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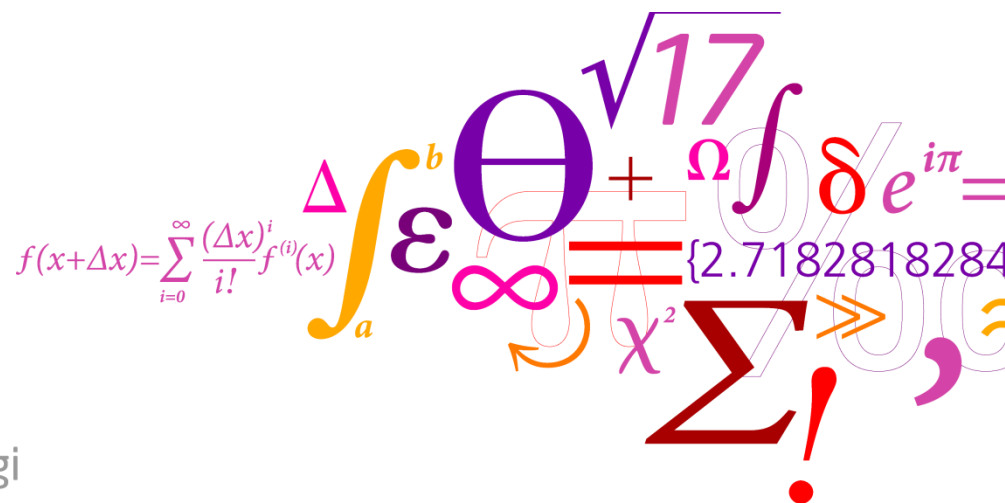
Frequency modeling of wind power fluctuation and the application on power systems

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Wind Division, Risø DTU

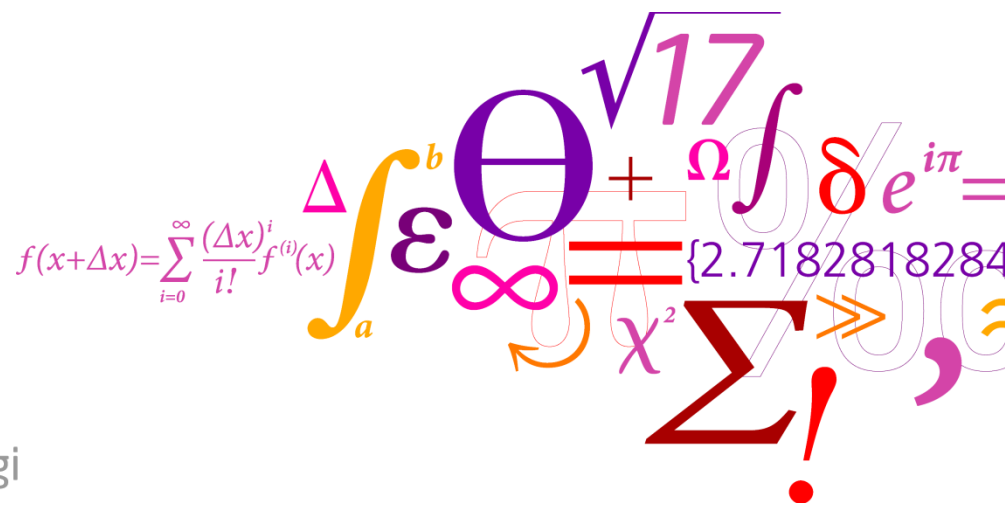
LIN Jin, SUN Yuanzhang, LI Guojie

Tsinghua University



Outline

- Introduction
- Frequency modeling of wind power
- The application in power system
- Conclusion



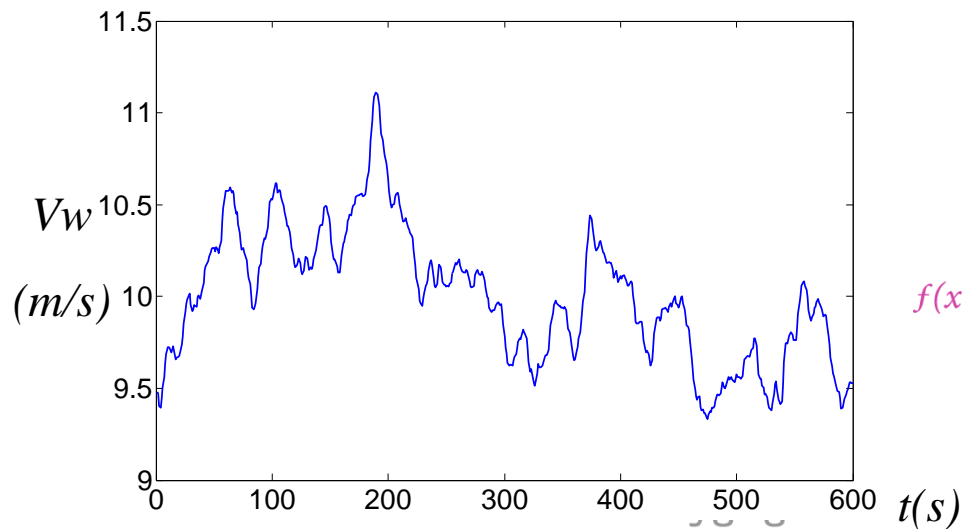
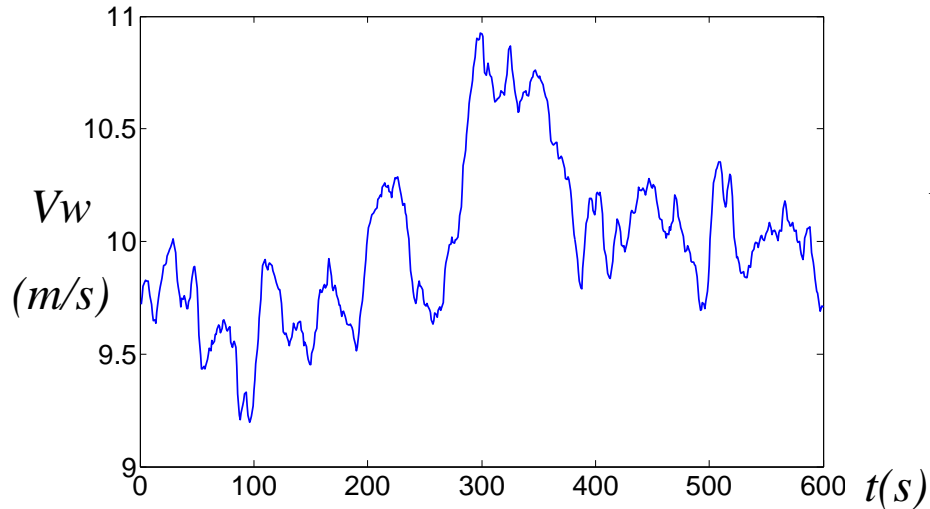
Introduction

- The penetration of wind power is rapidly growing
- Power fluctuation is a nature characteristic of wind power
- Especially a concentrated wind farm may bring more fluctuation injection
- Balance Grid V.S. Fluctuated Wind

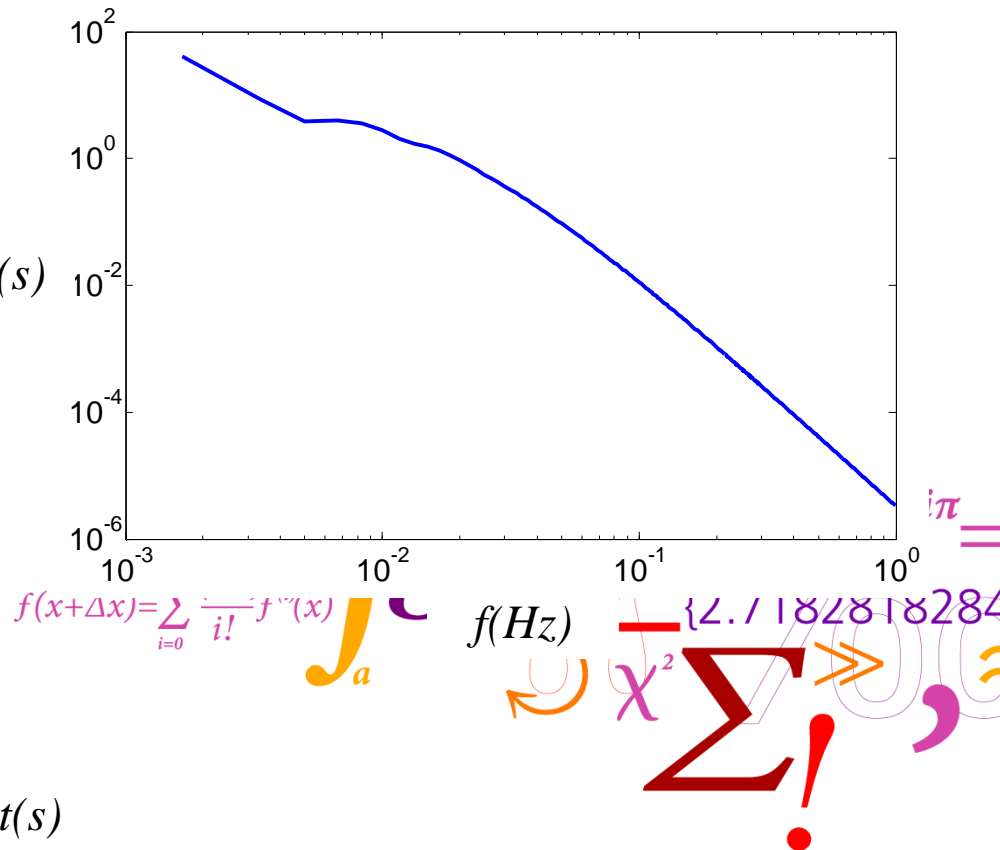
$$f(x+\Delta x) = \sum_{i=0}^{\infty} \frac{(\Delta x)^i}{i!} f^{(i)}(x)$$

Other symbols visible: \int_a^b , Θ , $\sqrt{17}$, Ω , $\delta e^{i\pi}$, ∞ , χ^2 , Σ , \gg , $\{2.7182818284\}$, π , ε , Δ .

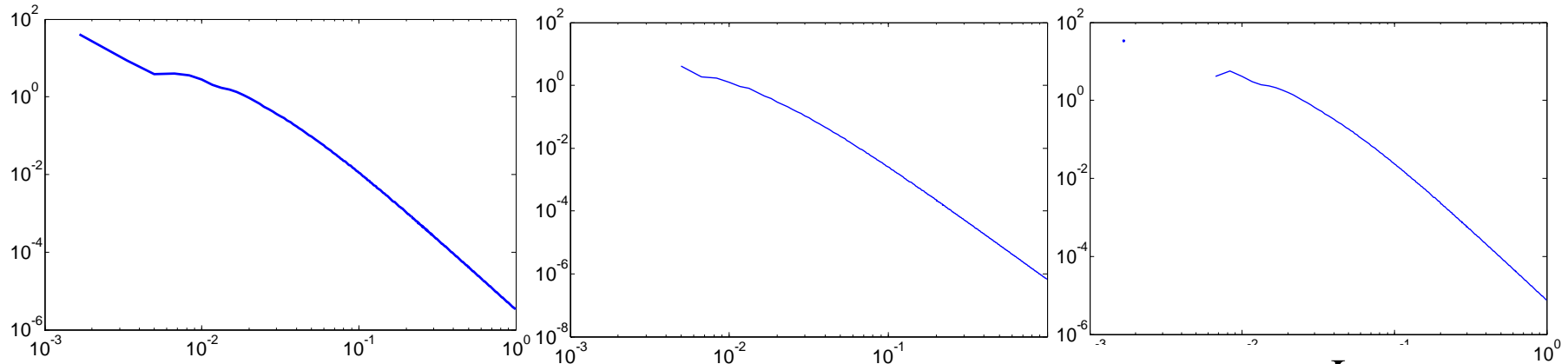
Frequency modeling of wind



PSD



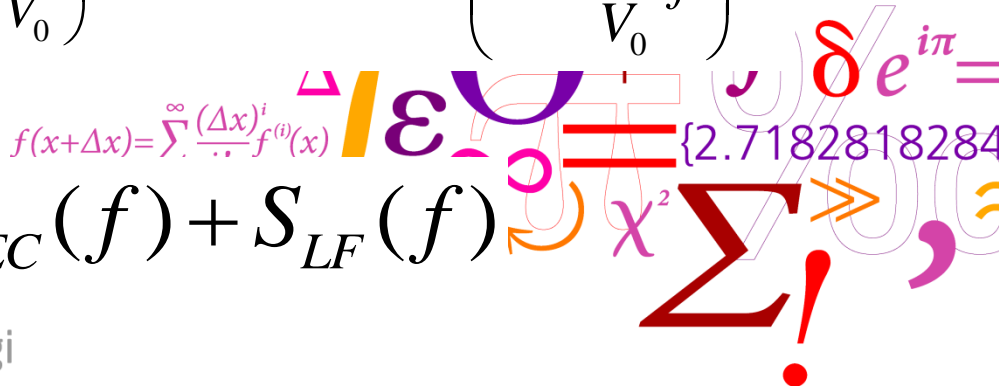
Frequency modeling of wind



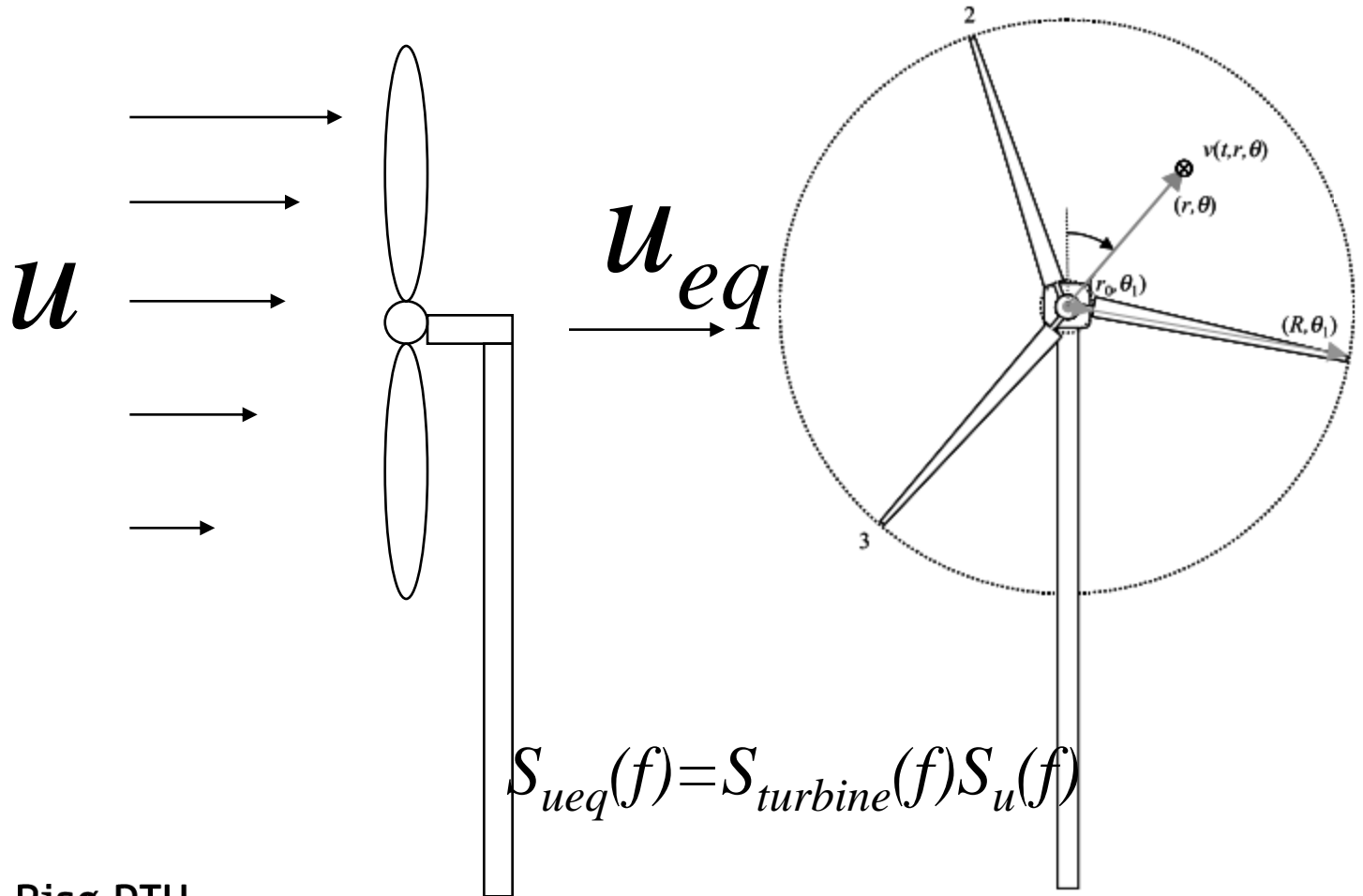
$$S_{LF}(f) = (\alpha_{LF} V_0 + \beta_{LF})^2 \frac{\frac{z}{V_0}}{\left(\frac{zf}{V_0}\right)^{5/3} \left(1 + 100 \frac{zf}{V_0}\right)}$$

$$S_{IEC}(f) = \sigma^2 \frac{2 \frac{L_1}{V_0}}{\left(1 + 6 \frac{L_1}{V_0} f\right)^{5/3}}$$

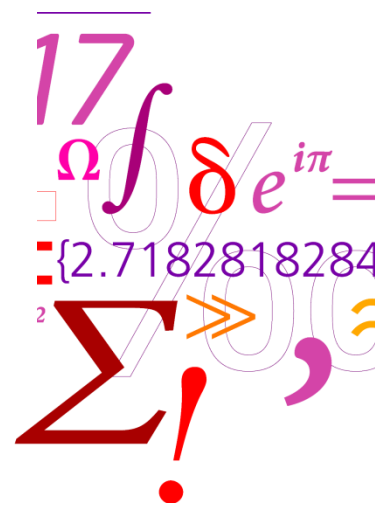
$$S_u(f) = S_{IEC}(f) + S_{LF}(f)$$



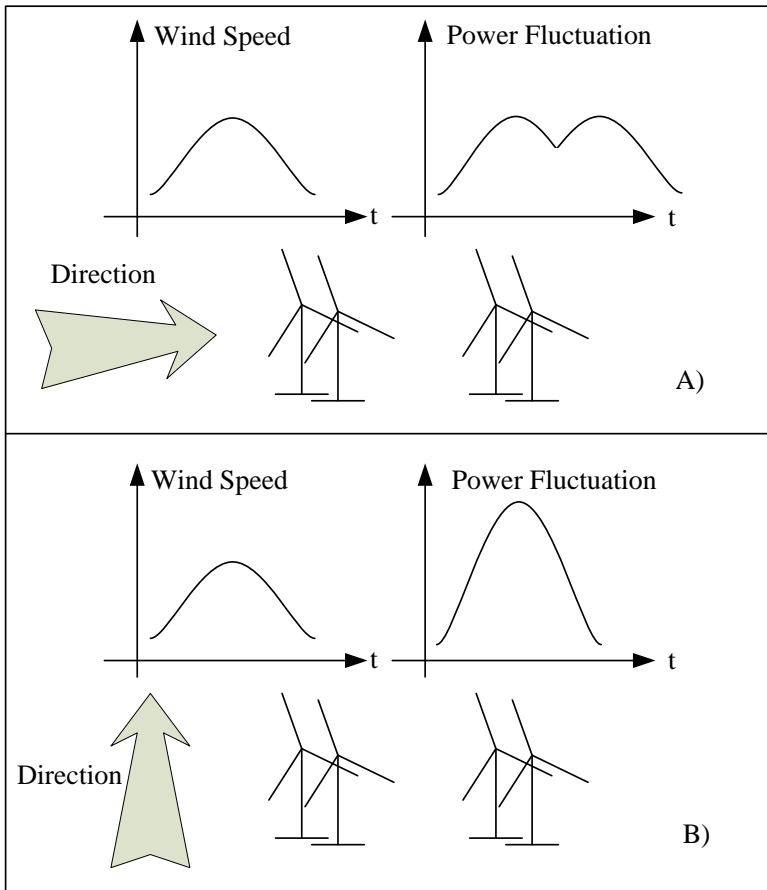
Equivalent wind passing through wind turbine



$$S_{ueq}(f) = S_{turbine}(f) S_u(f)$$



Coherence matrix of wind farm

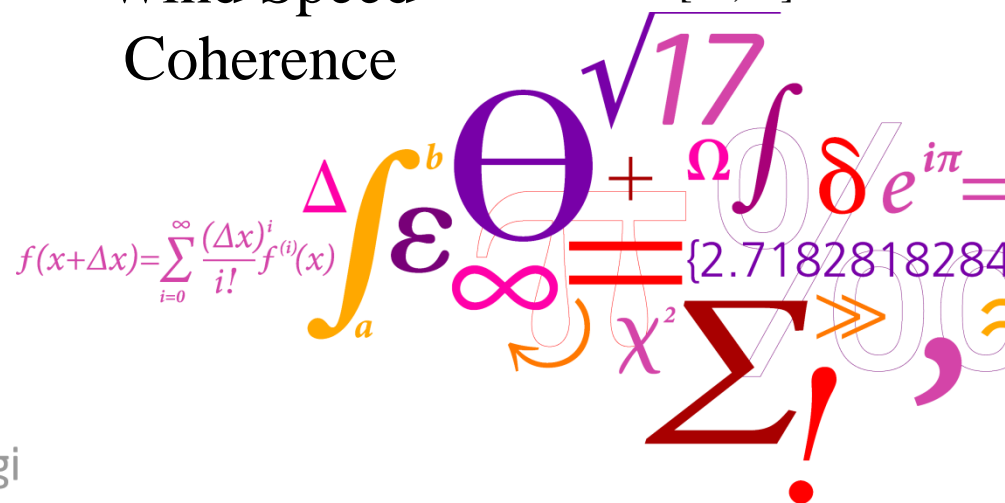


$$\gamma_{[1,1]}(f)$$

$$\begin{pmatrix} \square & \square & \square & \dots & \square \\ \square & \square & \square & \dots & \square \\ \square & \square & \square & \dots & \square \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \square & \square & \square & \dots & \square \end{pmatrix}$$

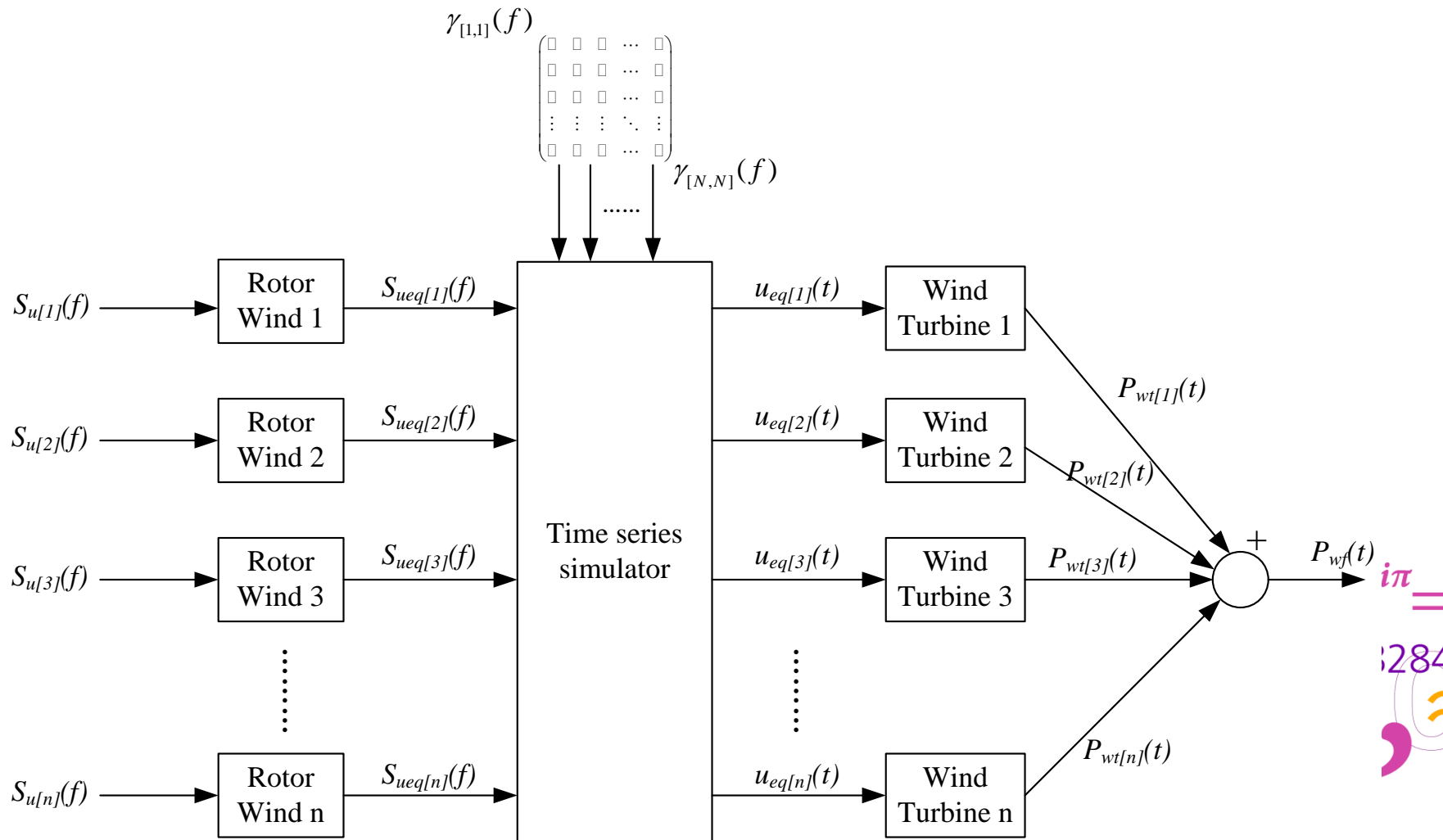
Wind Speed
Coherence

$$\gamma_{[N,N]}(f)$$

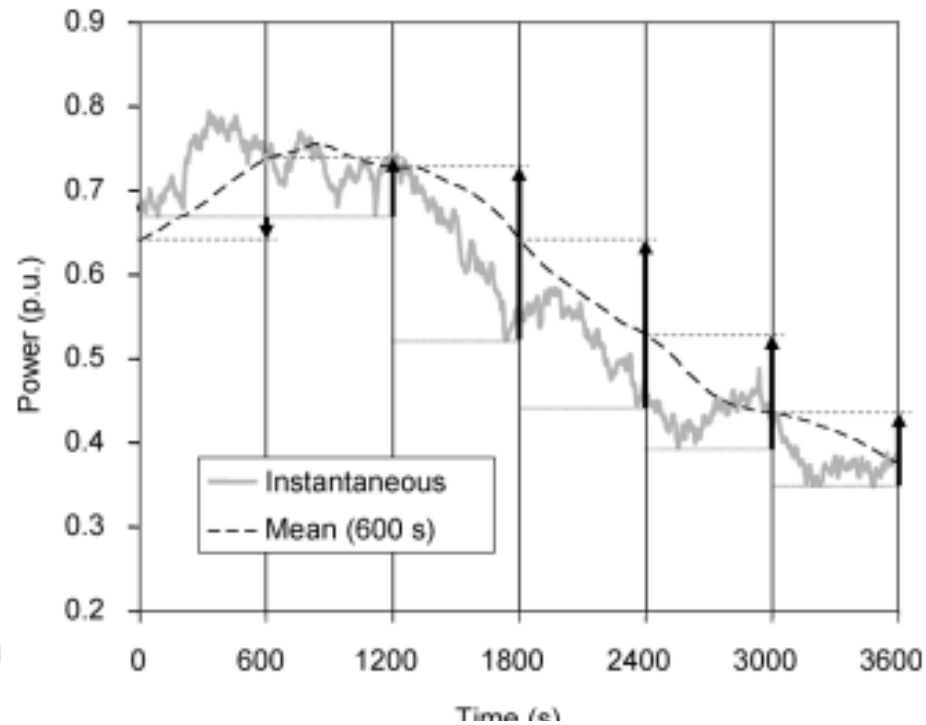
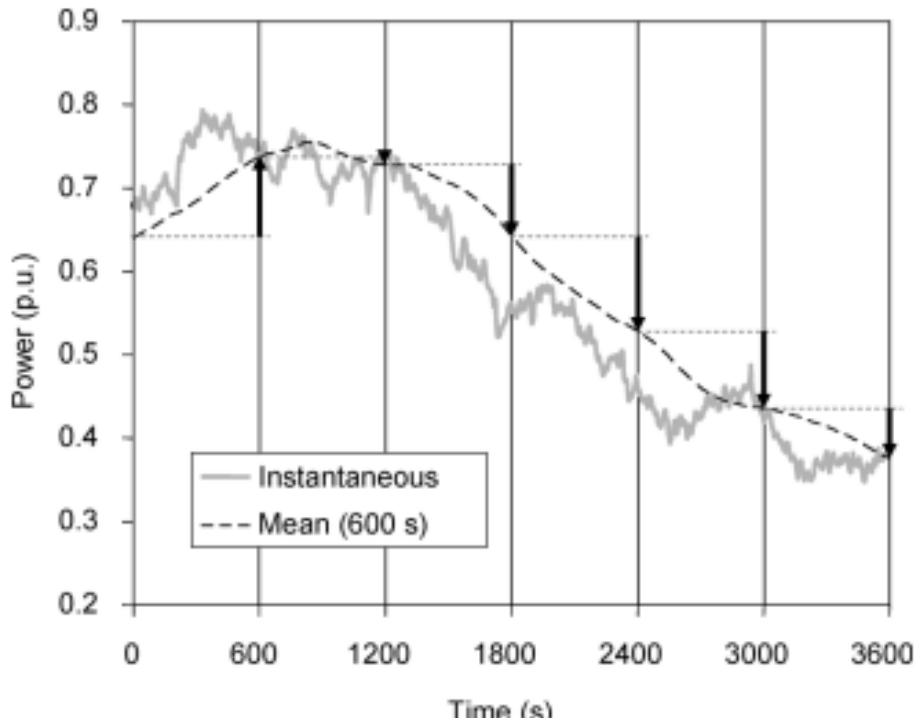


$f(x+\Delta x) = \sum_{i=0}^{\infty} \frac{(\Delta x)^i}{i!} f^{(i)}(x)$
 $\int_a^b \epsilon \Theta + \Omega \int \delta e^{i\pi} = \{2.7182818284\}$
 χ^2
 Σ
 ∞
 $\sqrt{17}$
 Δ
 ϵ
 Θ
 Ω
 δ
 $e^{i\pi}$
 $\{2.7182818284\}$
 χ^2
 Σ
 ∞
 $\sqrt{17}$

Frequency modeling of wind power fluctuation



Normal weather condition – ramp and reserve

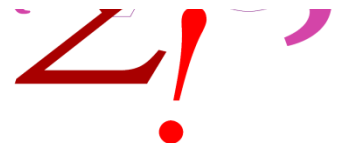


$$P_{ramp}(n) = P_{mean}(n+1) - P_{mean}(n)$$

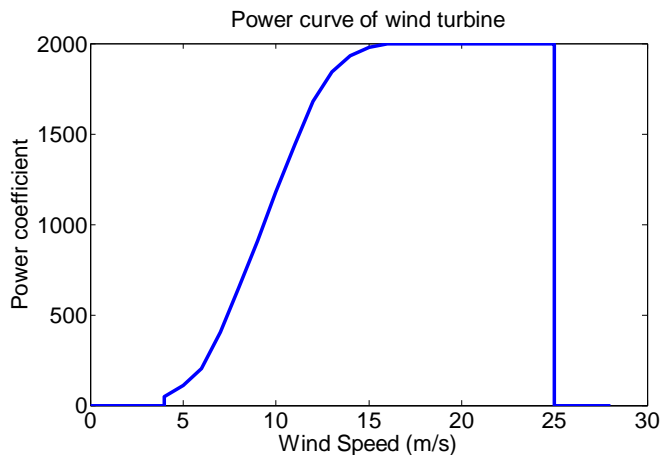
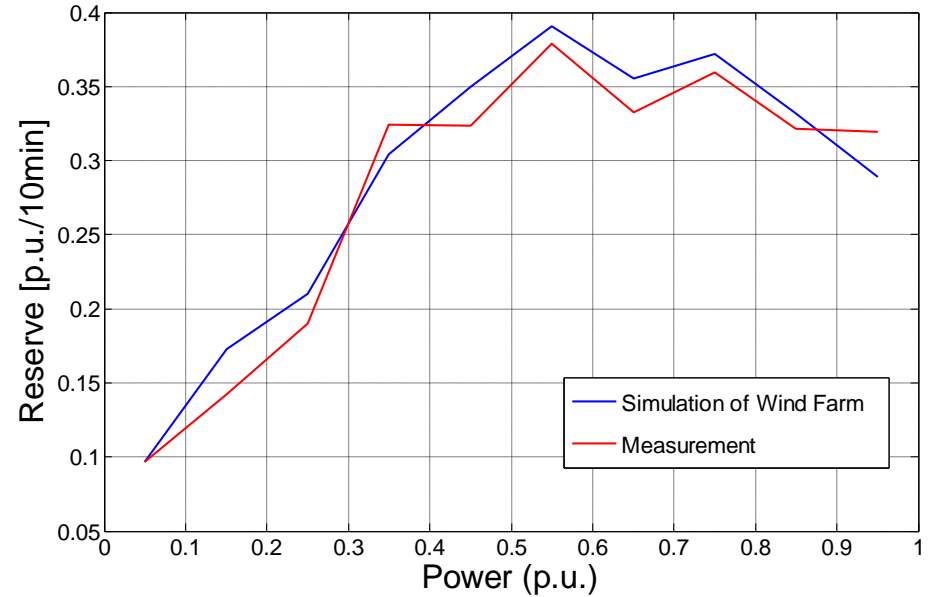
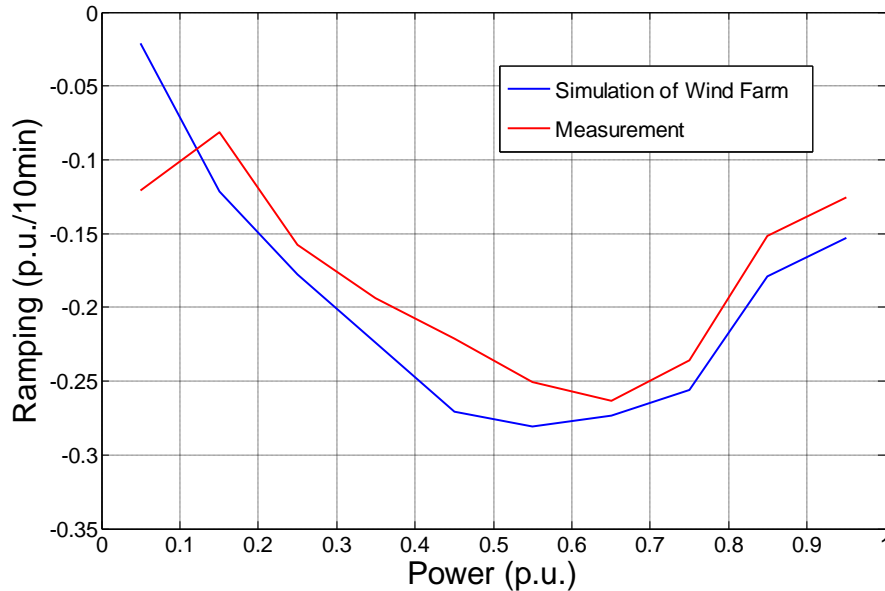
$$P_{res}(n) = P_{mean}(n) - P_{min}(n+1)$$

Risø DTU

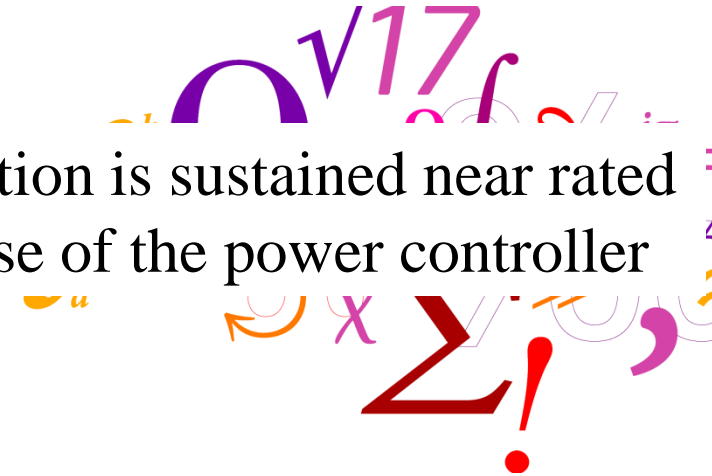
Nationallaboratoriet for Bæredygtig Energi



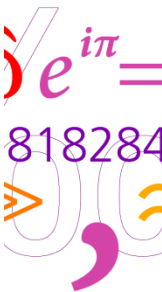
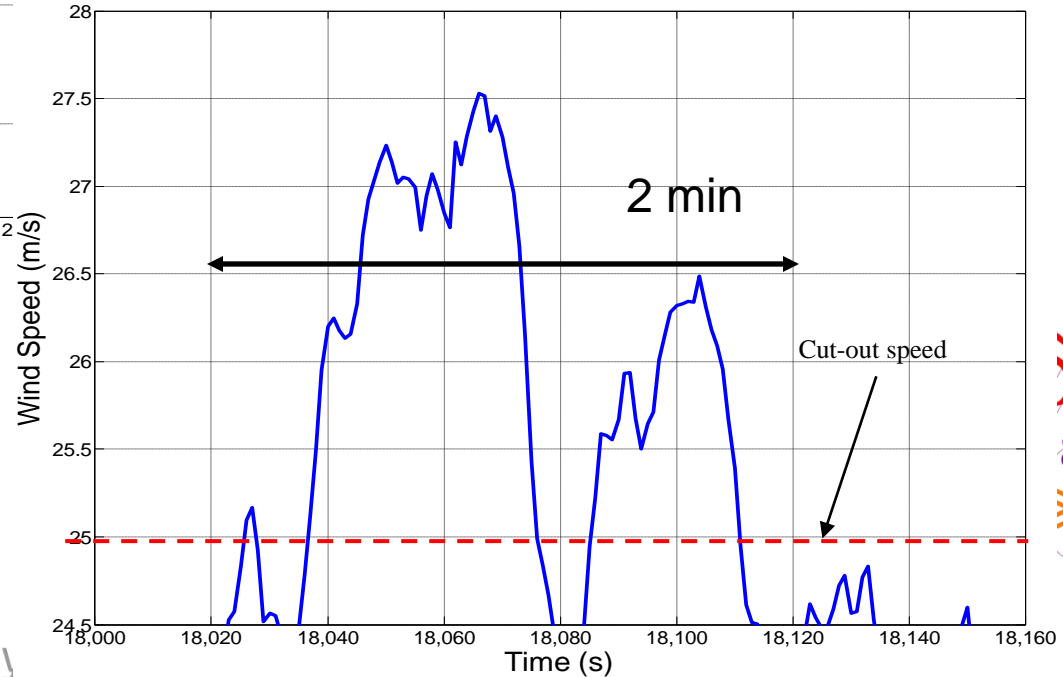
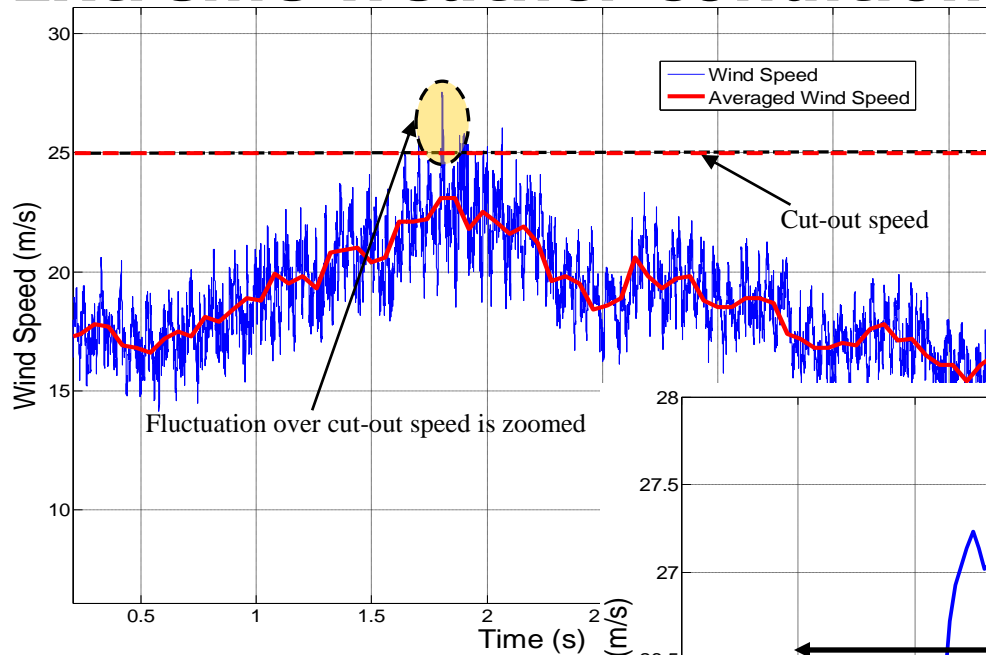
Normal weather condition – ramp and reserve



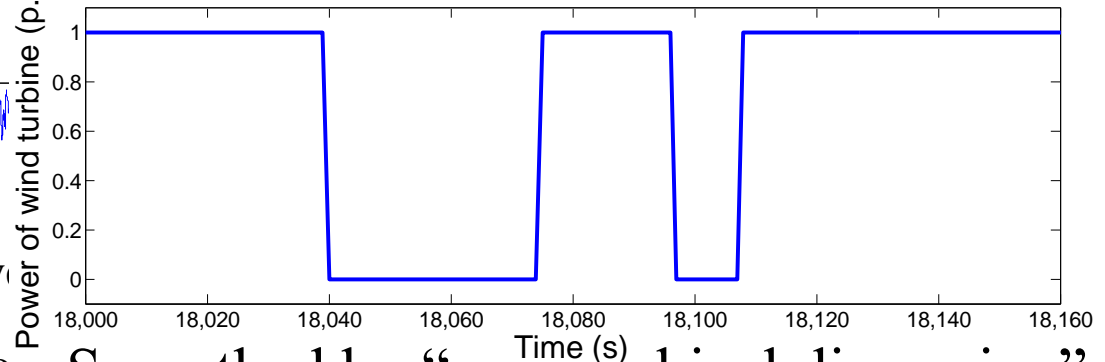
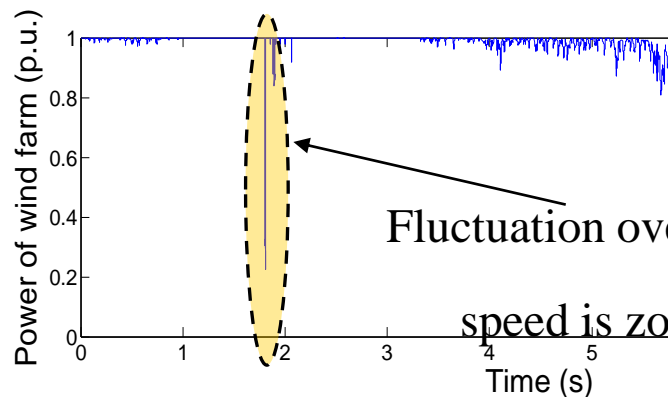
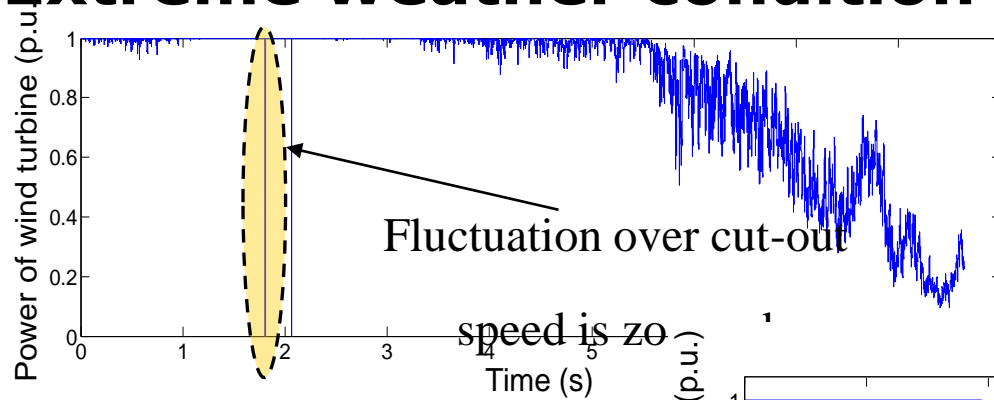
Power fluctuation is sustained near rated power because of the power controller



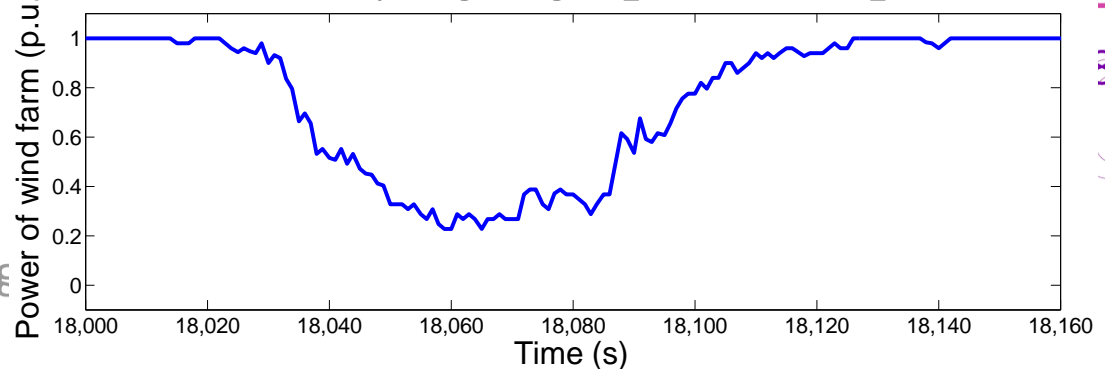
Extreme weather condition



Extreme weather condition



Smoothed by “geographical dispersion”

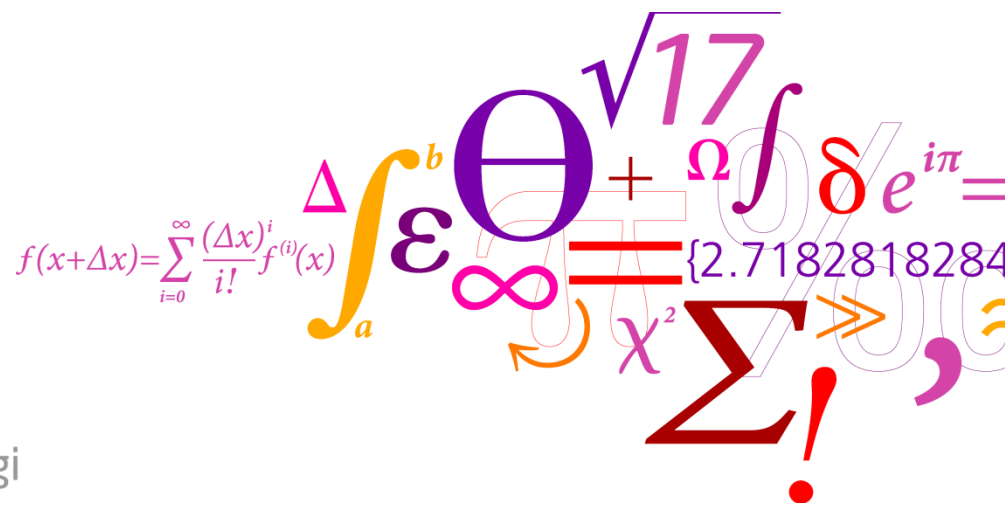


Conclusion

- Frequency model provides an unified way to describe the wind power fluctuation
- Simulation length can be hour to hour and resolution can be second to second
- Under normal condition, highest fluctuation risk happens when the wind farm is producing 0.7-0.9 p. u.
- Under extreme condition, "geographical dispersion" is simulated, which smoothes the power drop when a storm hits.
- In future, this model is extended to assess the frequency deviation risk and the smooth strategy design.

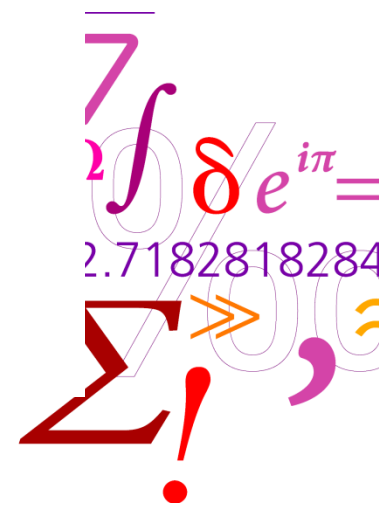
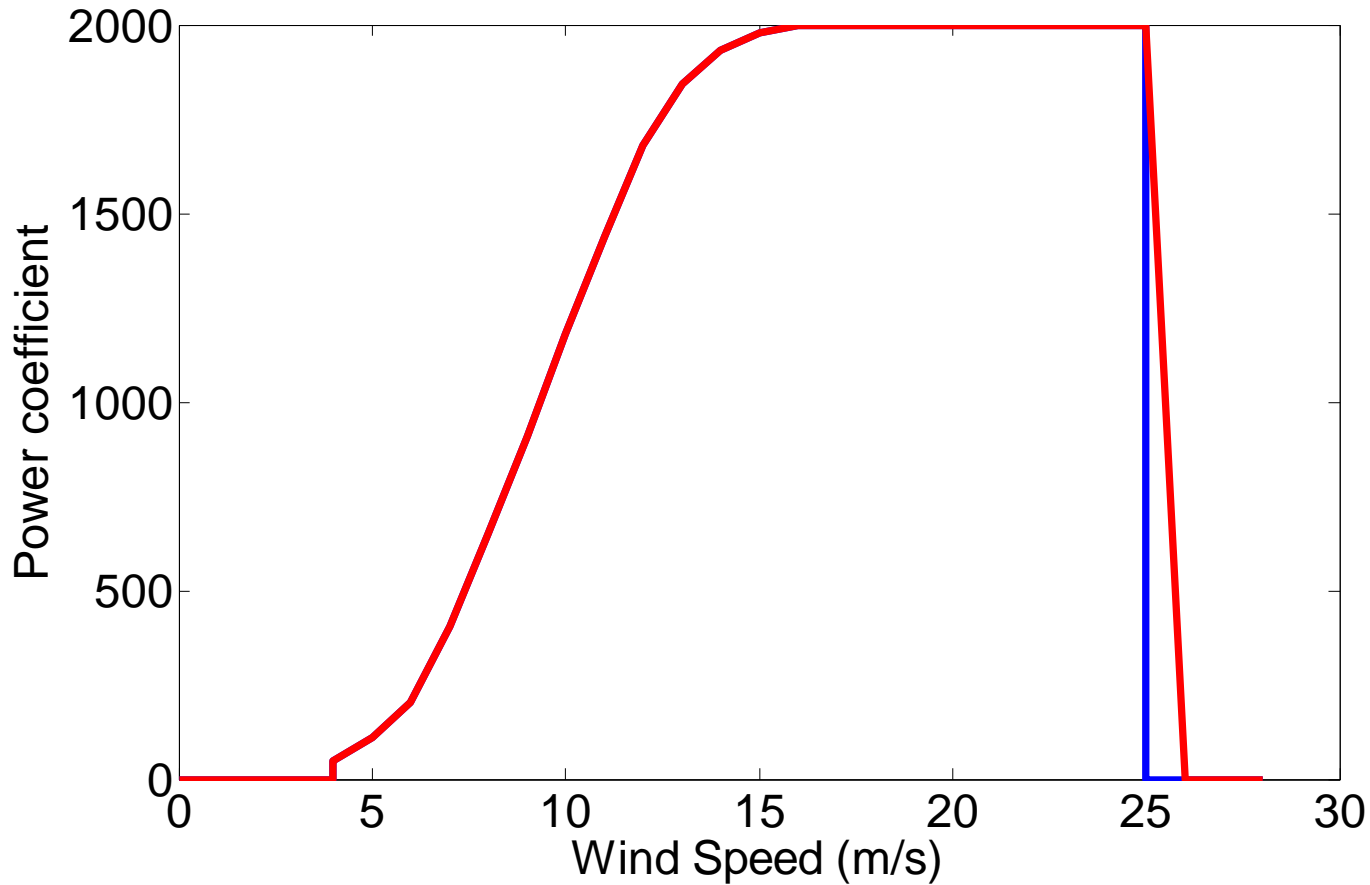
$$f(x+\Delta x) = \sum_{i=0}^{\infty} \frac{(\Delta x)^i}{i!} f^{(i)}(x)$$

Thank you!

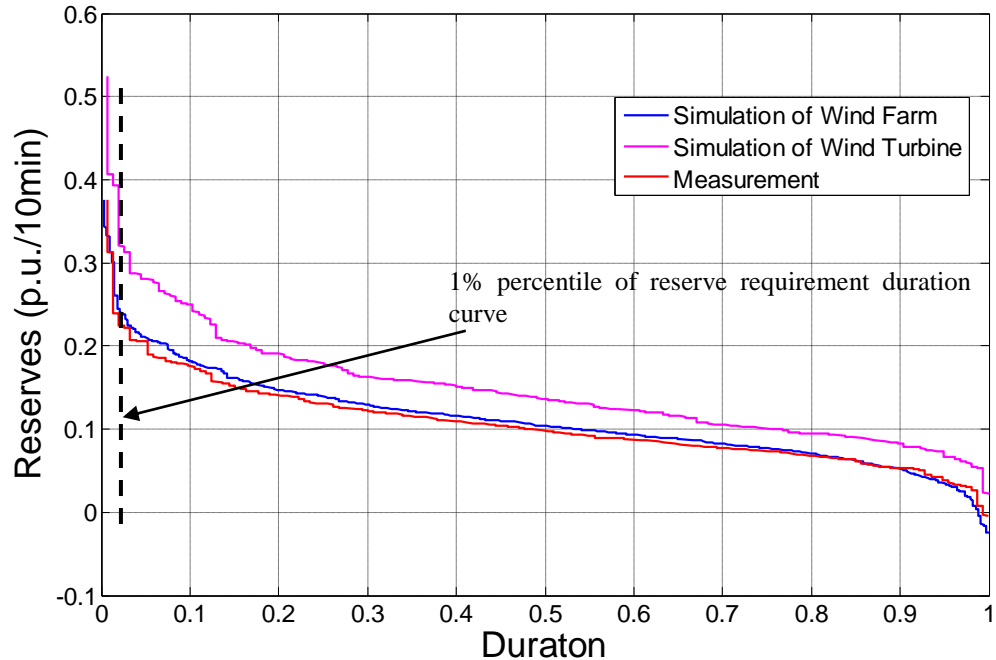
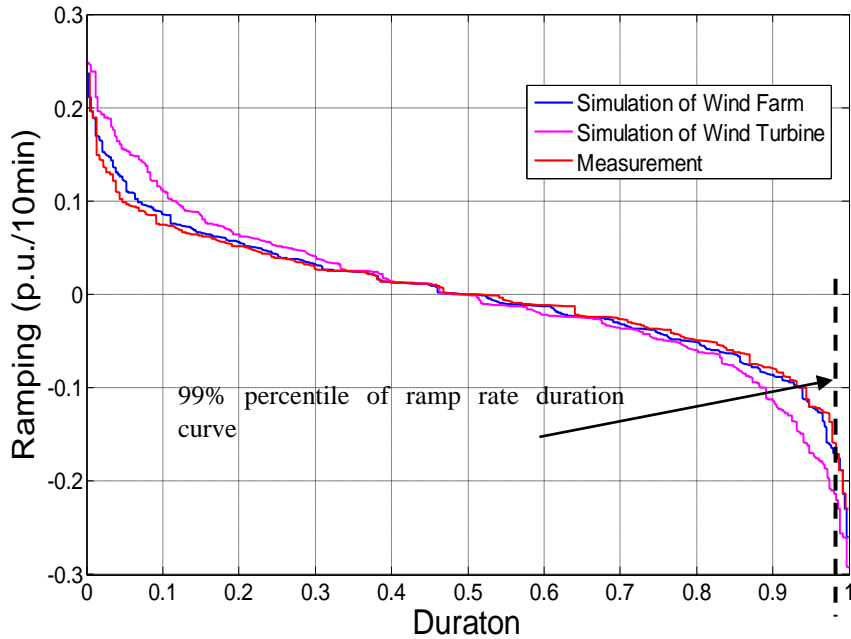


A collage of mathematical symbols and formulas. The central element is the Taylor series expansion: $f(x+\Delta x) = \sum_{i=0}^{\infty} \frac{(\Delta x)^i}{i!} f^{(i)}(x)$. Other symbols include a definite integral \int_a^b , a summation \sum , an infinity symbol ∞ , a Greek letter Θ , a square root $\sqrt{17}$, a plus sign $+$, a Greek letter Ω , a delta symbol δ , an exponential function $e^{i\pi}$, and a large sigma symbol Σ with an exclamation point below it. The symbols are rendered in various colors and sizes, creating a dense and colorful composition.

Extreme weather condition



Ramp and Reserve



$$f(x+\Delta x) = \sum_{i=0}^{\infty} \frac{(\Delta x)^i}{i!} f^{(i)}(x)$$

$$\int_a^b \epsilon \chi^2$$

$$= \{2.7182818284\}$$