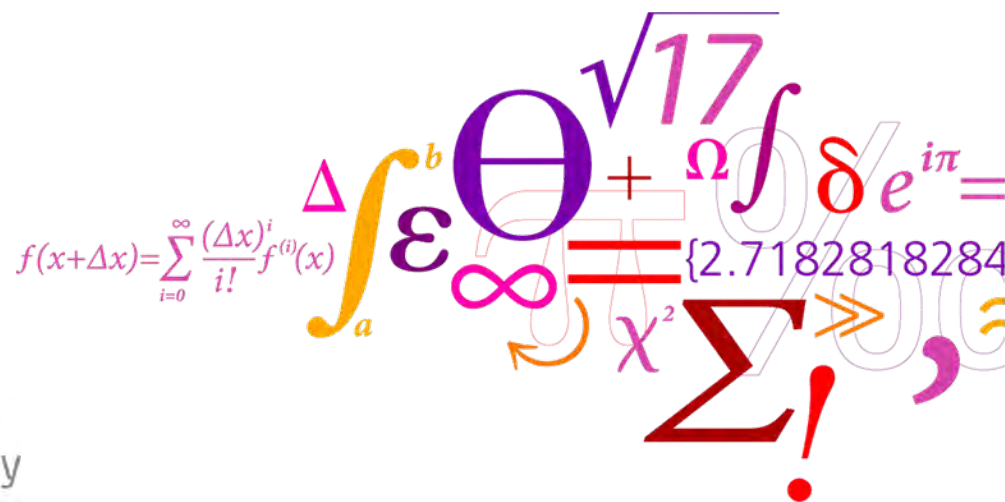


# Validation of power fluctuations simulation model

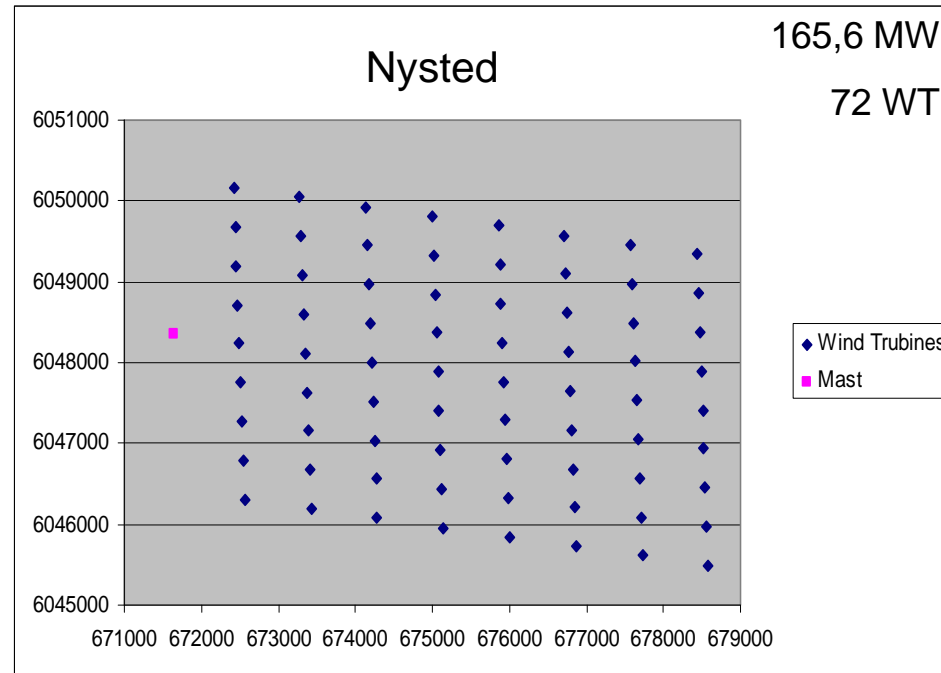
Nicolaos A. Cutululis



# Validation approach

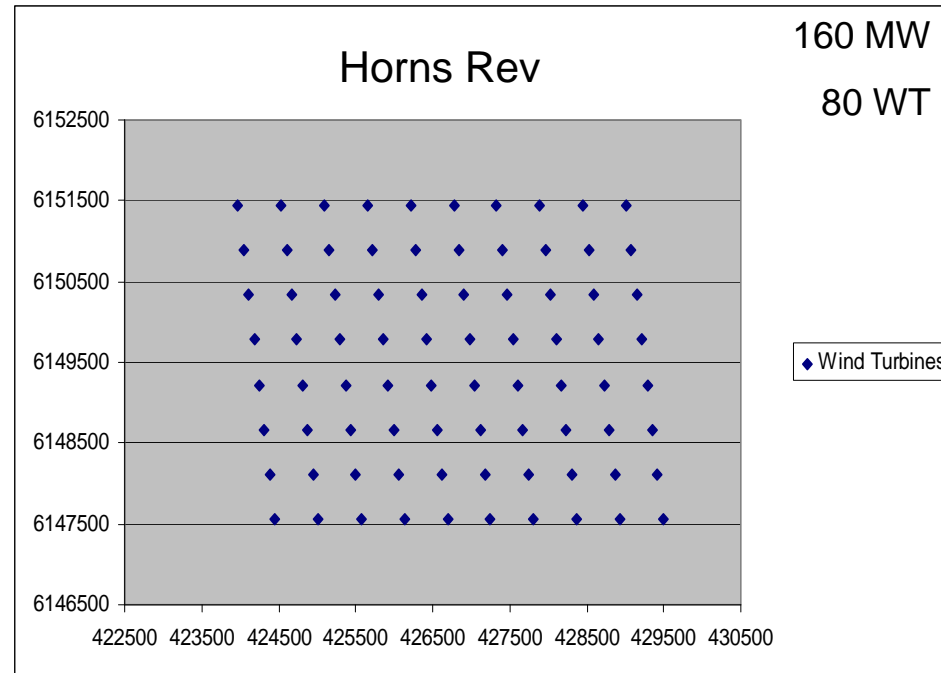
- Horns Rev and Nysted off-shore wind farms data
- Quantify the wind power variability in terms of ramp rates and reserves requirements
- Compare duration curves

# Available data



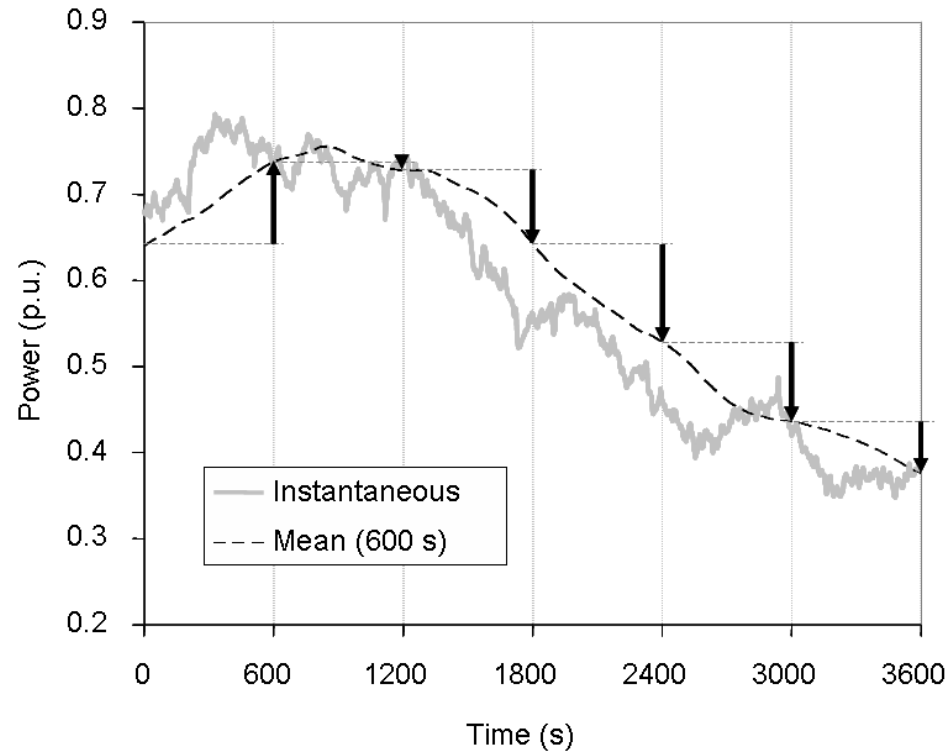
- 1Hz sampling frequency
- wind speed, power, power set point and yaw position used
- 1989 two-hour segments (165,75 days)
- wind speeds from 1 to 24 m/s

# Available data



- 1Hz sampling frequency
- wind speed, power, power set point and yaw position used
- 1110 two-hour segments (92,5 days)
- wind speeds from 1 to 19 m/s

# Analysis and validation – ramp rates

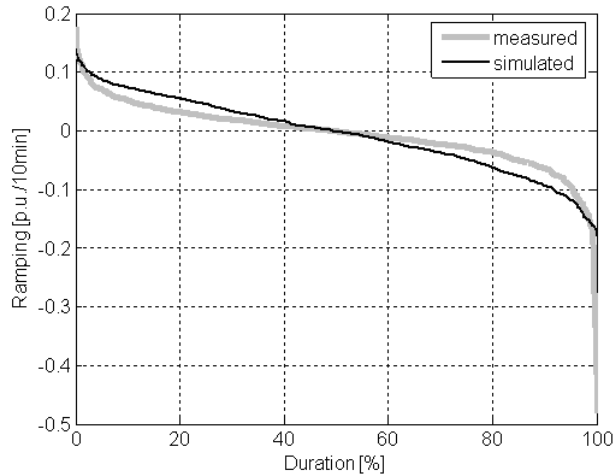


$$P_{\text{ramp}}(n) = P_{\text{mean}}(n + 1) - P_{\text{mean}}(n)$$

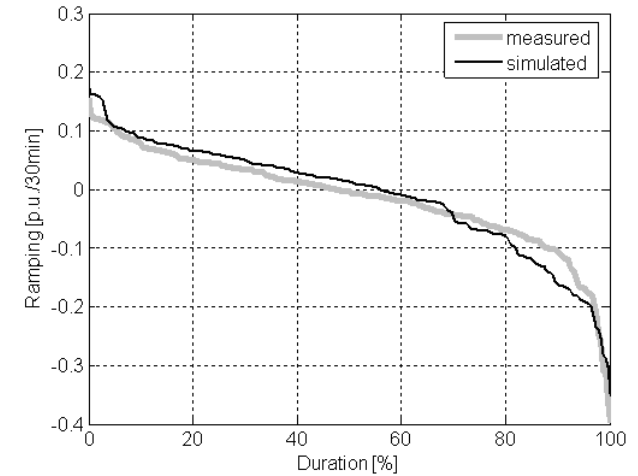
# Analysis and validation – ramp rates

Horns Rev – 0.8-0.9 p.u.

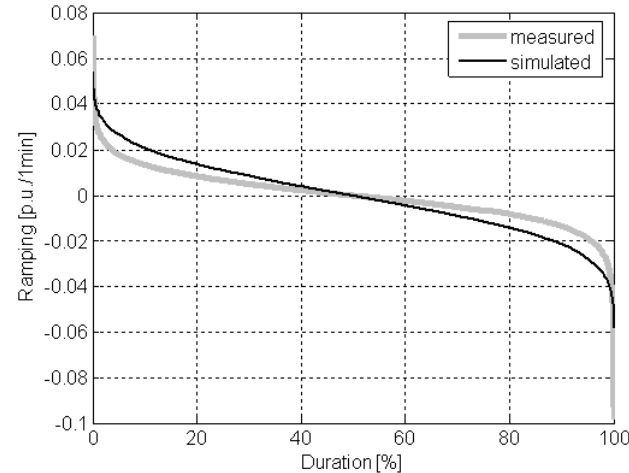
10 min



30 min



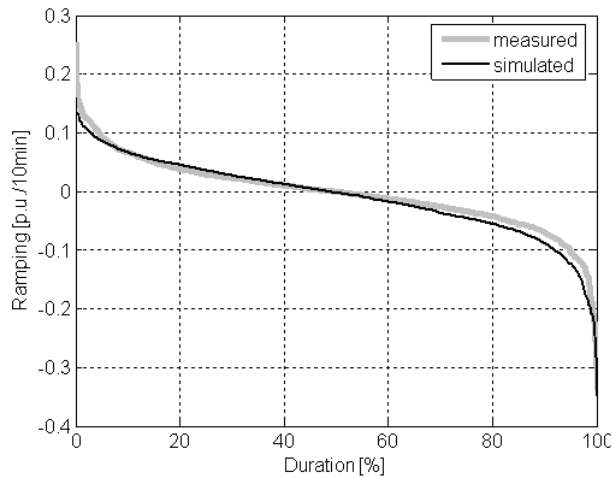
1 min



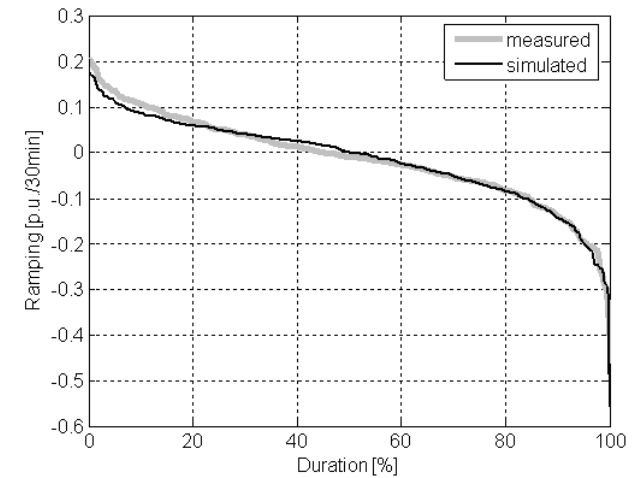
# Analysis and validation – ramp rates

Nysted – 0.8-0.9 p.u.

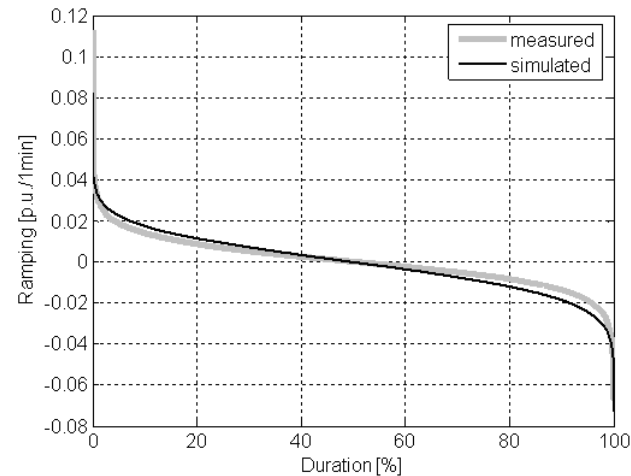
10 min



30 min

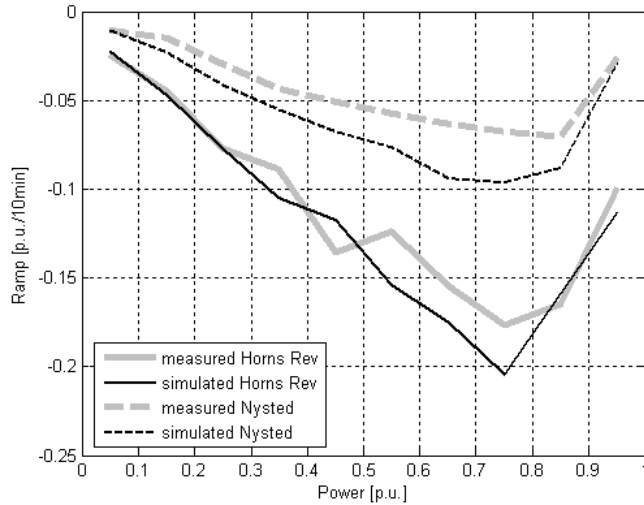


1 min

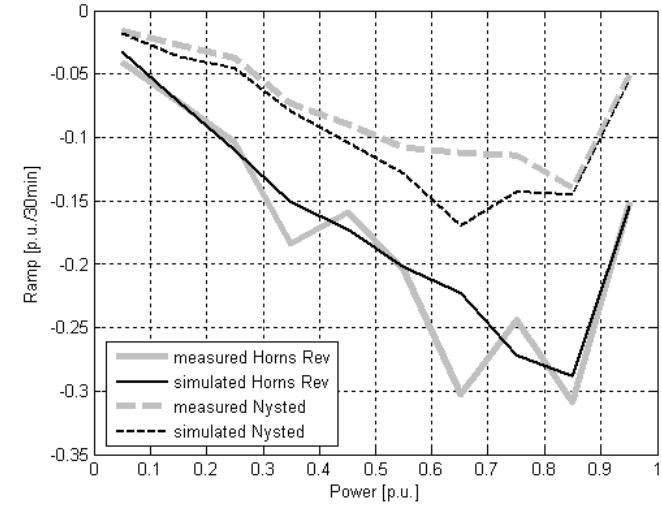


# Analysis and validation – 99% ramping

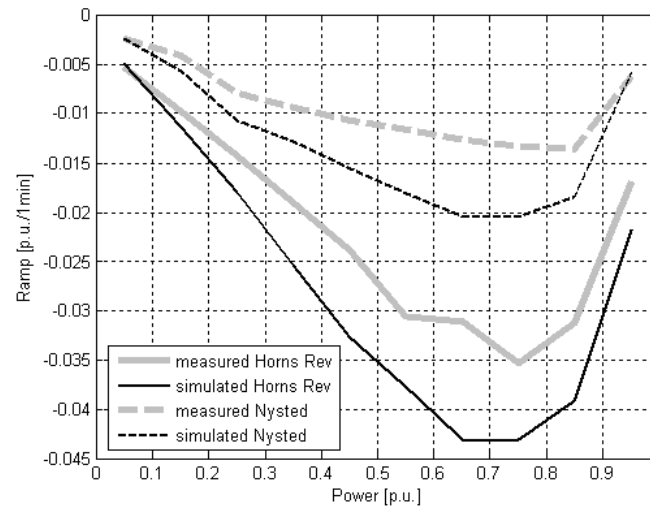
10 min



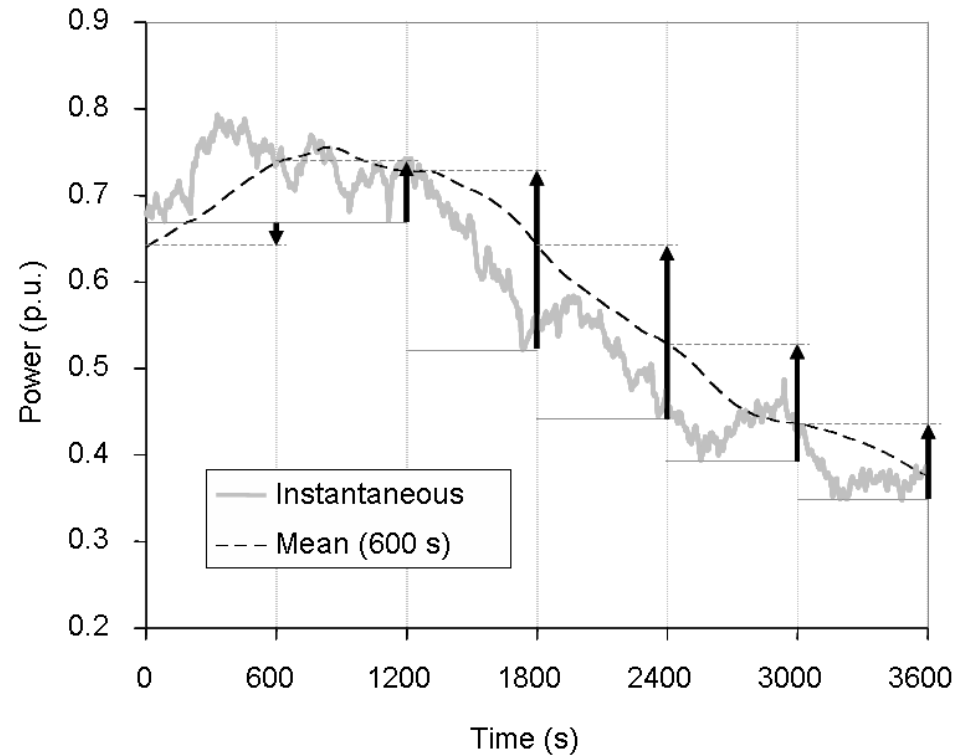
30 min



1 min



# Analysis and validation – reserves

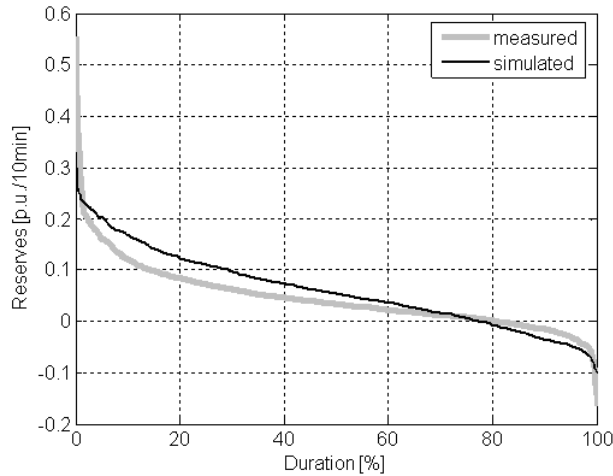


$$P_{\text{res}}(n) = P_{\text{mean}}(n) - P_{\text{min}}(n + 1)$$

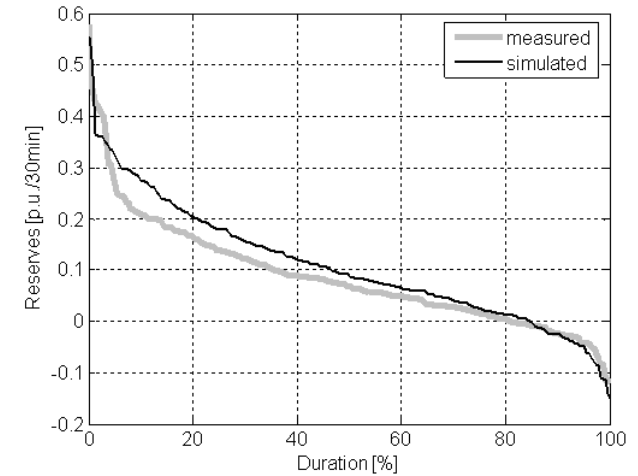
# Analysis and validation – reserves

Horns Rev -0.8-0.9 p.u.

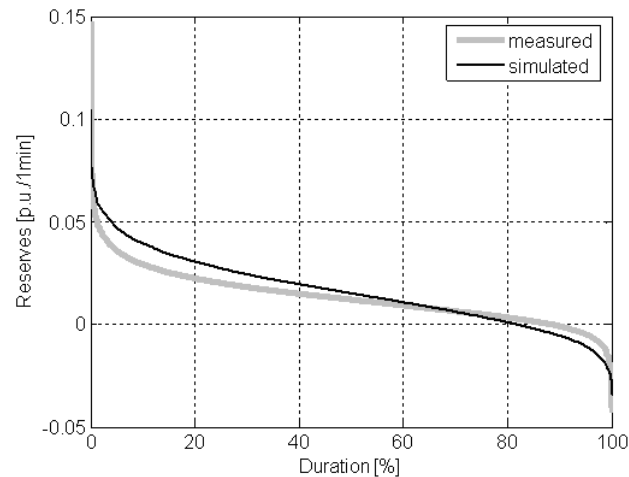
10 min



30 min



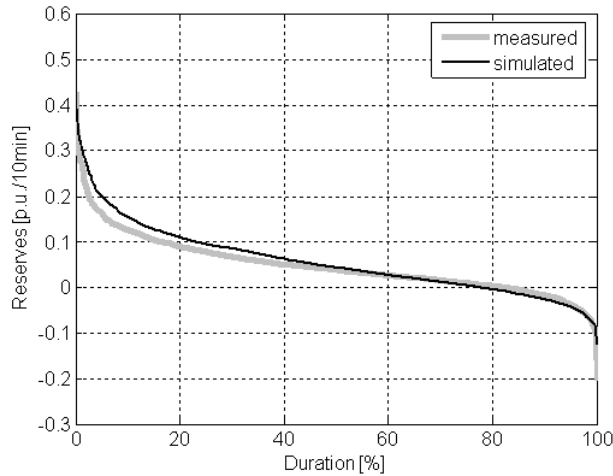
1 min



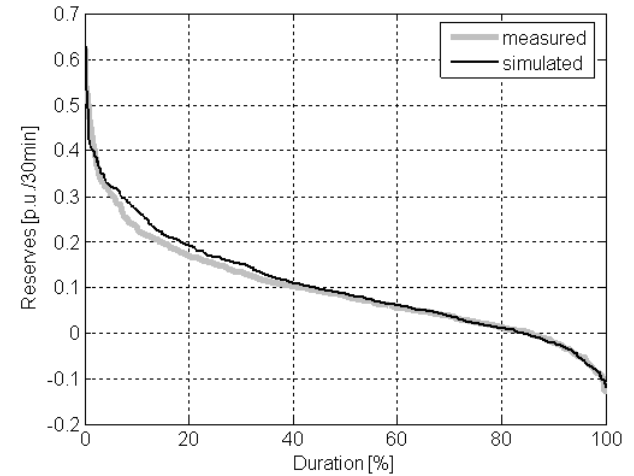
# Analysis and validation – reserves

Nysted – 0.8-0.9 p.u.

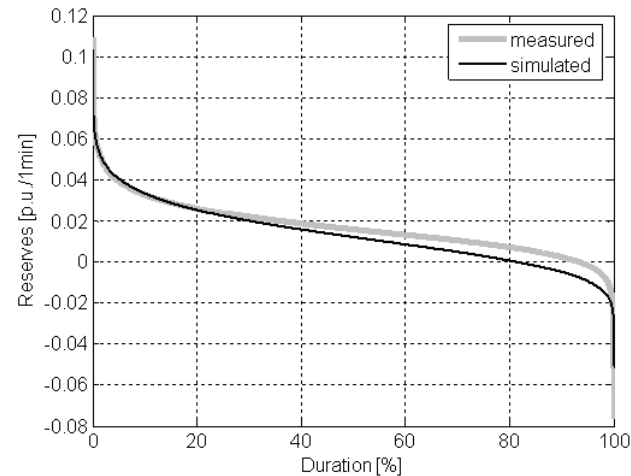
10 min



30 min

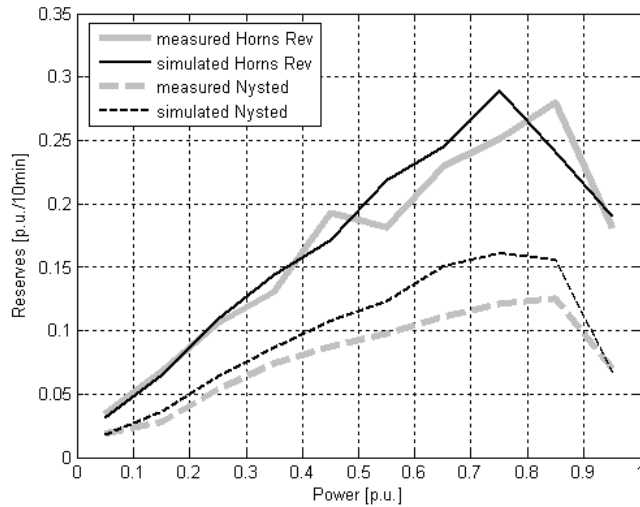


1 min

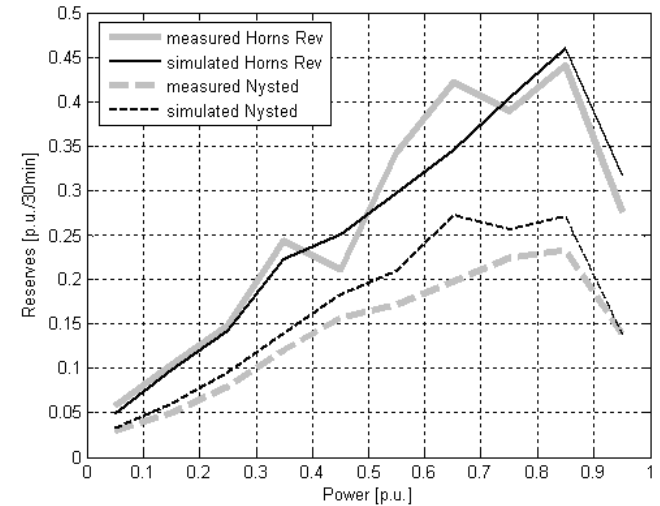


# Analysis and validation – 1% reserves

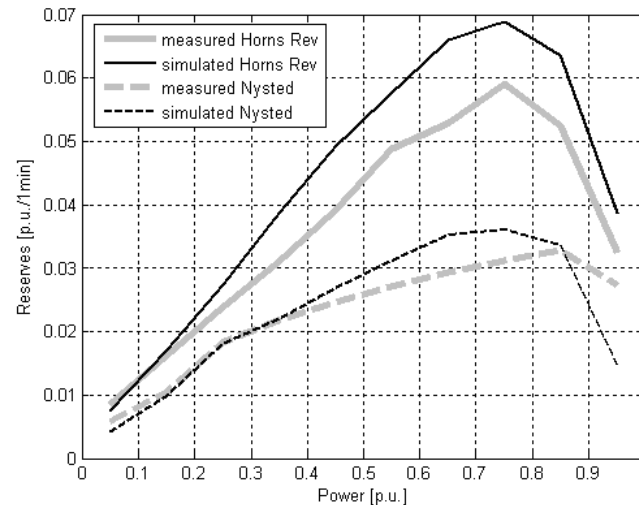
## 10 min period



## 30 min period



## 1 min period



# Conclusions

- The model can simulate power fluctuations from off-shore wind farms;
- The simulation length is limited to a couple of hours, when constant mean wind speed and direction are considered;
- Duration curves for ramp rates and reserve requirements are generally simulated to slightly higher values than measured;

Questions?

