Energy storage for stability enhancement in systems with high wind penetration

Claus Nygaard Rasmussen

Institute of Energy Technology
Aalborg University, Denmark

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- Power Systems
- Power Electronic Systems
- Electrical Machines
- Fluid Power Systems
- Combustion
- Thermal Energy systems

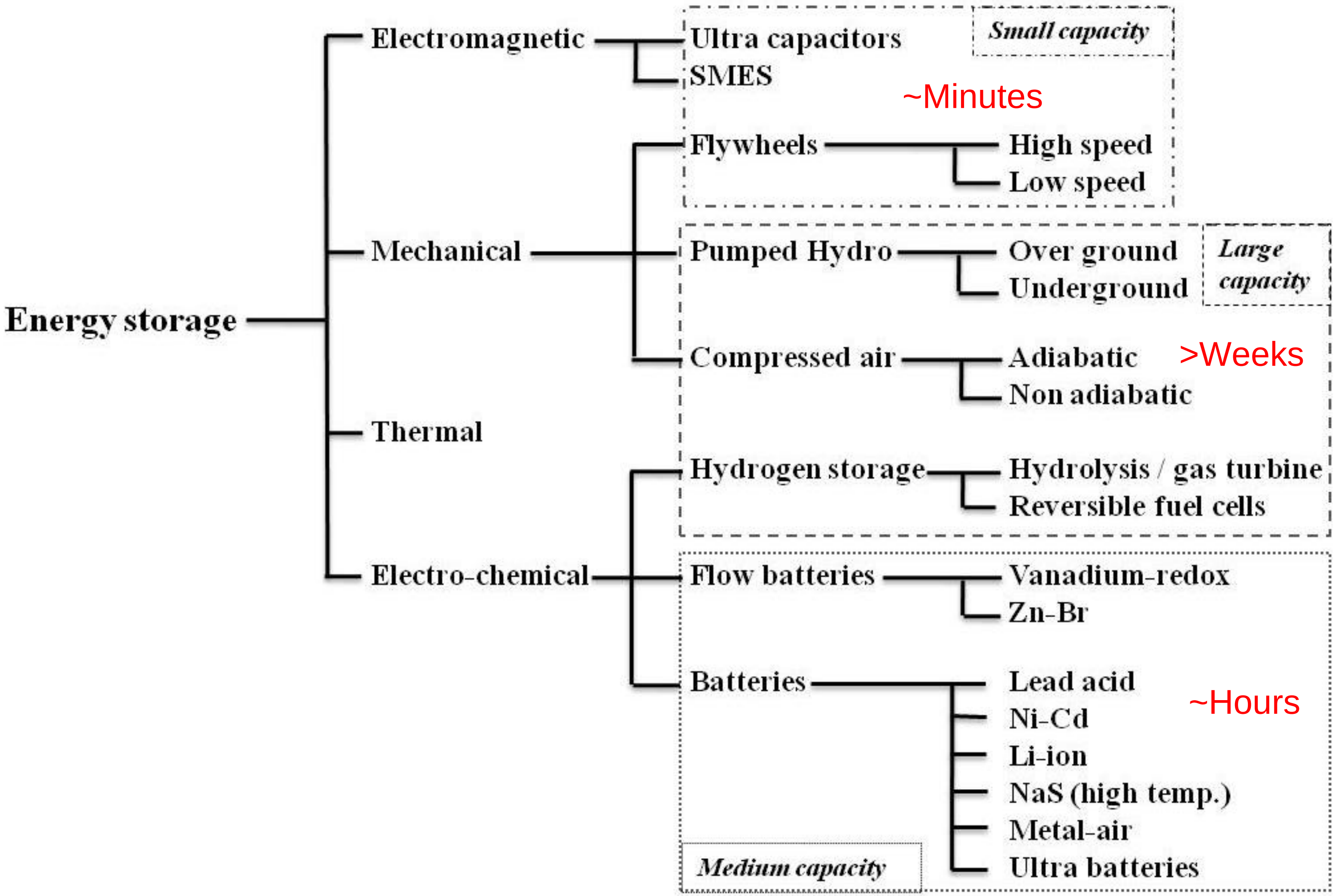
Multi-disciplinary research programmes

- Fuel cell Systems
- Wind Turbine Systems
- Biomass
- → Power Systems Analysis and Planning
- Green Power Converters
- Automotive & Industrial Drives
- High Efficient Fluid Power Systems
- → Active Grids & Energy Storage
- Thermal Design
- Mechatronic Design / Virtual Prototyping
- → Vestas power program

Energy storage areas of interest

- Application areas – the role of energy storage in the network
- Storage technology overview, applications and limitations
- Relation between energy storage capacity and the effect on wind power
- Cost/benefit of storage – How much benefit do we get from storage
- Storage operation schemes (modelling and laboratory testing)
- Battery operation and online lifetime estimation (modelling and laboratory testing)

Energy storage technologies

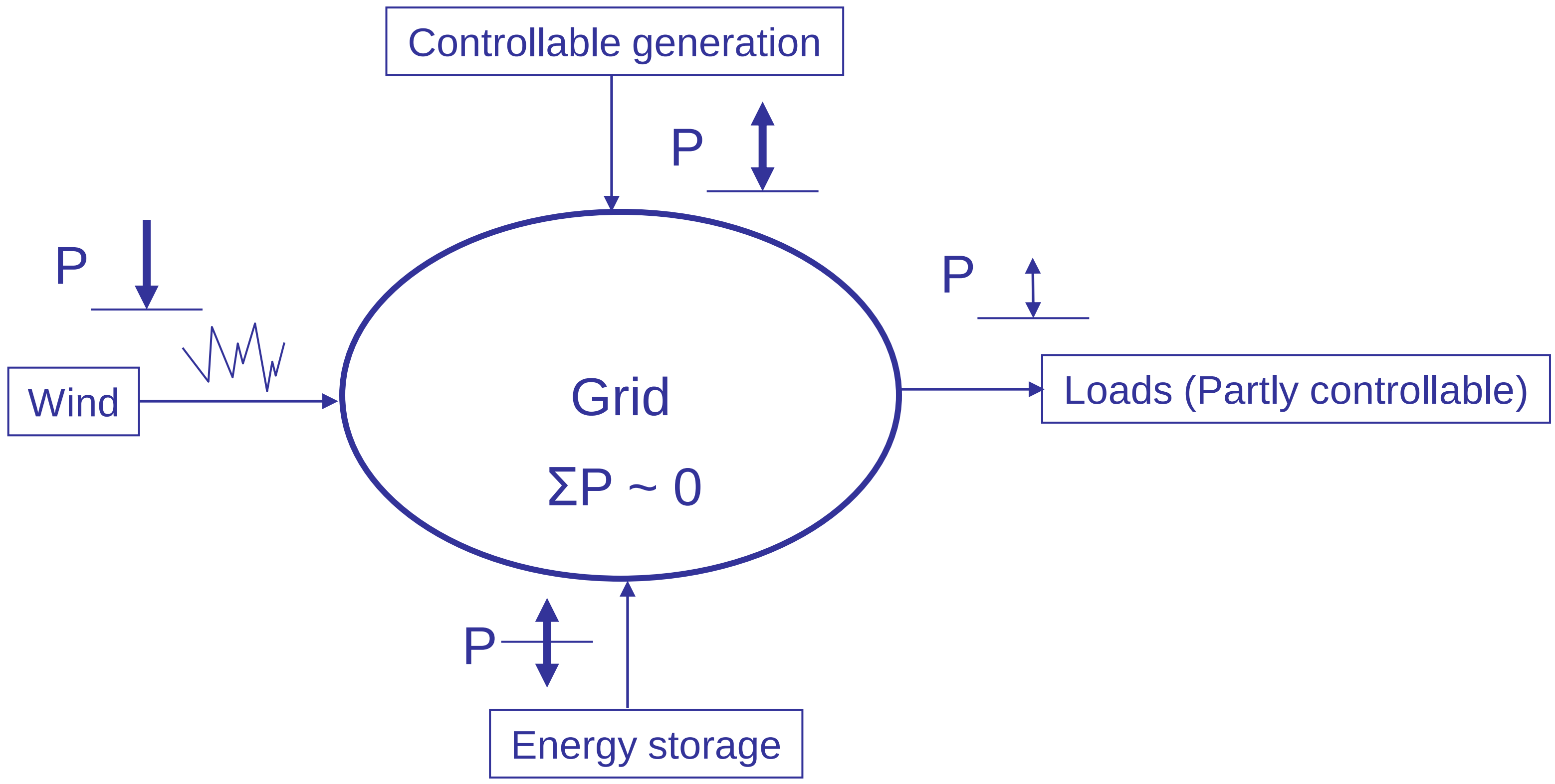


Energy storage application areas

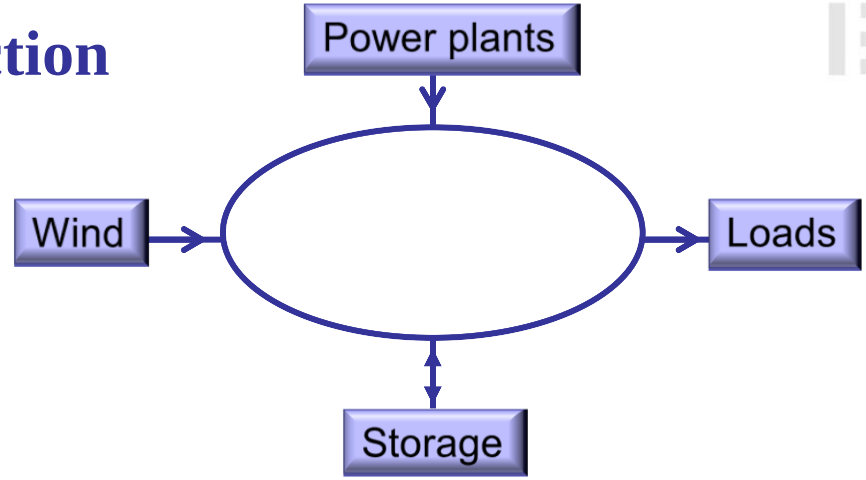
1	Reducing conventional generation. Increasing the overall wind penetration level by capturing and storing excess wind power for use at times with low wind.
2	Ensuring stability by reducing wind power fluctuation rates to a level that can be handled by the fully controllable generation remaining in the grid.
3	Ancillary services – services that storage may provide to the grid in order to improve power quality in general, or reduce the consequences of serious grid events. Short timescale services.

	Application	Power [p.u.]	Time [hours]
	Load following	1	>100
	Tertiary reserve	1	>10
1	Power levelling	0.7	>10
	Energy arbitrage	0.5	12
	Forecast improvement	*0.25*	*12 – 24*
	Stability enhancement	0.5	1 – 10
	Peak shaving	0.7	1 – 10
2	Reserve power	0.5 - 1	5 – 10
	Inertia enhancement	*0.2*	*< 0.1*
	Frequency regulation	*0.2*	*< 0.1*
	Soft stop	1	0.25
3	Black start	0.1	0.1
	Voltage stabilisation	-	< 0.1
	Low voltage ride through	0.1	< 0.1

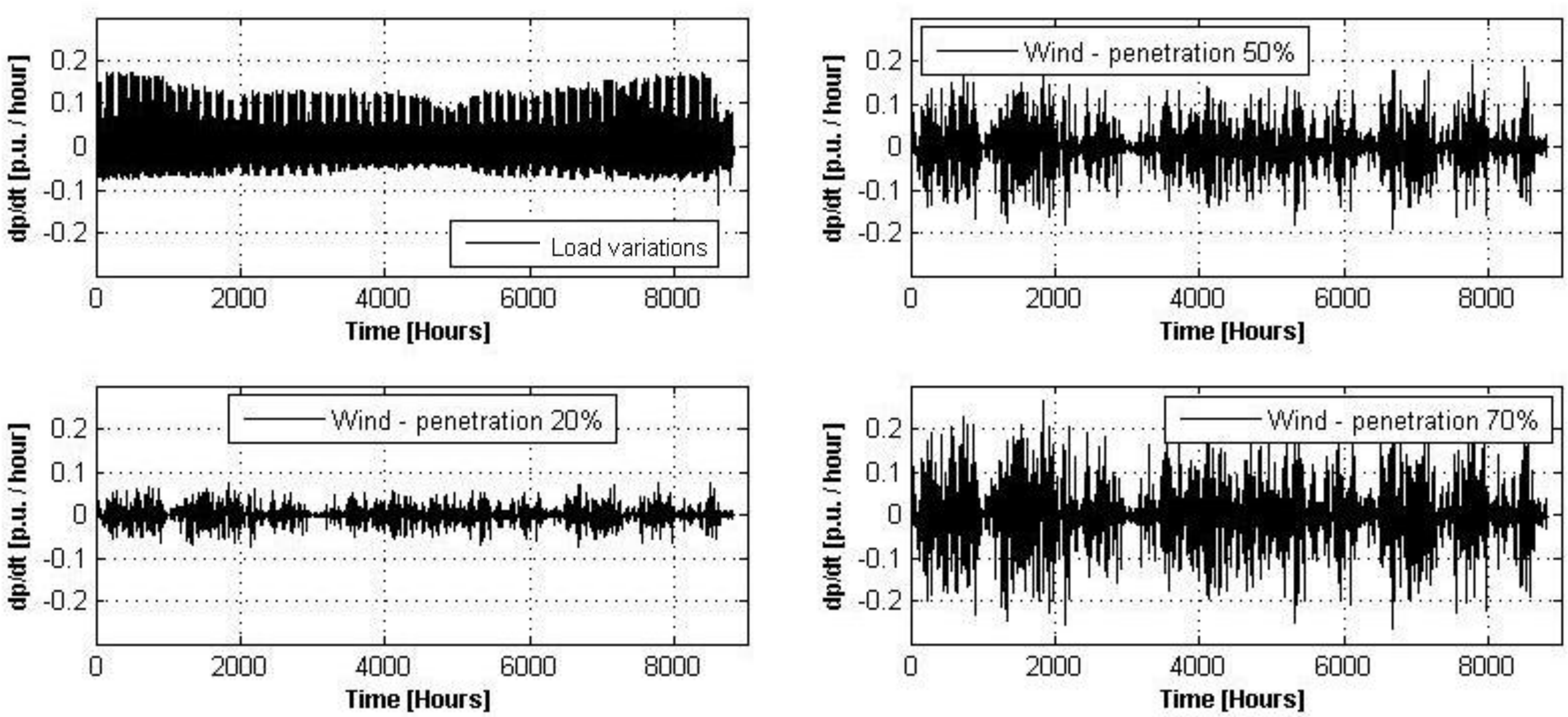
Grid stability – Δp/Δt reduction



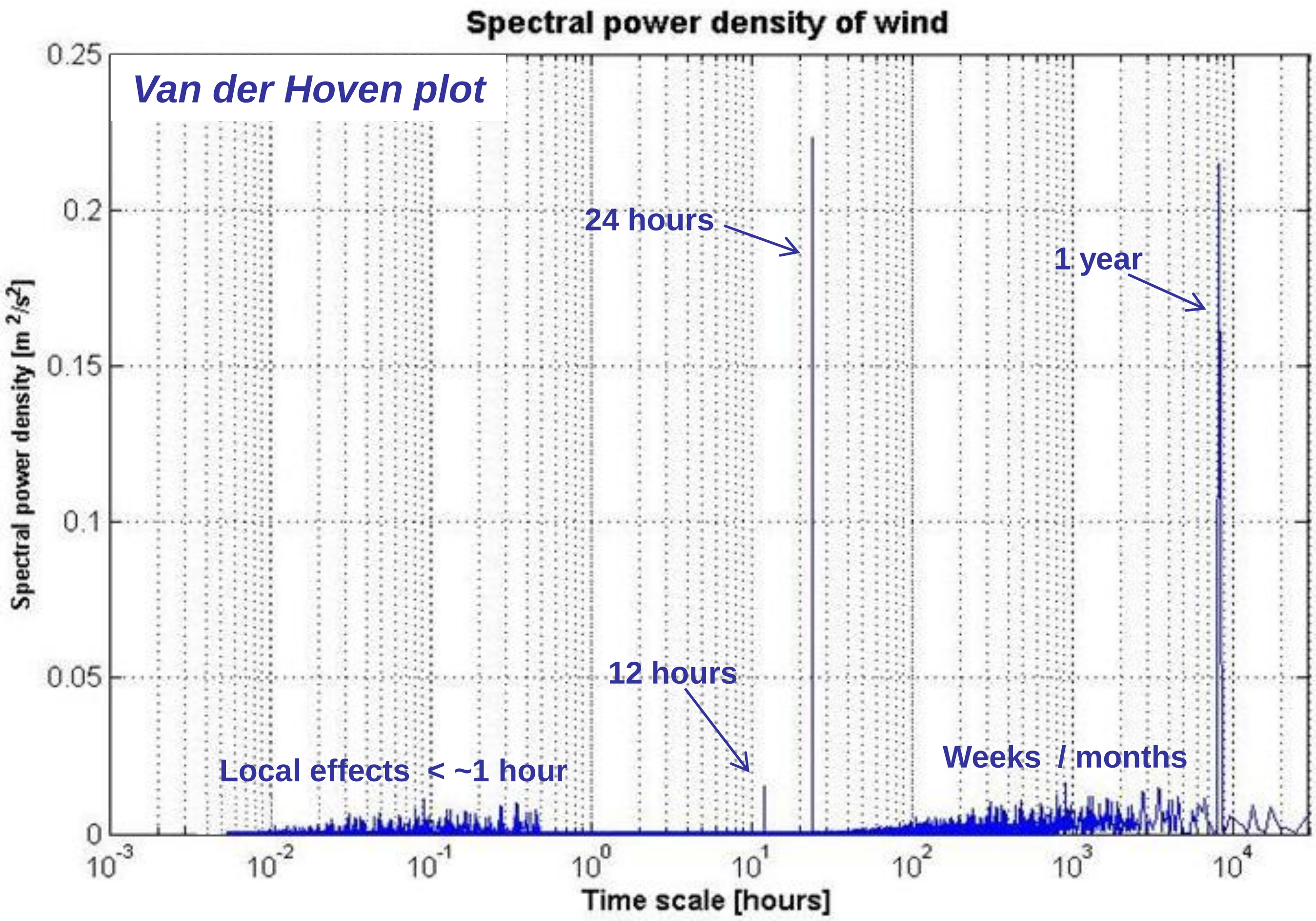
Grid stability – Δp/Δt reduction



Fluctuations – Western Denmark



The nature of wind power variations



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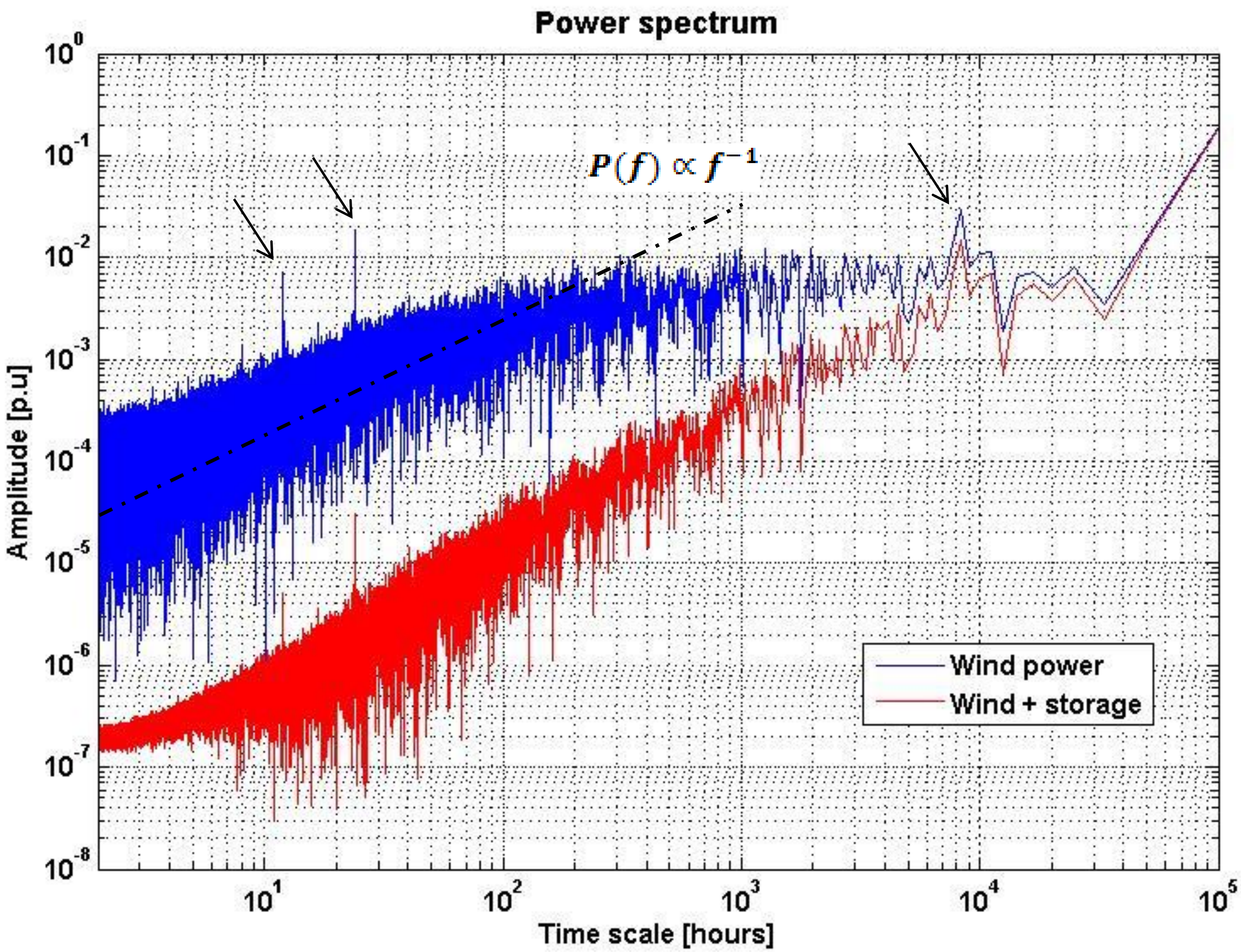
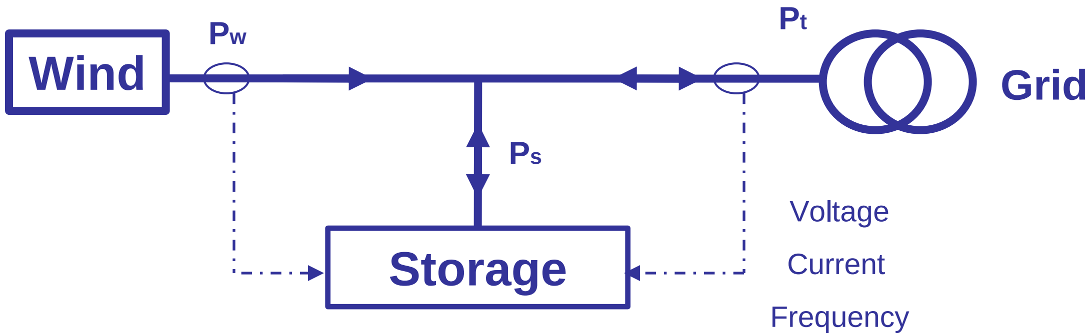
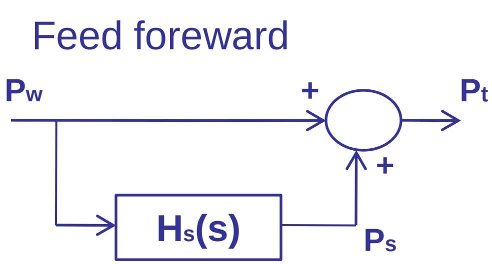
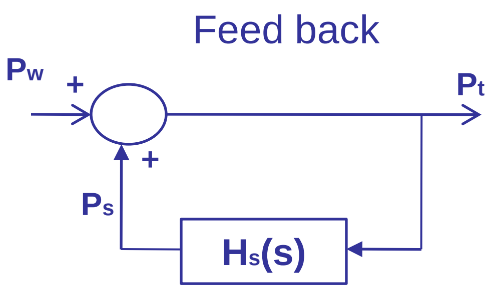


Storage operation scheem







Storage operation scheem

Discharge (P_s>0): $$\frac{dE_s}{dt} = \frac{-P_s}{\varepsilon(P_s, E_s)}$$

Charge (P_s<0): $$\frac{dE_s}{dt} = -P_s \cdot \varepsilon(P_s, E_s)$$

Power control: $$P_s = (P_{req} - P_w) + \frac{(E_s - E_{max} \cdot psoc)}{\tau}$$ $-P_{max} \leq P_s \leq P_{max}$

Required power: $$P_{req} = \frac{1}{\Delta t}\int_{t-\Delta t}^{t} P_w dt$$ (Or P_{req} determined by system operator)

τ – Time constant related to charge rate

psoc – Preferred state of charge

P_{max} – Storage power rating

E_{max} – Storage energy capacity

High availability: $$\tau_1 = \frac{4 \cdot E_s}{P_{avg}}$$

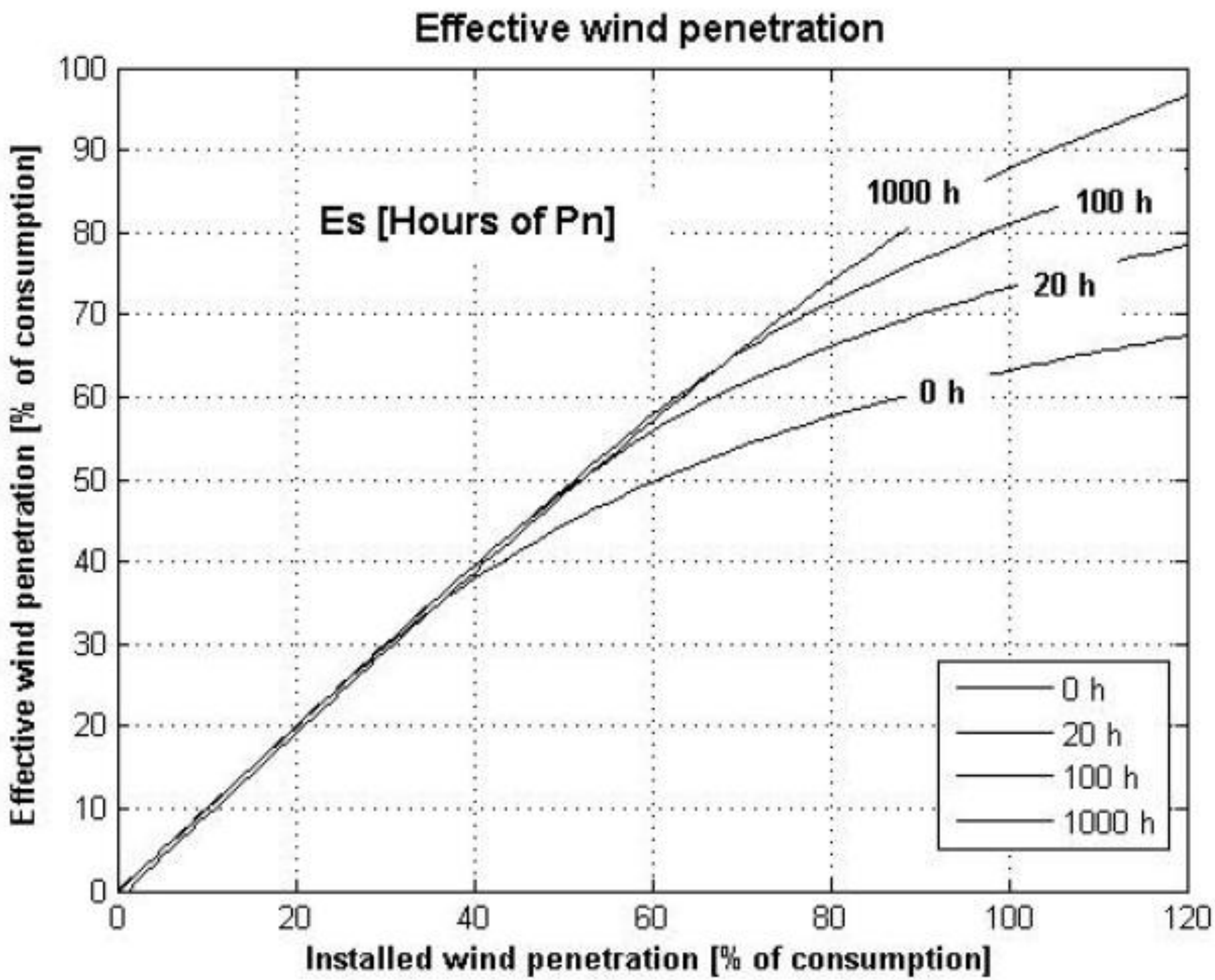
Full dp/dt reduction: $$\tau_2 = \frac{E_s}{2 \cdot P_s}$$

Modelling results

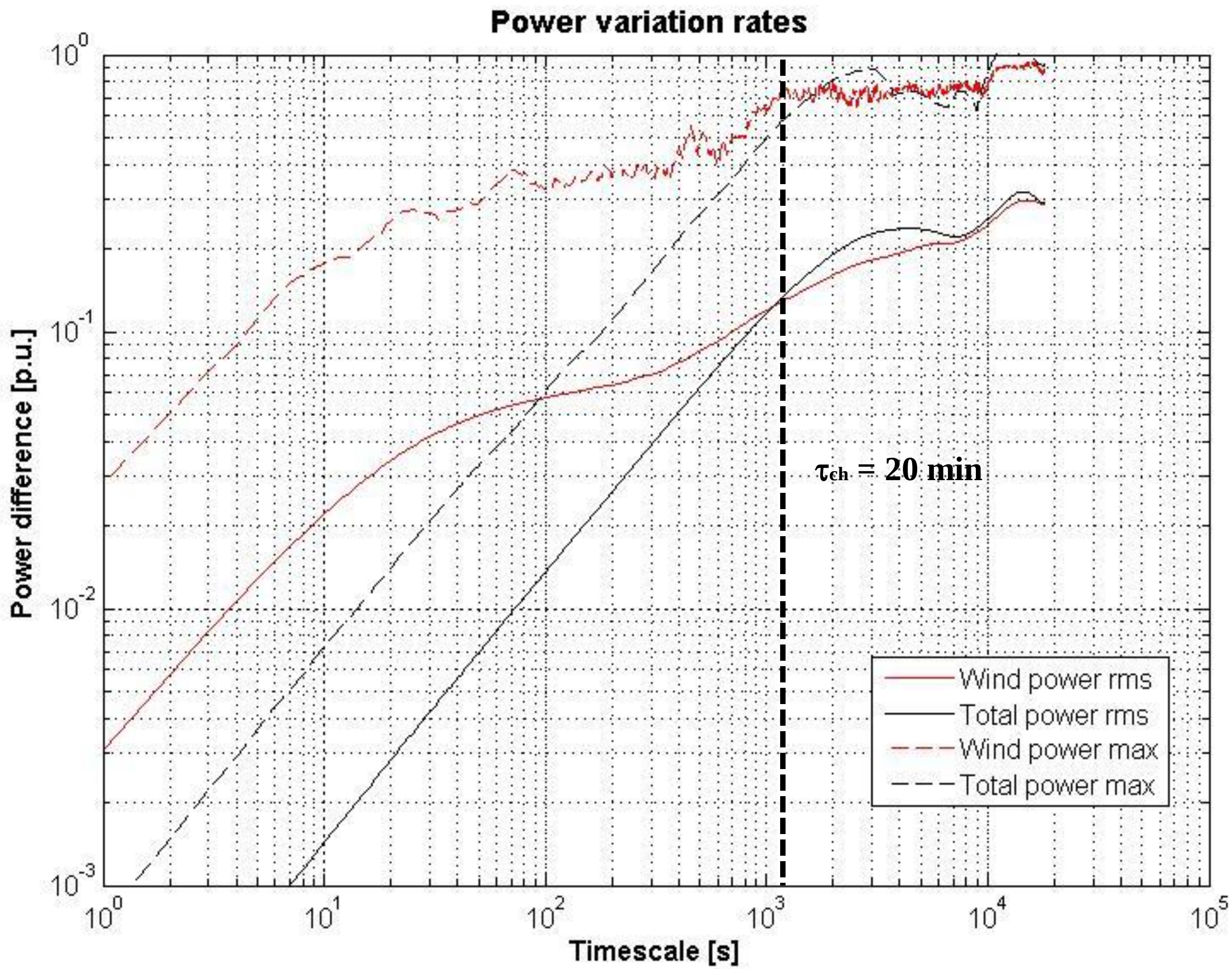
- Capturing excess energy - ES influence on wind penetration level
- Reduction of fluctuation rates (dp/dt)
- The influence of wind power aggregation
- Large scale variation reduction with storage
- High wind penetration system modelling

Capturing excess energy –

ES influence on wind penetration level



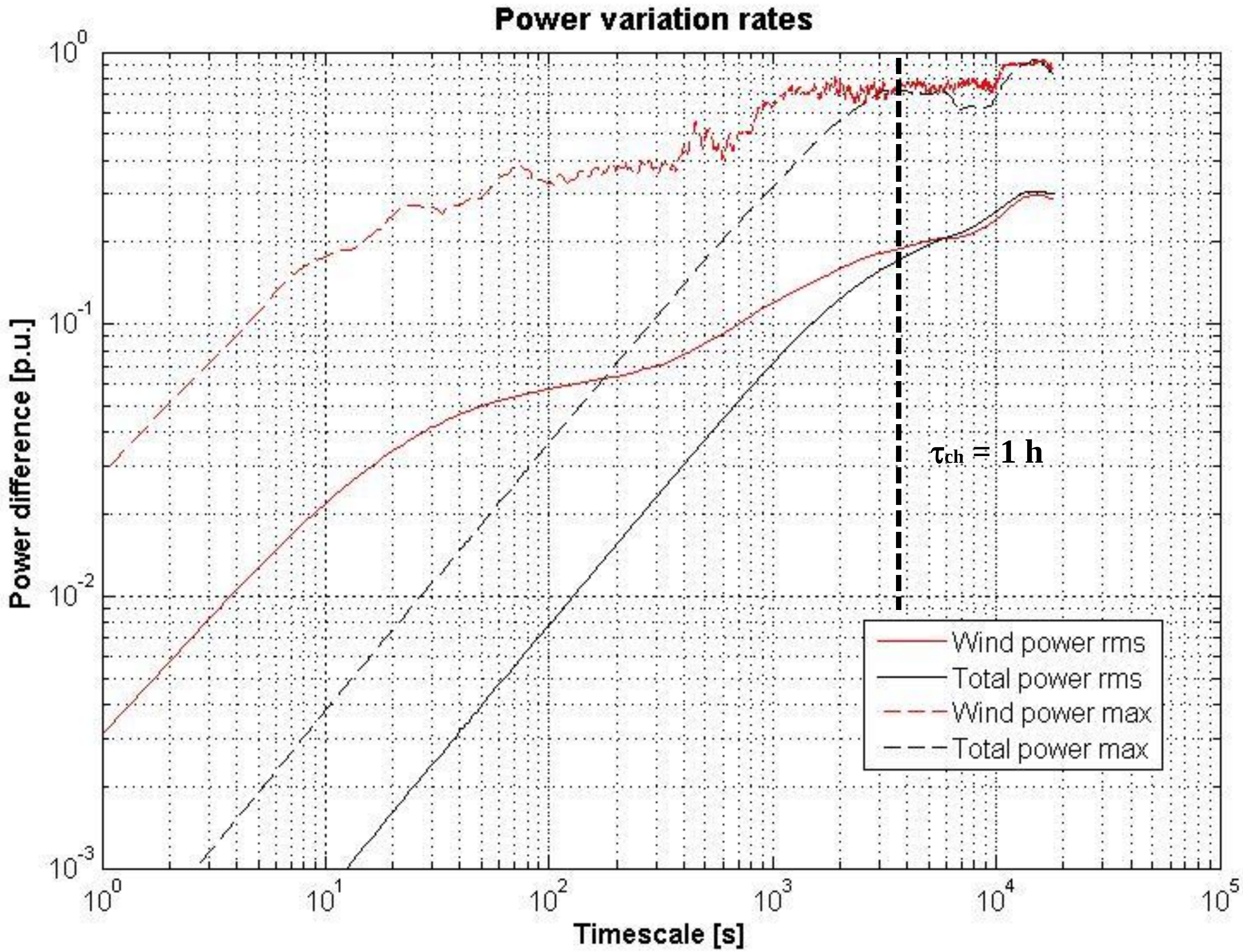
Modelling results – fluctuation rates



Ps = ½ Pn

Es/Pn = 10 min

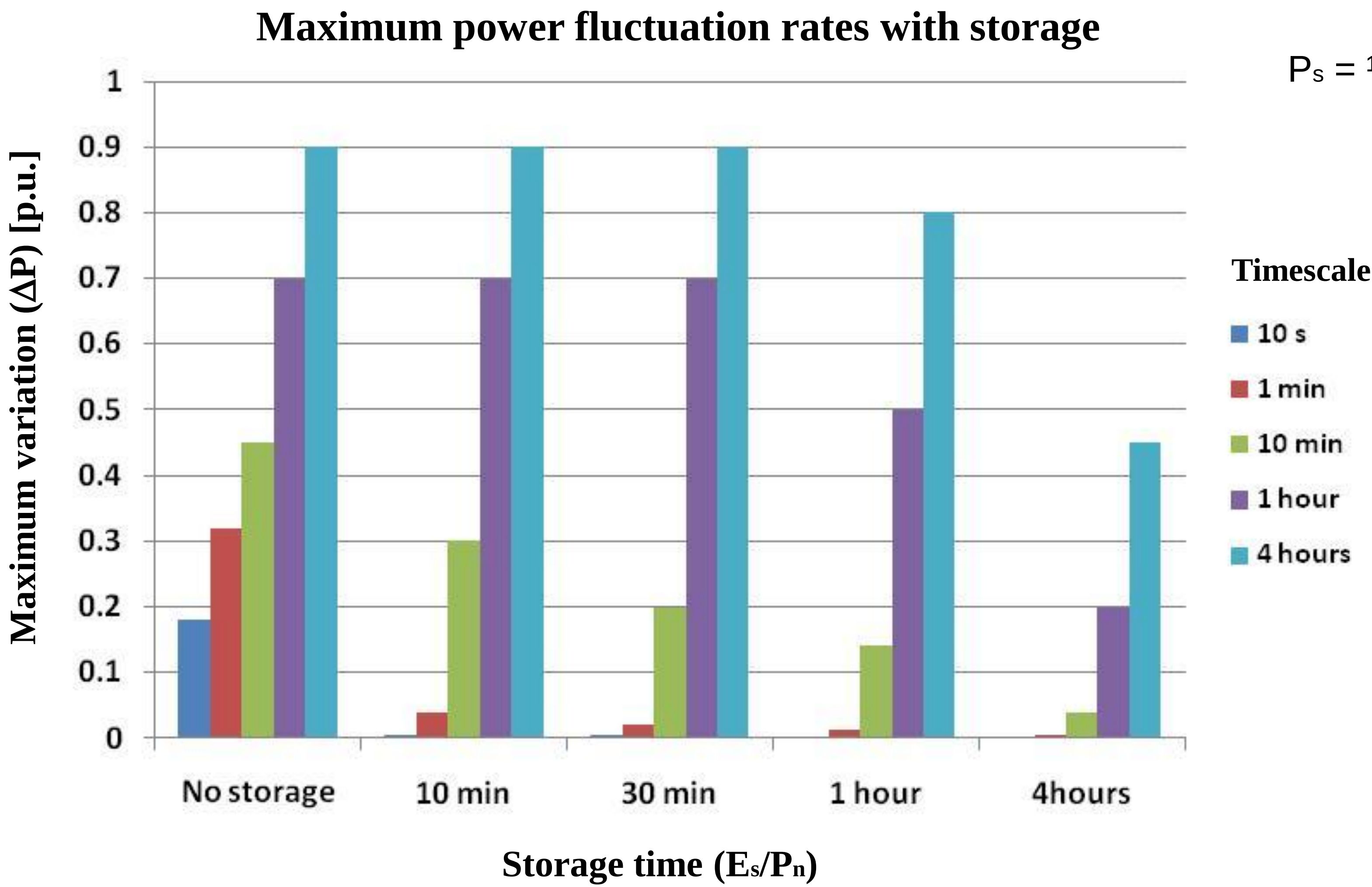
Modelling results – fluctuation rates



Ps = ½ Pn   Es/Pn = ½ hour

Modelling results – fluctuation rates

$P_s = ½ P_n$



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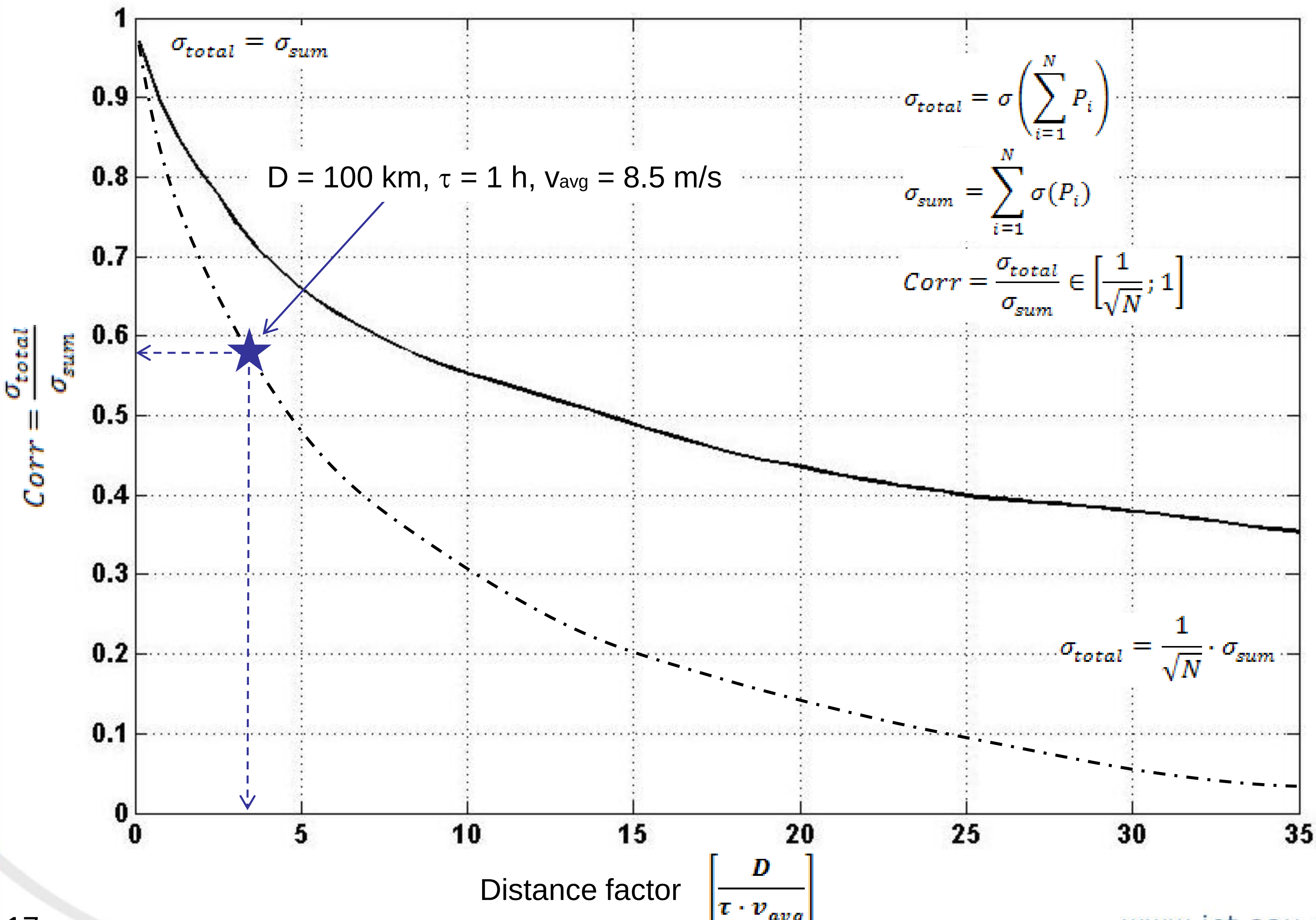
The influence of wind power aggregation



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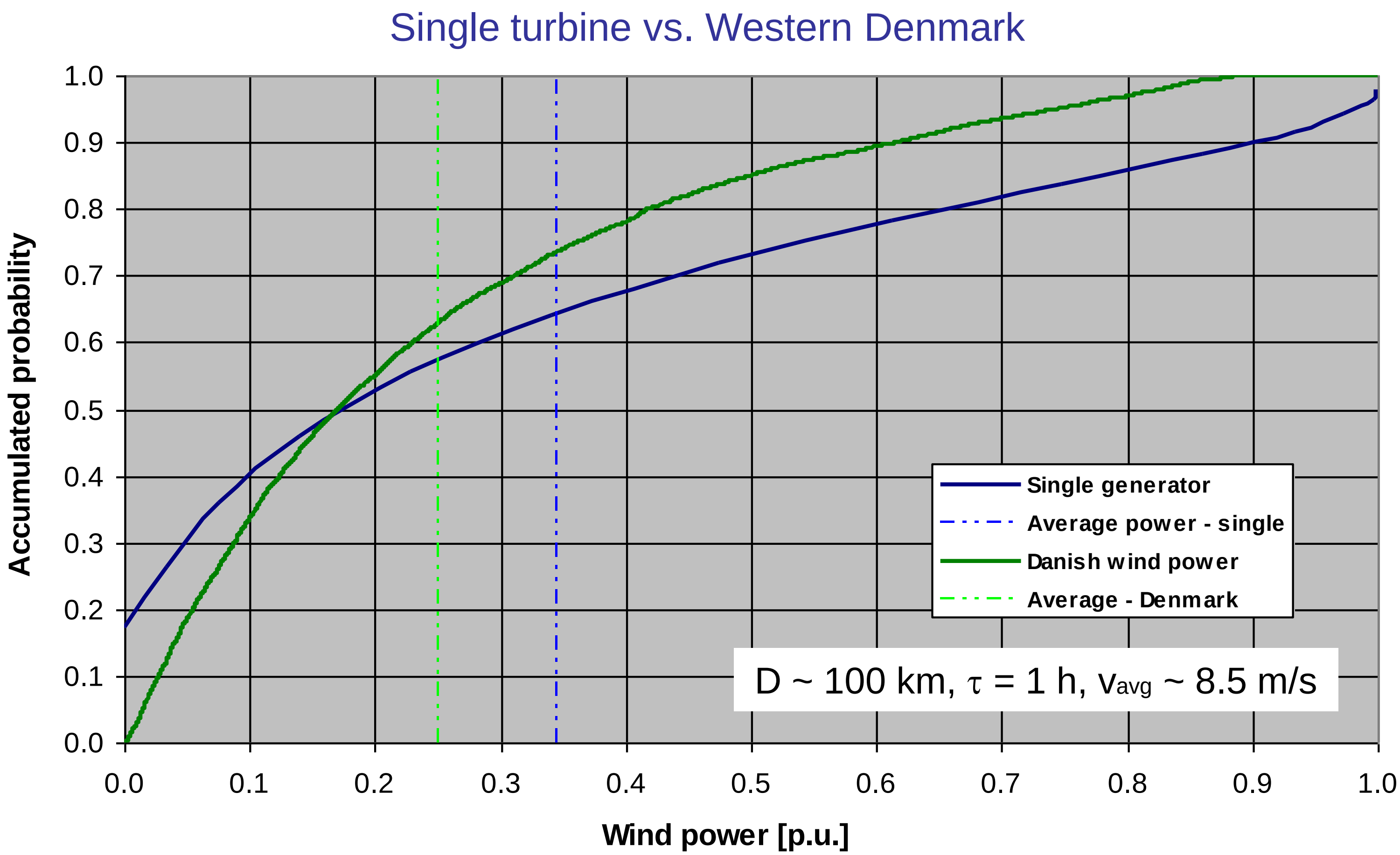
The influence of wind power aggregation



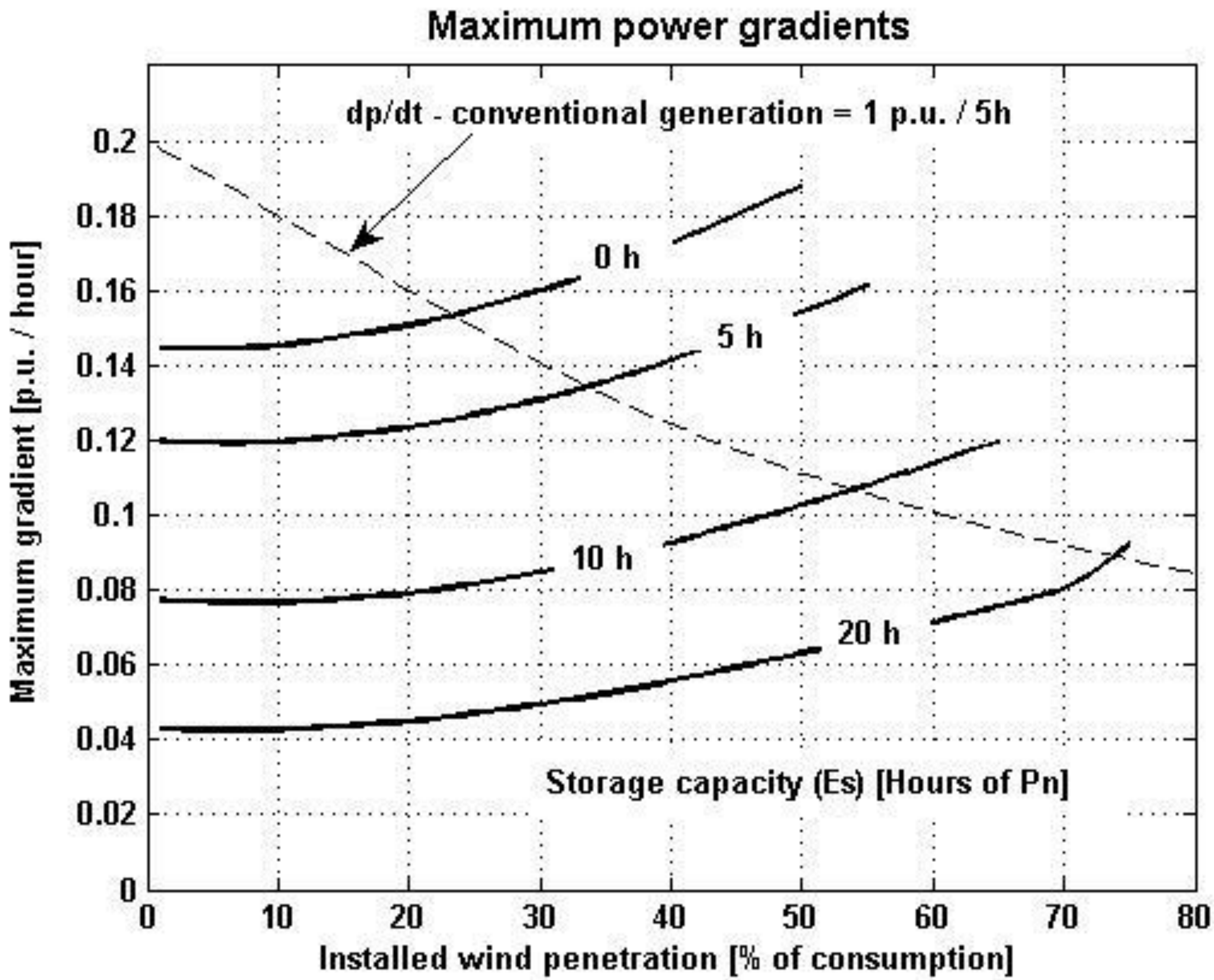
Single turbine: σ_s ~ 0.65 p.u.

Western Denmark: σ_{tot} ~ 0.37 p.u.

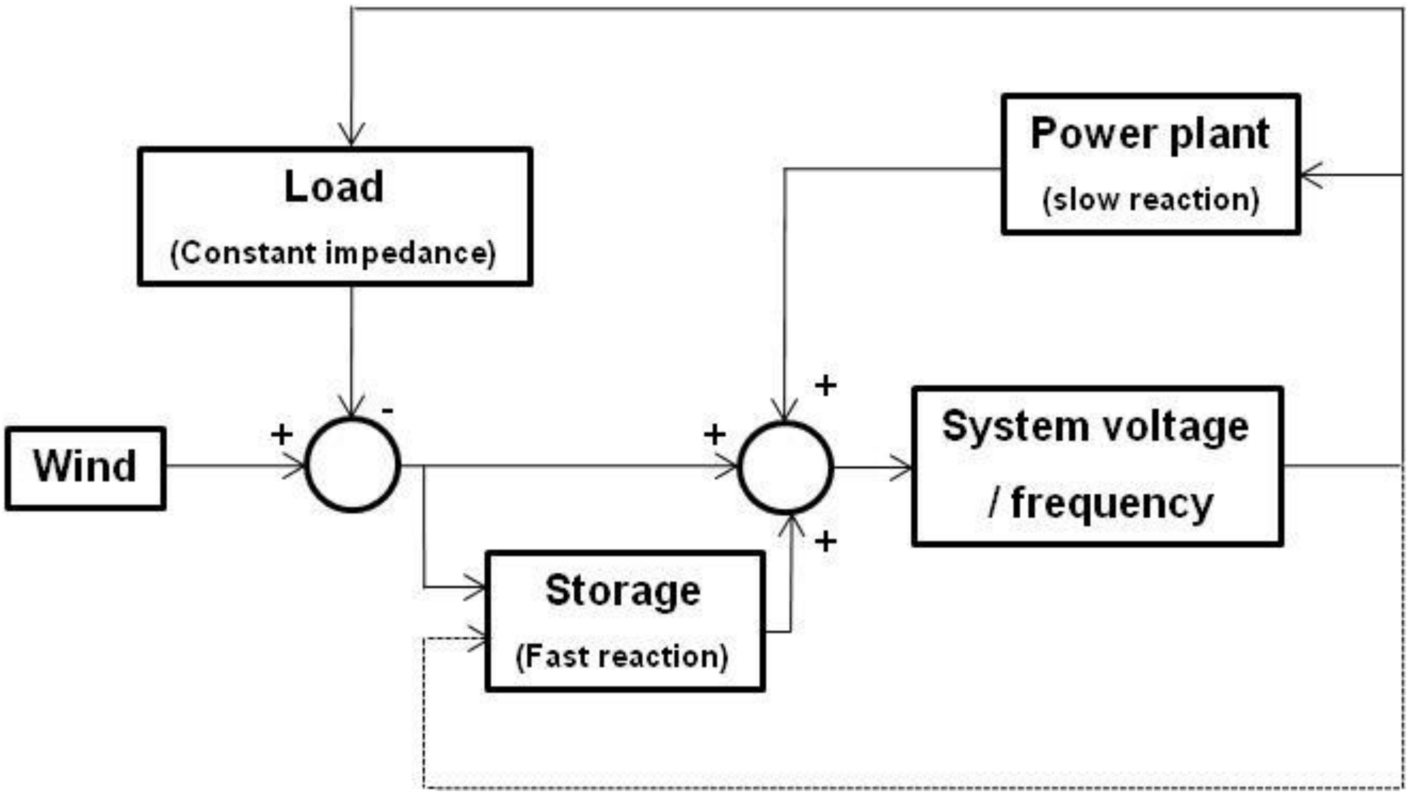
$$Corr = \frac{\sigma_{total}}{\sigma_{sum}} \approx 0.57$$

Distance factor $\left[\frac{D}{\tau \cdot v_{avg}}\right] \approx 3.2$

Large scale variation reduction with storage



High wind penetration system modelling



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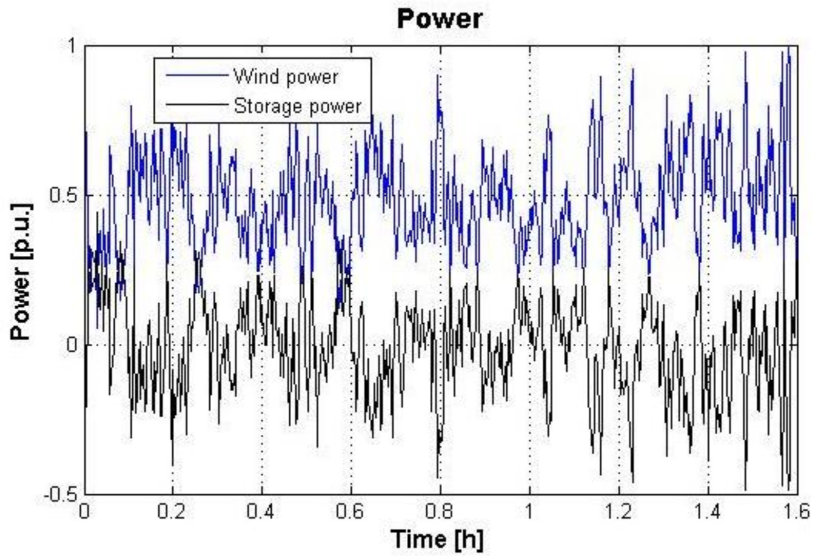
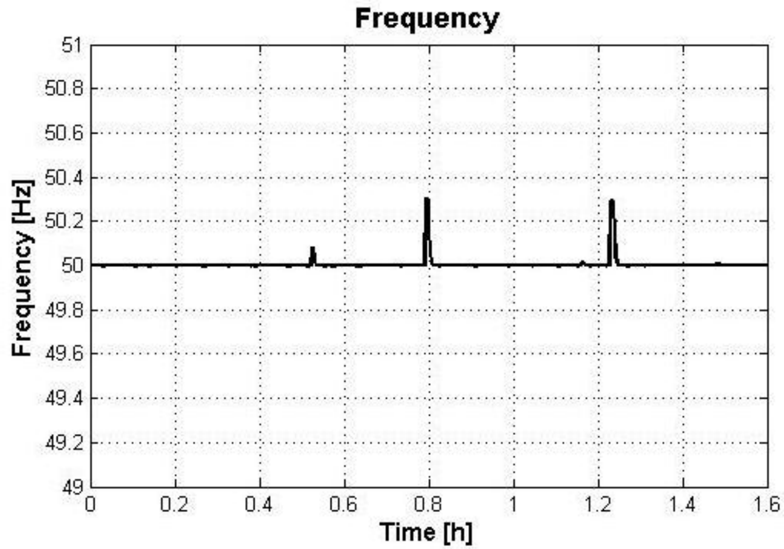
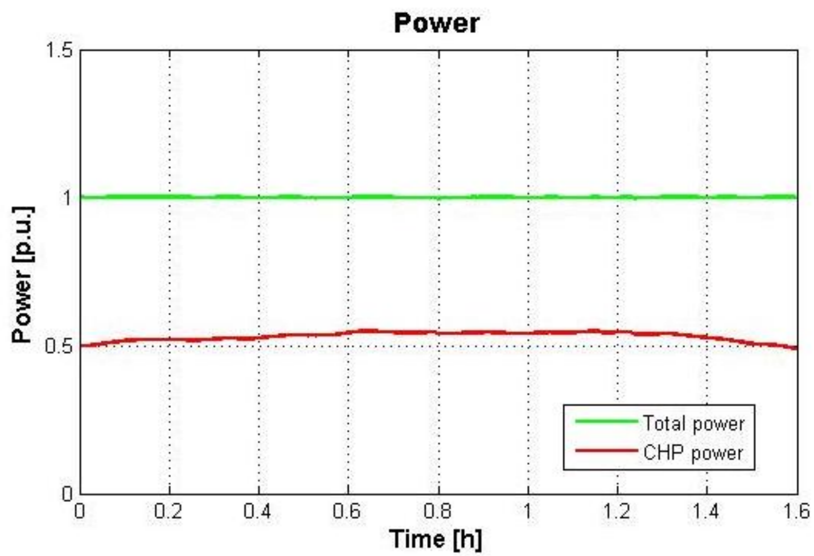
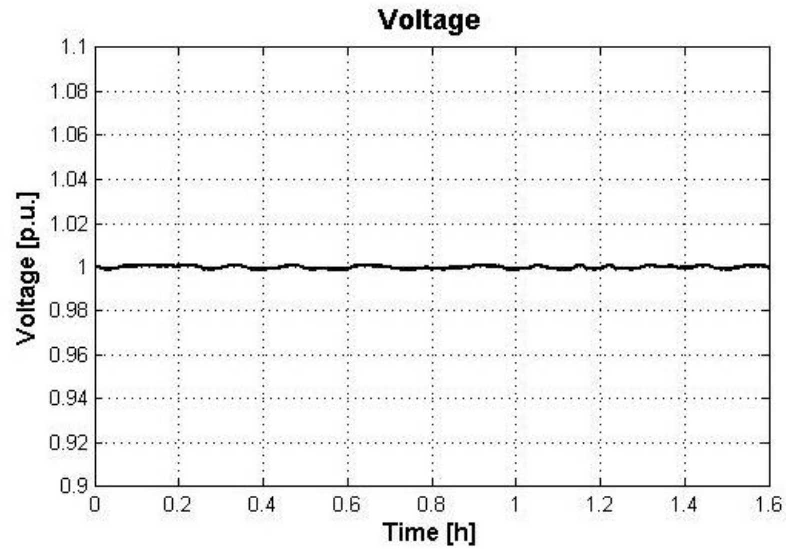
High wind penetration system modelling

$P_s = 0.5$ p.u. $E_s = 1/6$ hour $\cdot P_s$ $\tau_1 = 4 \cdot E_s / P_{avg} \approx 2/3$ hour



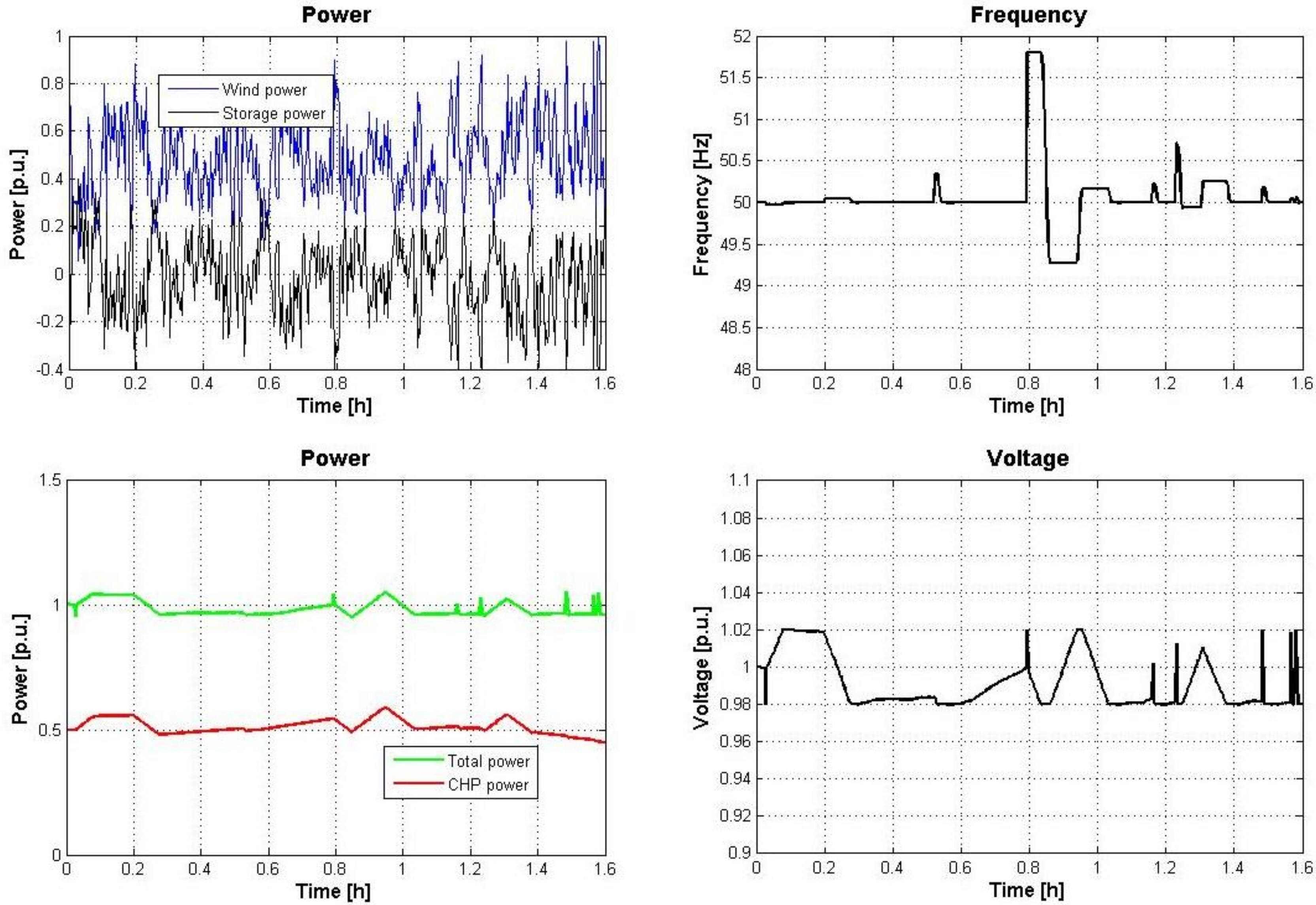






High wind penetration system modelling

P_s = 0.4 p.u. E_s = 1/5 hour · P_s $\tau_1 = 4 \cdot E_s / P_{avg} \approx 2/3$ hour



Conclusions

Storage application areas:

1) Energy management → better use of renewable sources (large capacity)
2) Stability enhenacement → increased maximum wind penetration level (medium capacity)
3) Ancillary services (small to medium capacity)

Storage sizing for stability enhancement:

$E_s \sim ¼ \cdot \tau \cdot P_{avg}$ τ = 1h - 10h => E_s = ¼h - 4h of nominal wind power

$P_s \sim ½ \cdot P_n$

Storage operation scheem:

1) Low-pass filter with cut of frequency $f_0 = 1/\tau$
2) Artificial inertia enhancement
3) Power on demand

Stability =>
- **Aggregation**
- **Active loads**
- **Storage**