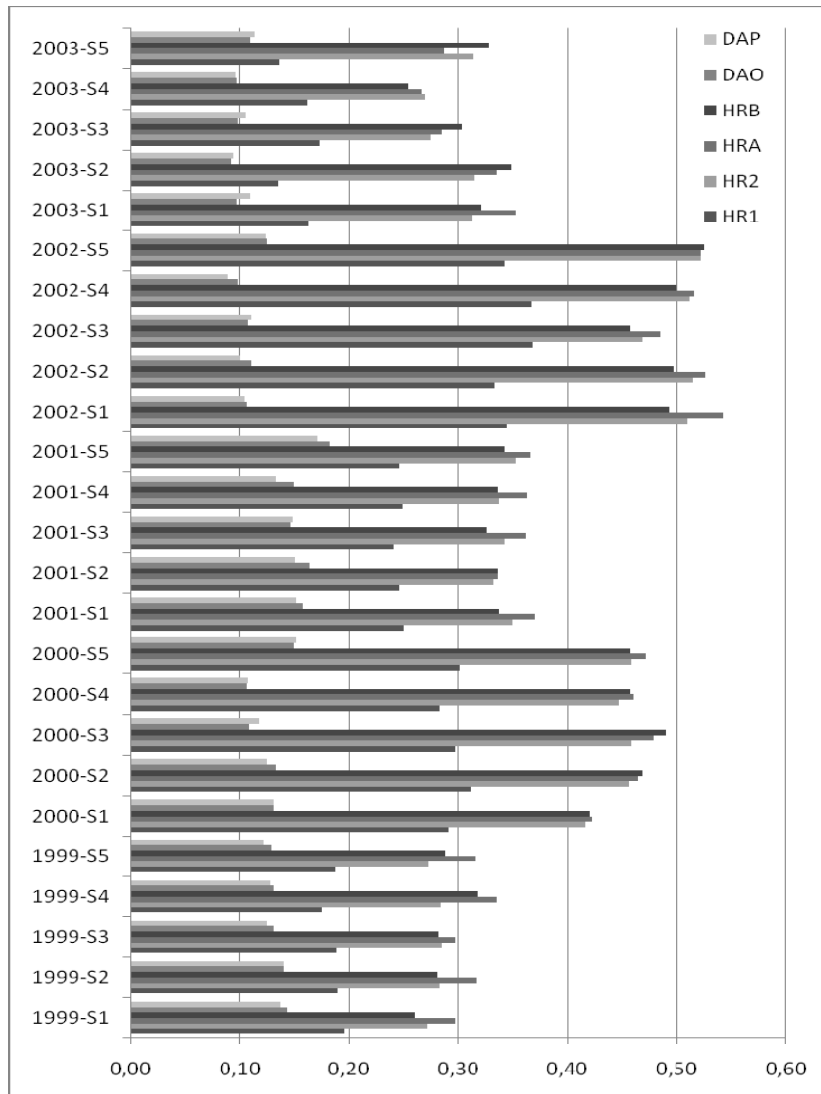
## Wind power region level



# Simulation results

1. Frequency and Duration of Occurrence
2. Lost Energy (capacity factor)
3. Ramp Rates and Reserves Requirements

# Lost Energy – Capacity factor



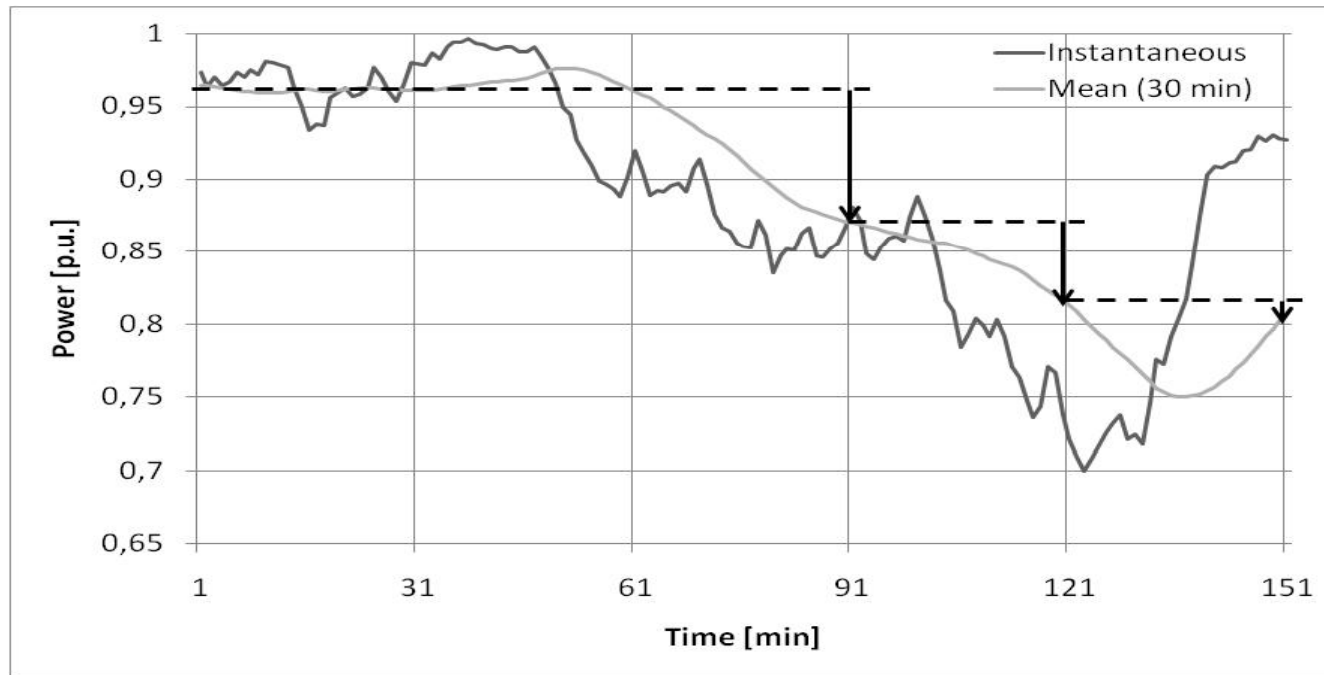
$$C_F = \frac{E_a}{N_h \cdot Cap}$$

Name	HR1	HR2	HRA	HRB	DAO	DAP
Capacity factor difference %	0,25	0,37	0,39	0,38	0,13	0,12
Equivalent full load hours	21,65	32,80	34,26	33,04	11,02	10,81

# Simulation results

1. Frequency and Duration of Occurrence
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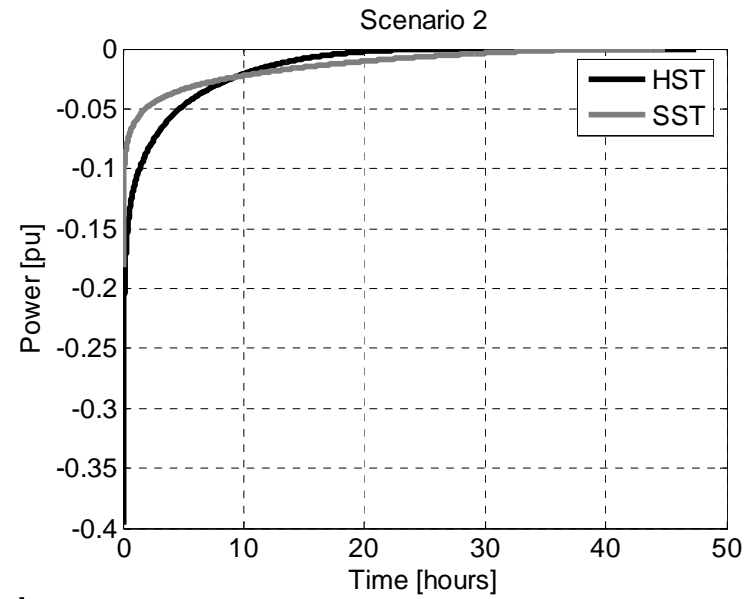
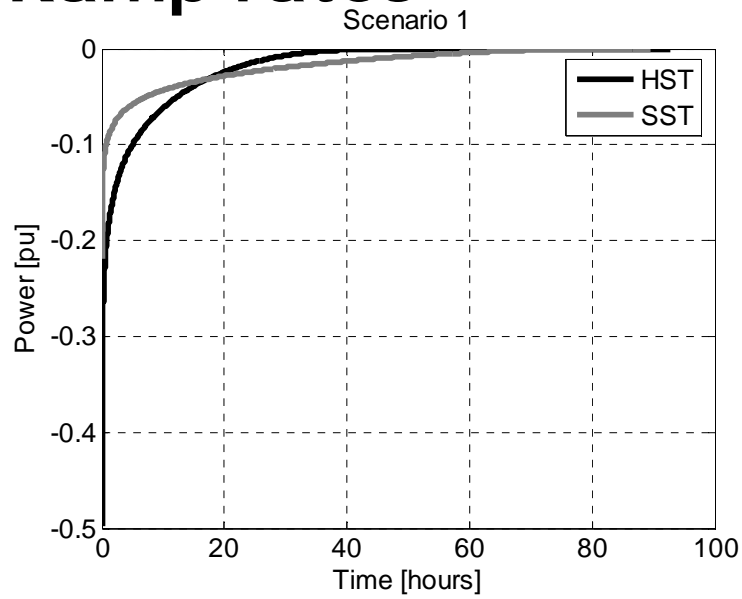
# Ramp rates



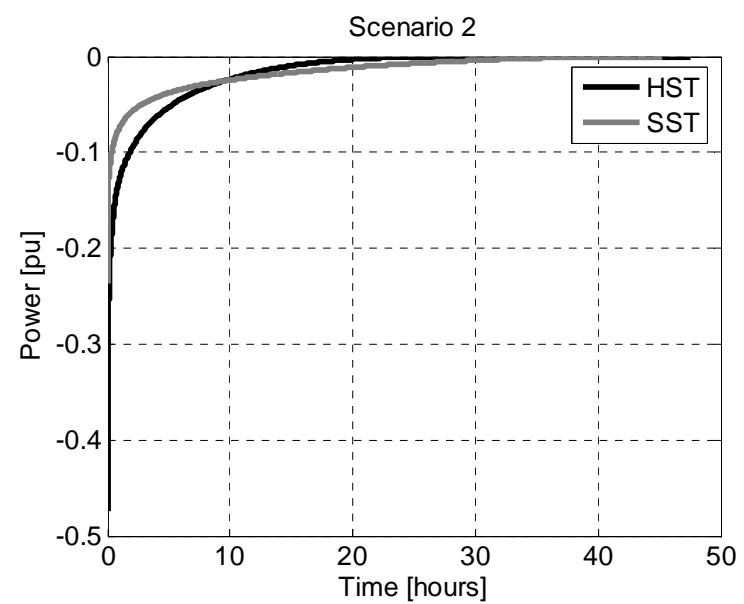
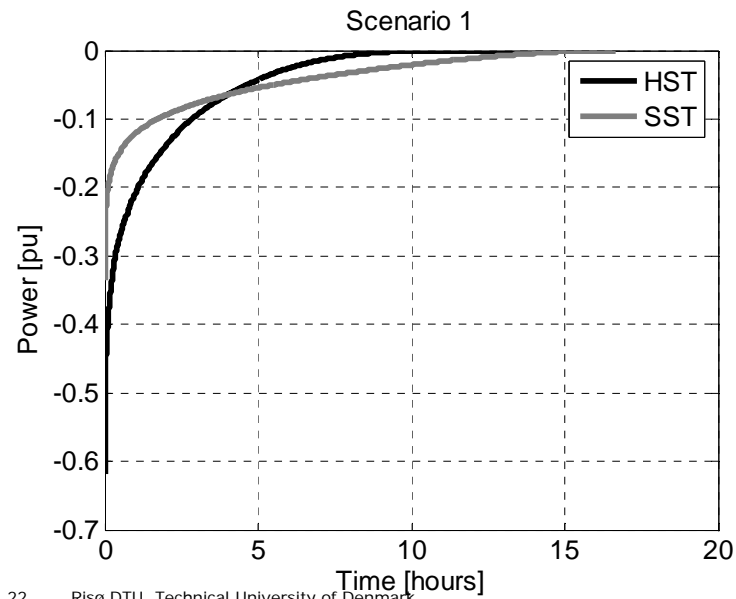
$$P_{\text{ramp}}(n) = P_{\text{mean}}(n+1) - P_{\text{mean}}(n)$$

# Ramp rates

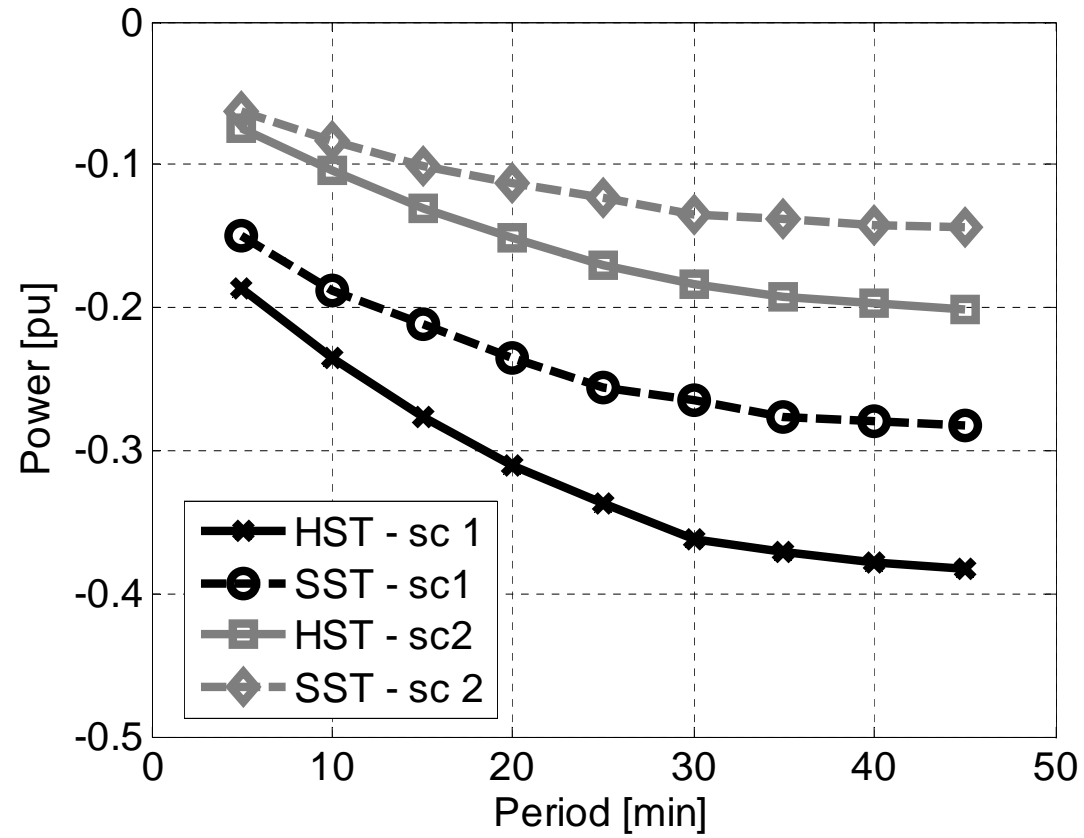
15 min



30 min



# Ramp rates

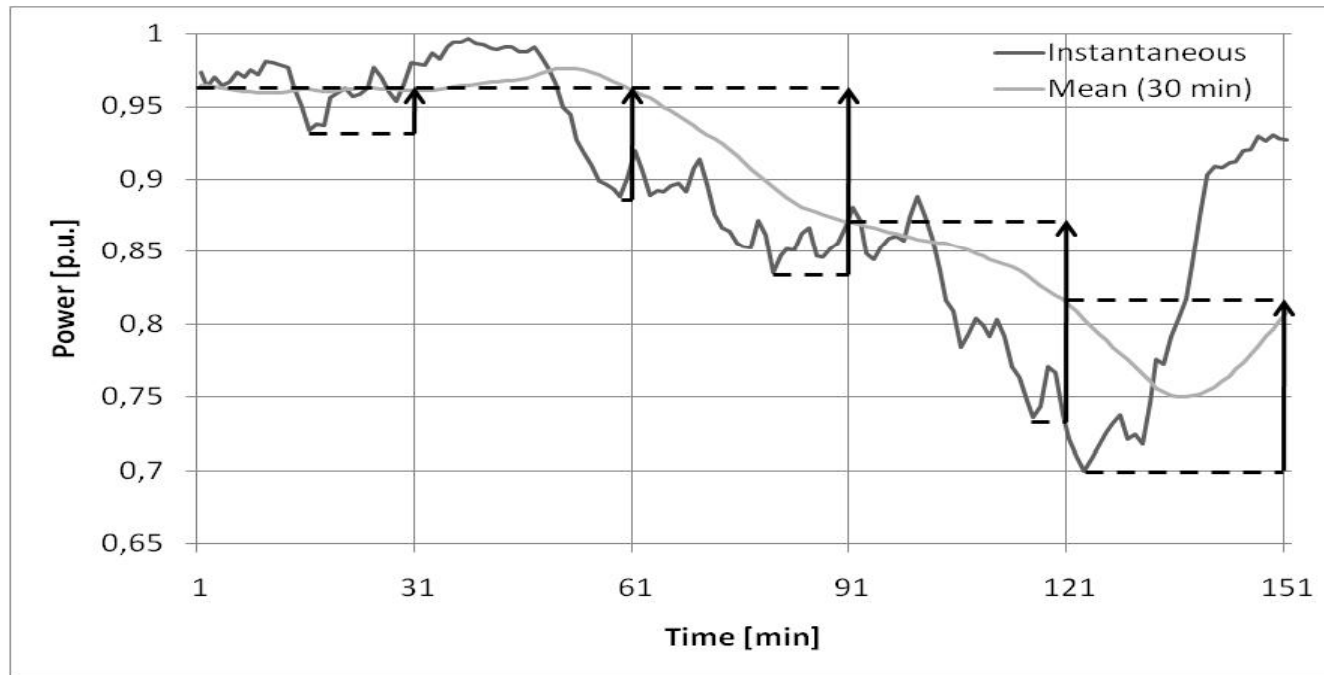




# Simulation results

1. Frequency and Duration of Occurrence
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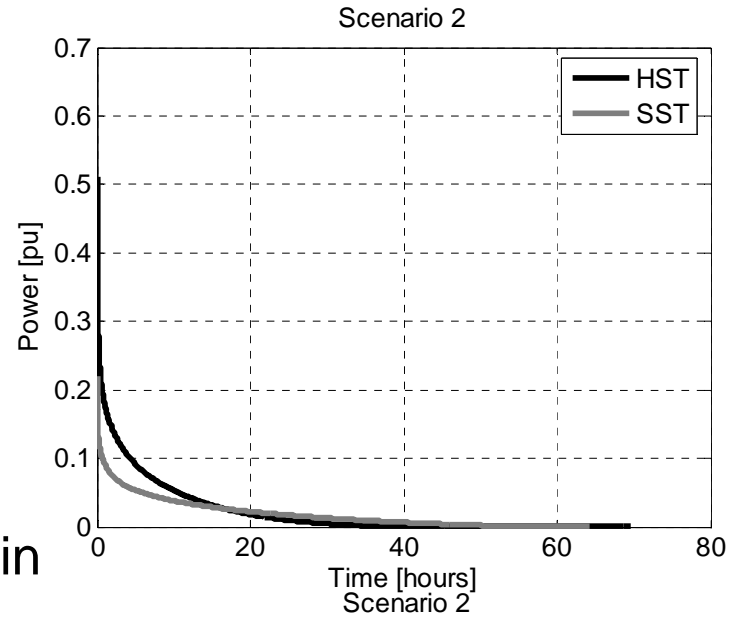
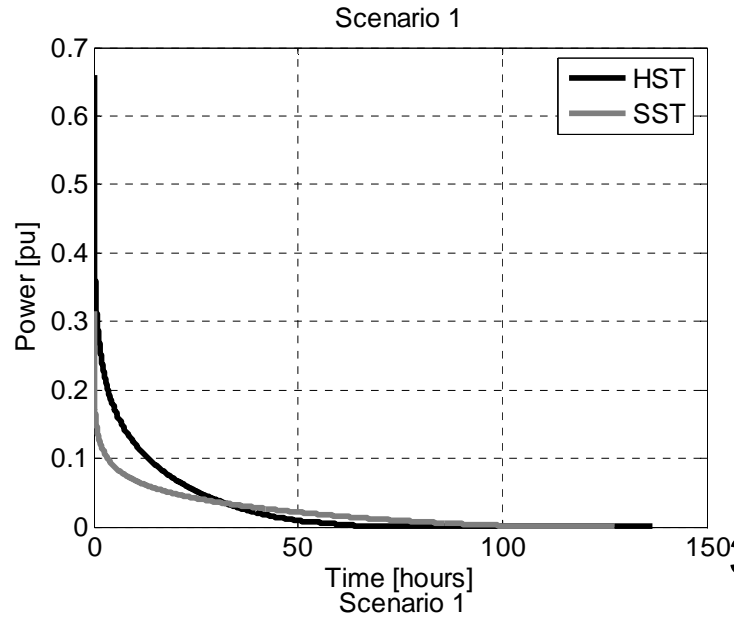
# Reserve requirements



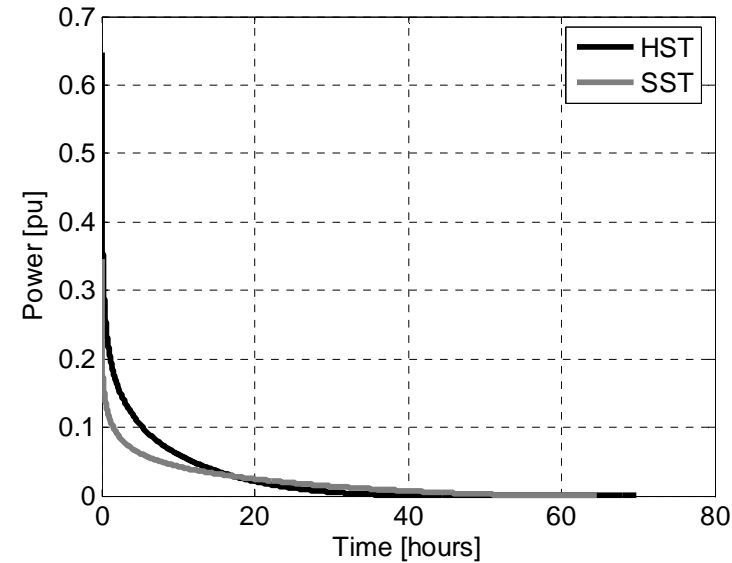
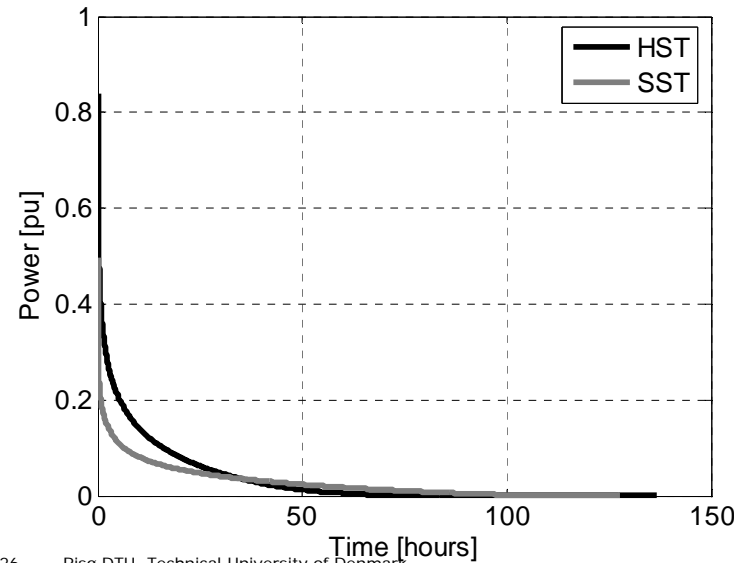
$$P_{\text{reserve}}(n) = P_{\text{mean}}(n) - P_{\text{min}}(n+1)$$

# Reserve requirements

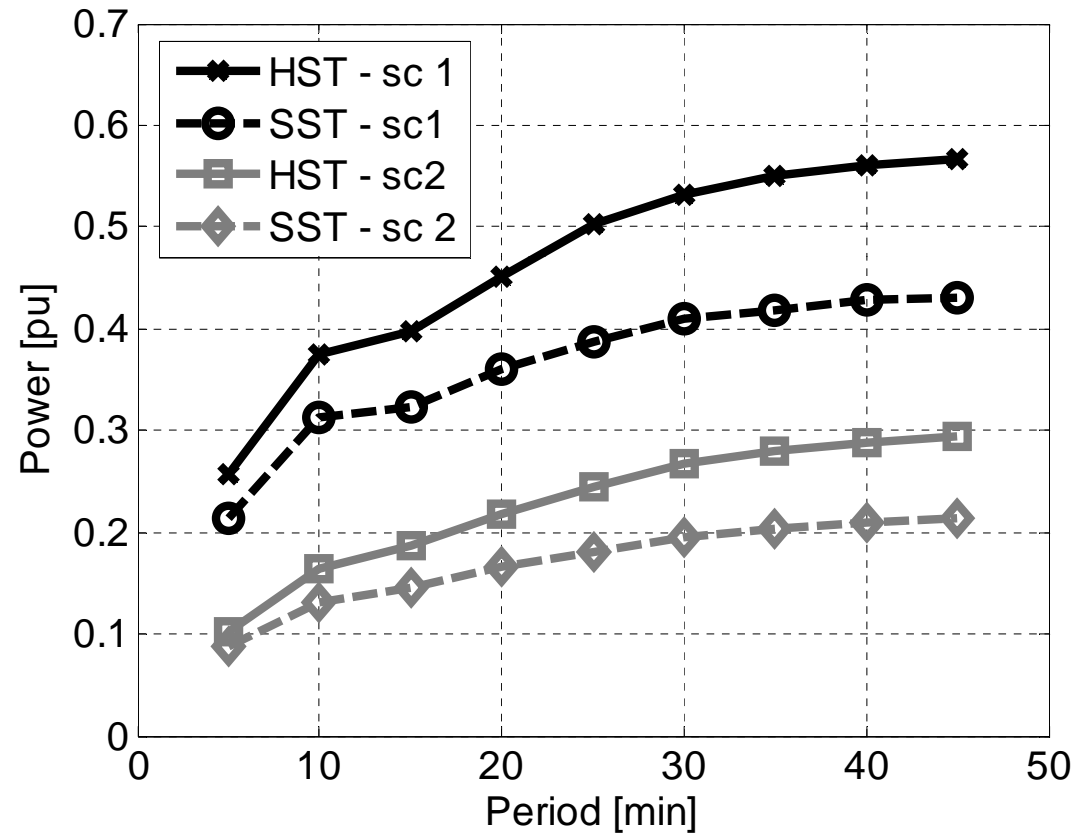
15 min



30 min



# Reserves requirements



# Conclusions

- Offshore wind farms operational under extreme wind conditions reliability analysis is important
- Control strategies play a crucial role in increasing the reliability of offshore wind farms power production under extreme wind conditions
- Availability of wind power production at power region level can be improved by proper wind farm location selection