

IEA Task 23 Back-to-Back Workshop:
Offshore wind farms – wake effects and power fluctuations

Comparison of Power fluctuations from onshore and offshore wind farms

S. Martín, A. Viguera-Rodríguez & E. Gómez-Lázaro



1.Introduction

2.Wind Farms analyzed

3.Power Fluctuations

4.Conclusions

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Introduction

- Current and future rising of wind energy
- High wind penetration
- Analysis of power fluctuations from several wind farms
- Smoothing of the fluctuations due to the geographical spreading

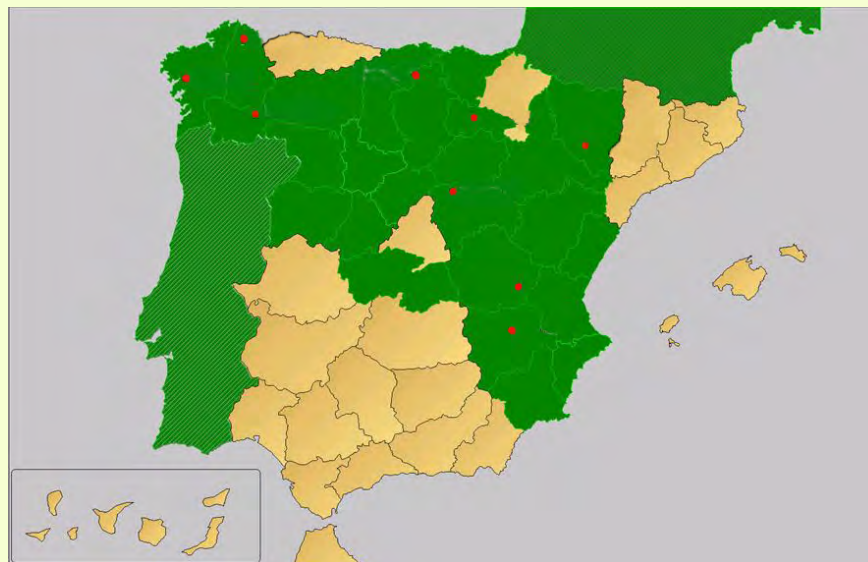
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Wind farms analyzed

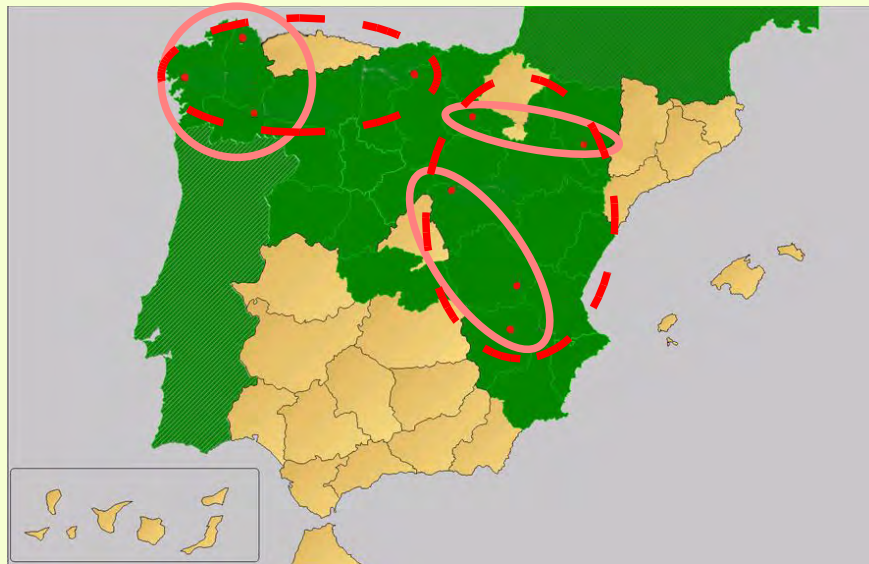


Nº	Wind farm	Nominal Power	Wind turbine model	Number of wind turbines
1	Viveiro	36.5 MW	Gamesa G52	850 x 43
2	Monte Treito	30.4 MW	Gamesa G58/G47	850 x 21 / 660 x 19
3	Serra do Burgo	27.2 MW	Gamesa G58/G52	850 x 19 / 850 x 13
4	Tardienta I	49.5 MW	Gamesa G47	660 x 75
5	Campisabalos	24.4 MW	Gamesa G47	660 x 37
6	Mira	38.3 MW	Gamesa G52	850 x 45
7	Higueruela	37.6MW	Gamesa G47	660 x 57
8	Valdeporres	31.4 MW	Gamesa G52	850 x 37
9	Sierra de Alcarama I	6.8 MW	Gamesa G58/G52	850 x 2 / 850 x 6
<i>X</i>	<i>Nysted</i>	<i>165.6 MW</i>	<i>Bonus 2.3 MW</i>	<i>2300 x 72</i>

Total nominal power of all onshore wind farms: 282.2 MW

Aggregation of wind farms

- Geographical combinations



NE	N_WFs
GAL	3
CLM	3
All WFs	9
NE	2
E	5
NW	4

- Pairs of wind farms

36 combinations of 2 Wind Farms from the 9 considered in this analysis. In such combinations the distance varies between 86 km and 744km, with a combined nominal power from 31 MW to 88 MW

Aggregation of wind farms

- Geographical combinations

Comb.	N_WFs	N_WTs	Pn (MW)	Max. Dist. (km)	Avg. Dist (km)
GAL	3	115	94	143	130
CLM	3	139	100	295	195
All WFs	9	374	282	744	400
NE	2	83	56	132	132
E	5	222	157	344	235
NW	4	152	126	405	237
<i>Nysted+Høvsøre</i>	<i>2</i>	<i>152</i>	<i>326</i>	<i>275</i>	<i>275</i>

$$d_{avg} = \frac{\sum_i^N \sum_{j=i+1}^N d_{i,j} \cdot (P_i + P_j)}{2 \cdot P_{sum}}$$

- Pairs of wind farms

36 combinations of 2 Wind Farms from the 9 considered in this analysis. In such combinations the distance varies between 86 km and 744km, with a combined nominal power from 31 MW to 88 MW

Aggregation of wind farms

- Similarities between Nysted WF and other onshore wind farms or combinations of them
 - $WF4 \rightarrow P_n = 49.5 \text{ MW}$, 75 WTs
 - $Comb E \rightarrow P_n = 157 \text{ MW}$, 222 WTs , 5 WFs ,
 $d_{max} = 344 \text{ km}$, $d_{avg} = 235 \text{ km}$
 - $Comb NW \rightarrow P_n = 126 \text{ MW}$, 152 WTs , 4 WFs ,
 $d_{max} = 405 \text{ km}$, $d_{avg} = 237 \text{ km}$
 - Several Pairs, $\sim 72 \text{ WTs}$, $P_n \in [50, 70] \text{ MW}$

1.Introduction

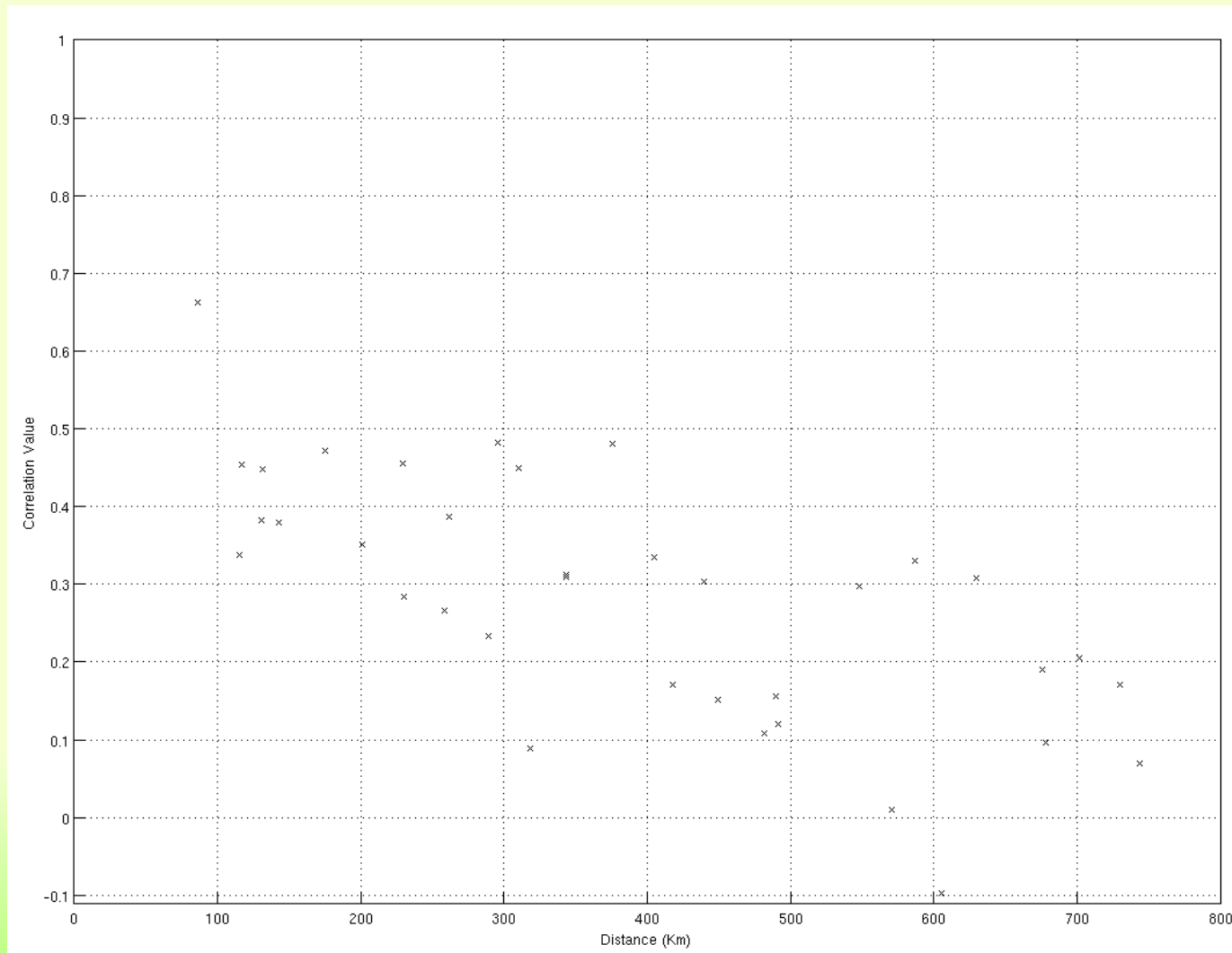
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4.Conclusions

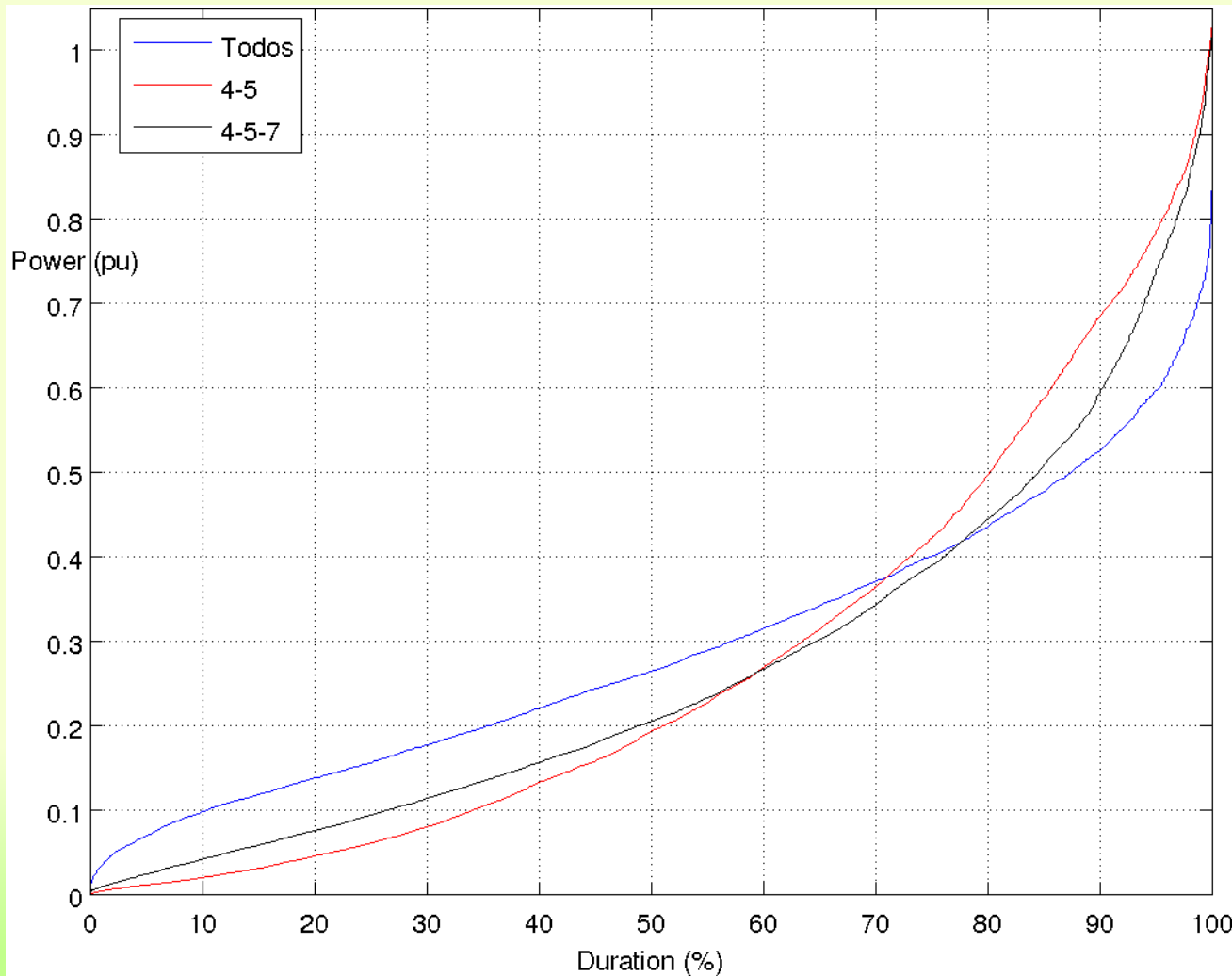
Power Fluctuations

- Aggregation of WFs – Correlation



Power Fluctuations

- Average power of aggregated onshore WFs
- Periods of 1 h -



All WFs
Max P. = 0.84 pu
 $\bar{P} < 0.1 pu$ less than 10
% of the hours

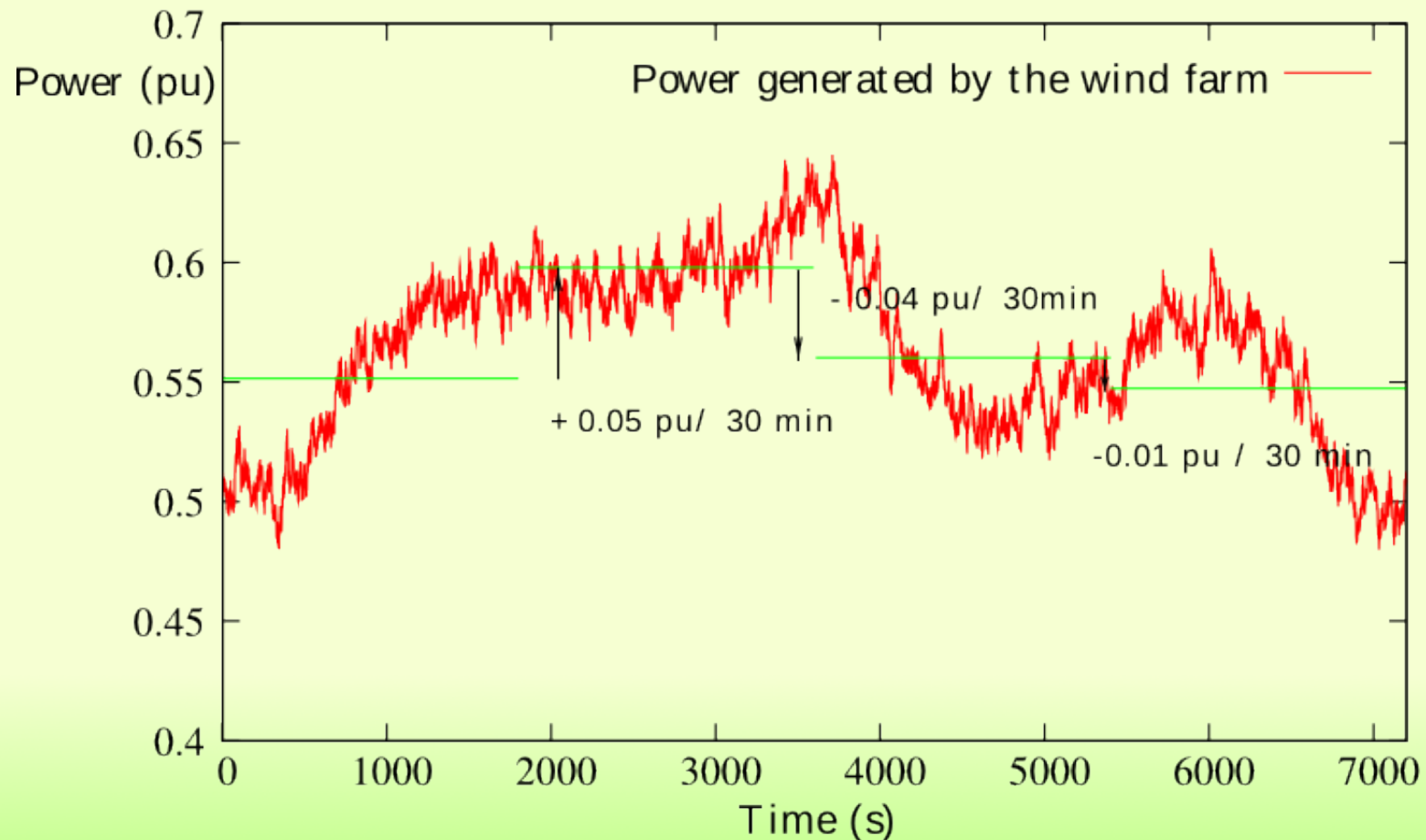
3 WFs
 $P_n = 112 MW$
 $d_{max} = 344 km$
 $\bar{P} < 0.1 pu$ $d_{avg} = 293 km$
less than 27%

2 WFs
 $P_n = 74 MW$
 $\bar{P} < 0.1 pu$ $d = 230 km$
less than 35% of the
hours


Power Fluctuations

- Ramping rates

$$P_{ramp,T} = \frac{\overline{P_{n+1}(t)} - \overline{P_n(t)}}{T}$$



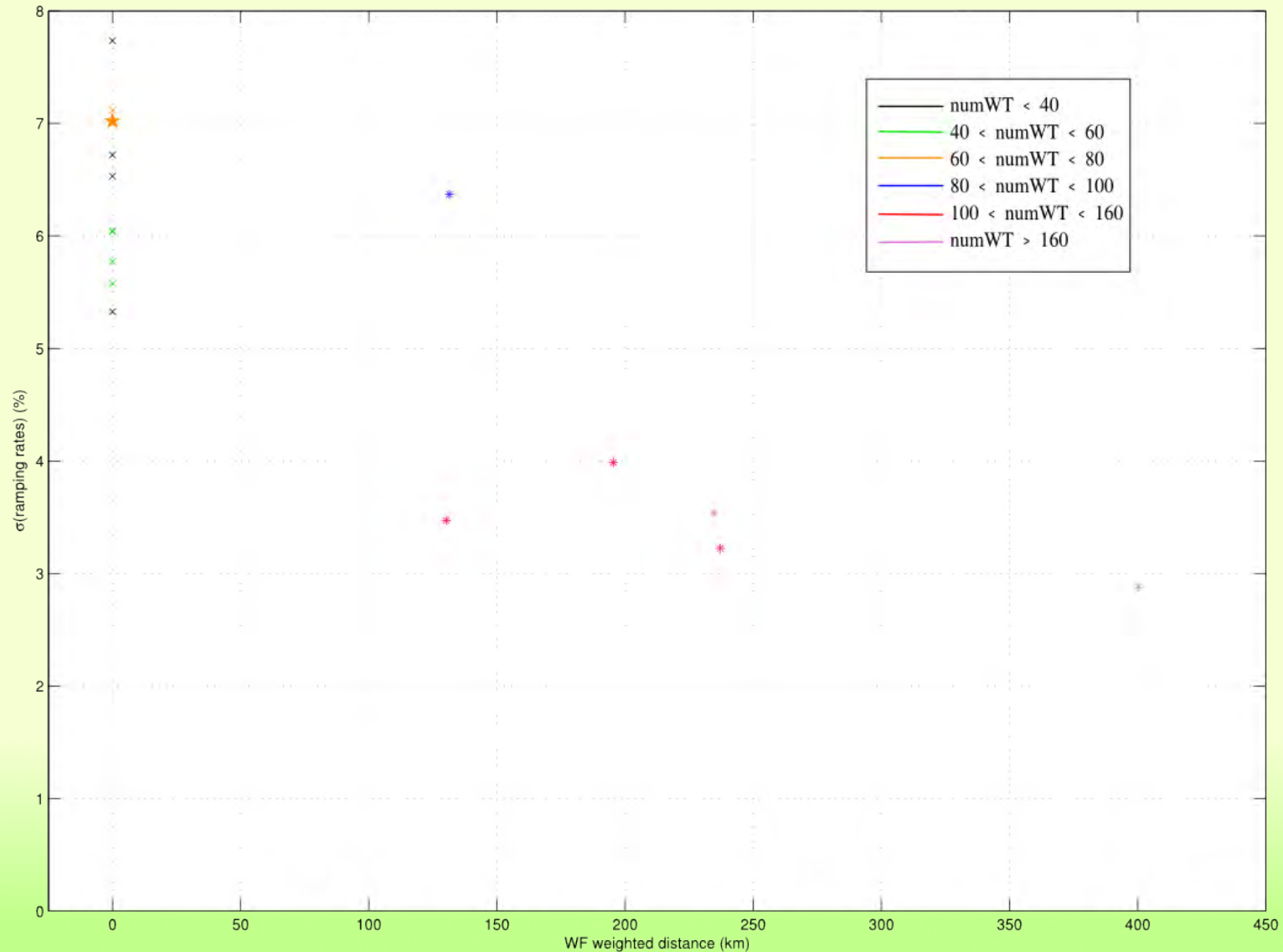
Power Fluctuations

- Duration curves of ramping rates
- $\downarrow P_{ramp,T}$  Worse situations for compensating such energy drops
- Percentiles can be used for that purpose

-
- Standard dev. of Ramps $\sigma(P_{ramp,T})$

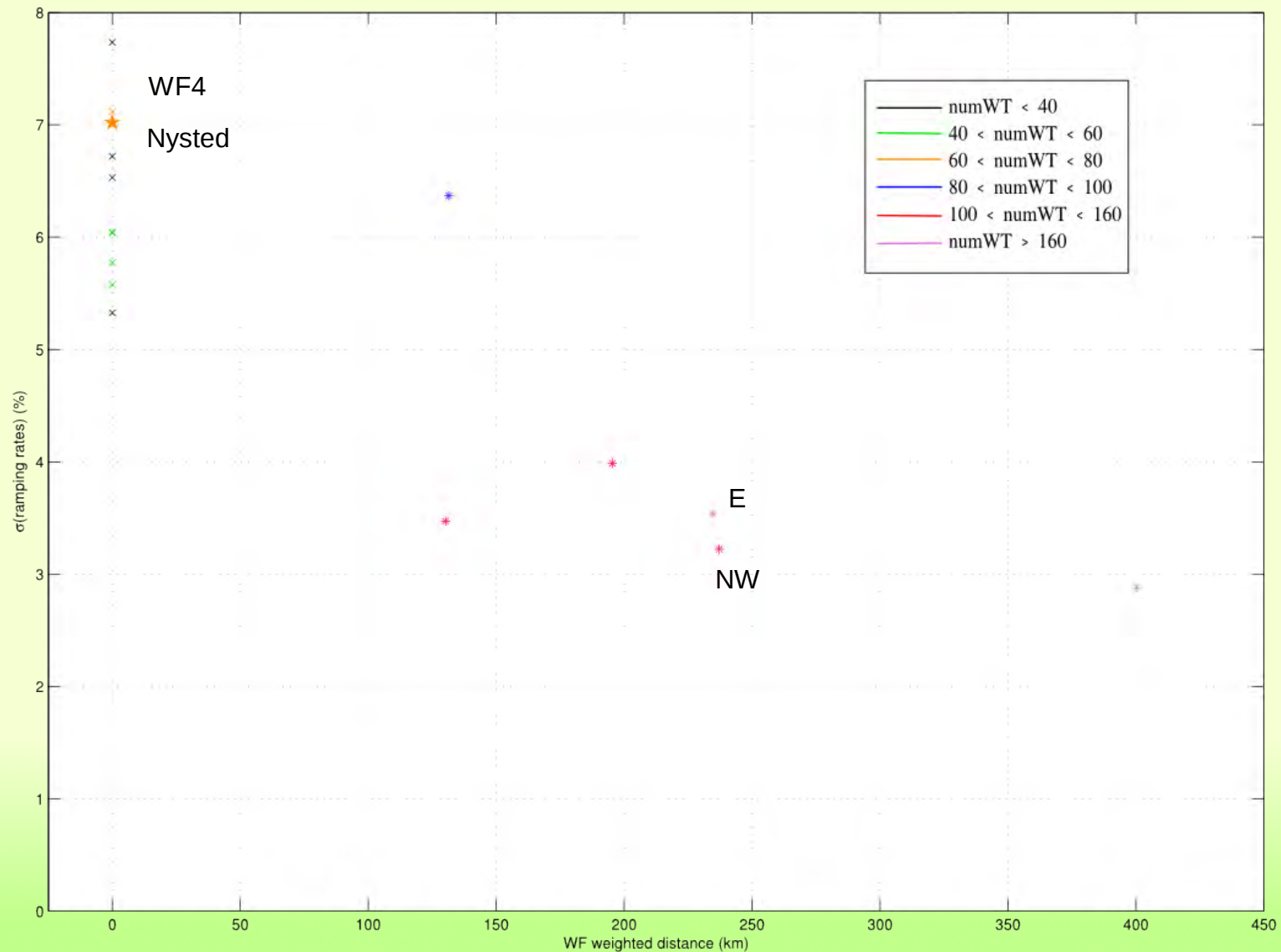
Power Fluctuations

- Standard dev. of Ramps $\sigma(P_{ramp,T})$ $T = 30 \text{ min}$



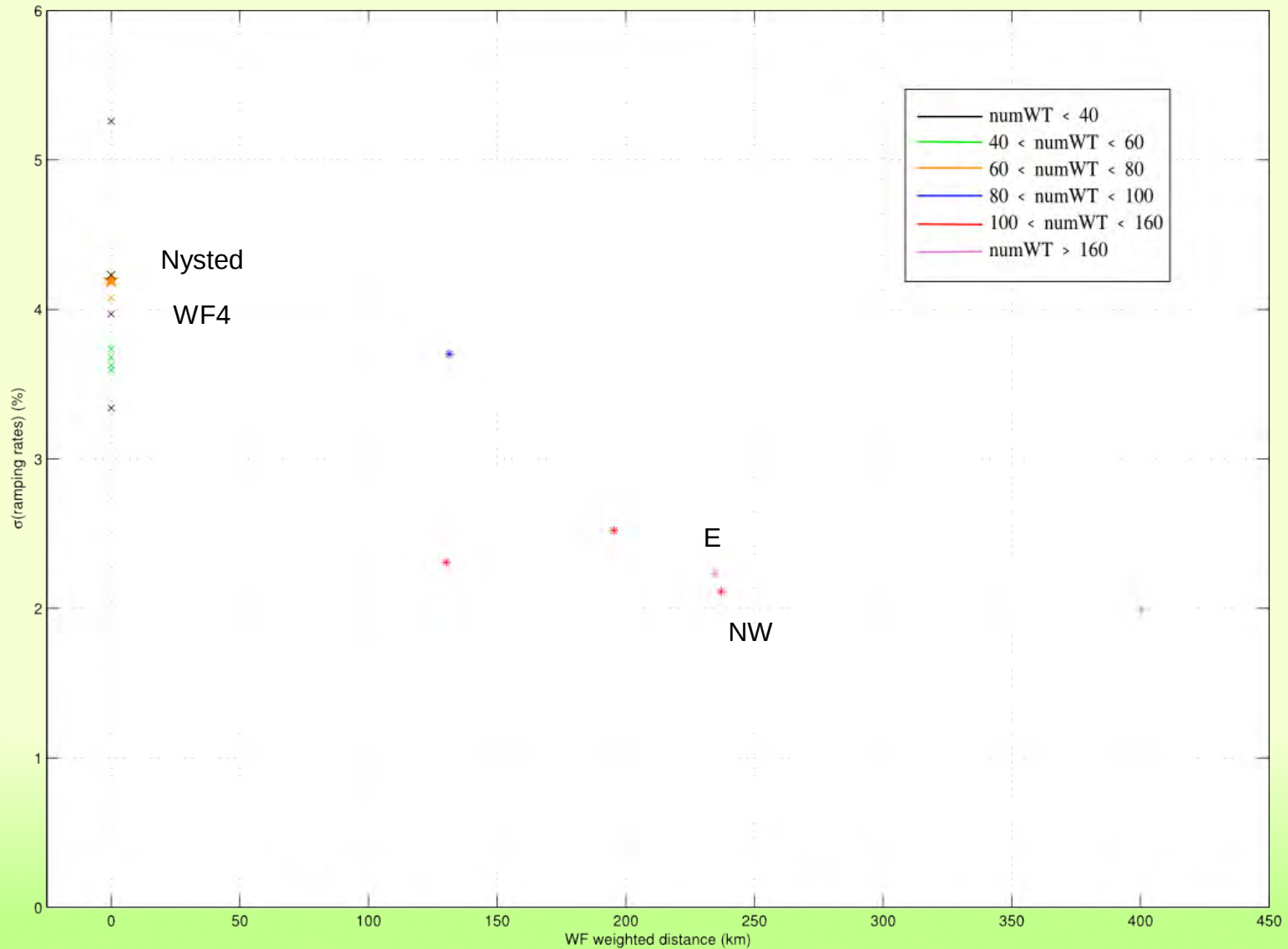
Power Fluctuations

- Standard dev. of Ramps $\sigma(P_{ramp,T})$ $T=30\text{ min}$



Power Fluctuations

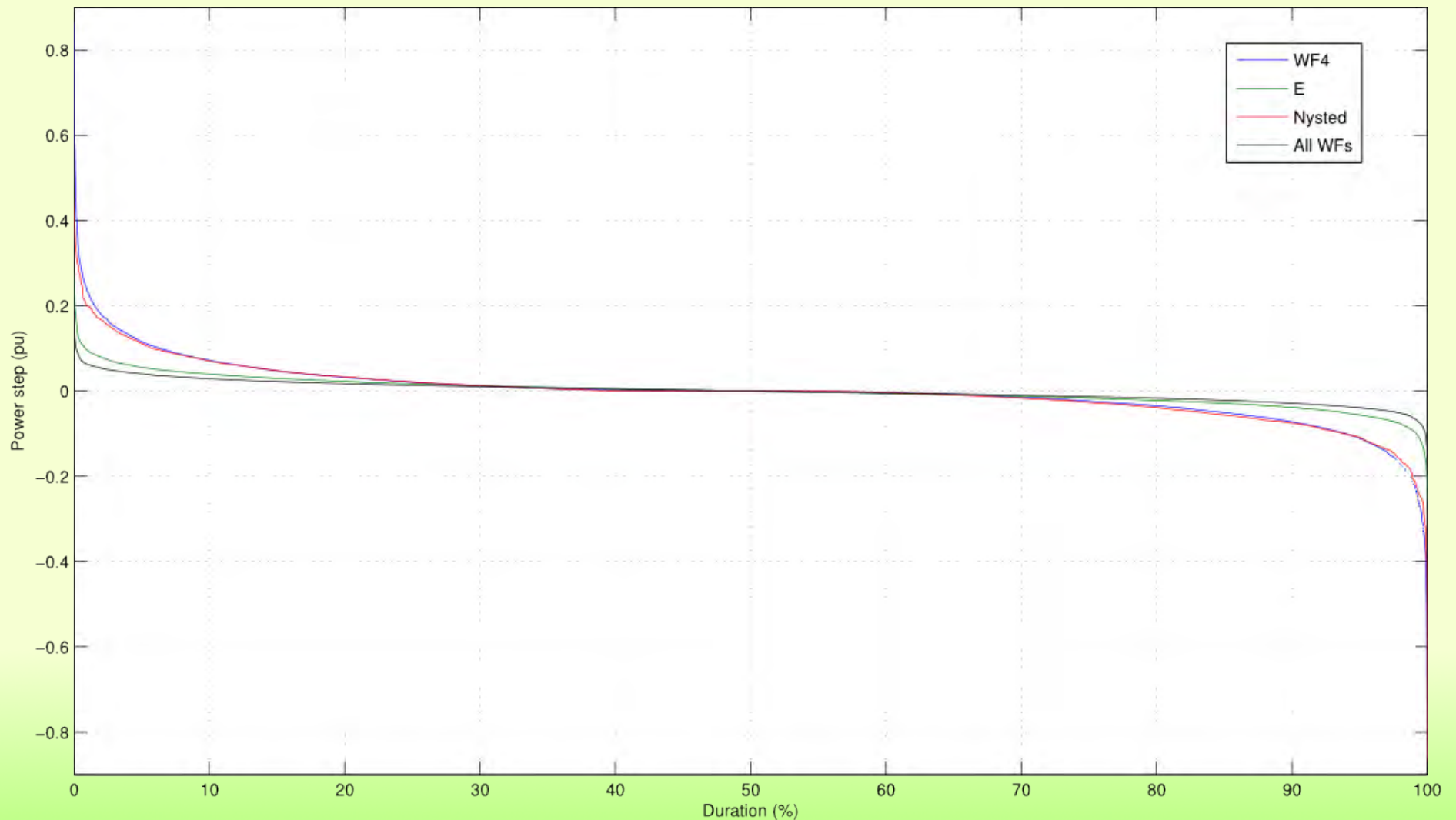
- Standard dev. of Ramps $\sigma(P_{ramp,T})$ $T = 10 \text{ min}$



Power Fluctuations

- Ramping rates - Duration curve

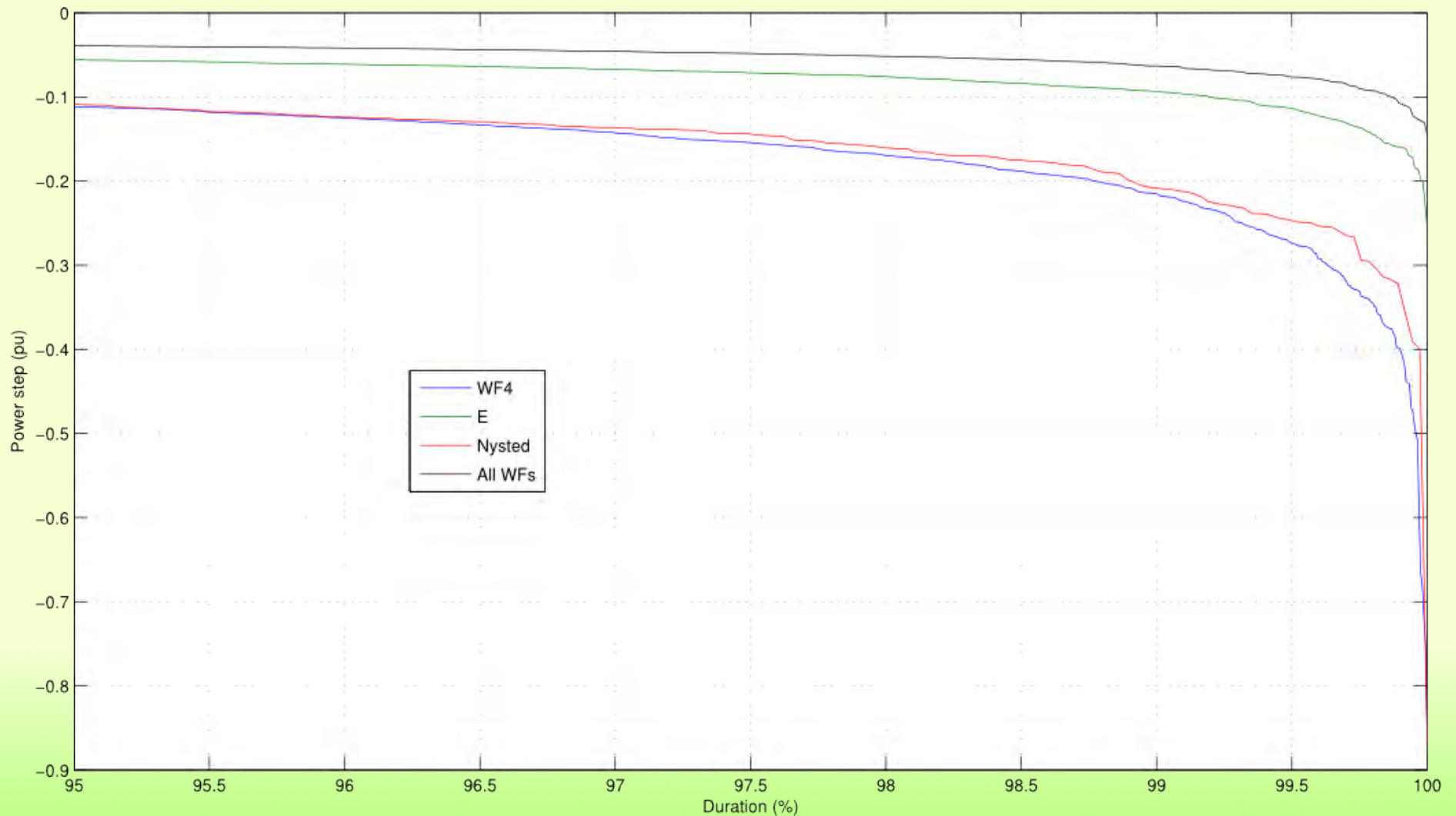
$T = 30 \text{ min}$



Power Fluctuations

- Ramping rates - Duration curve

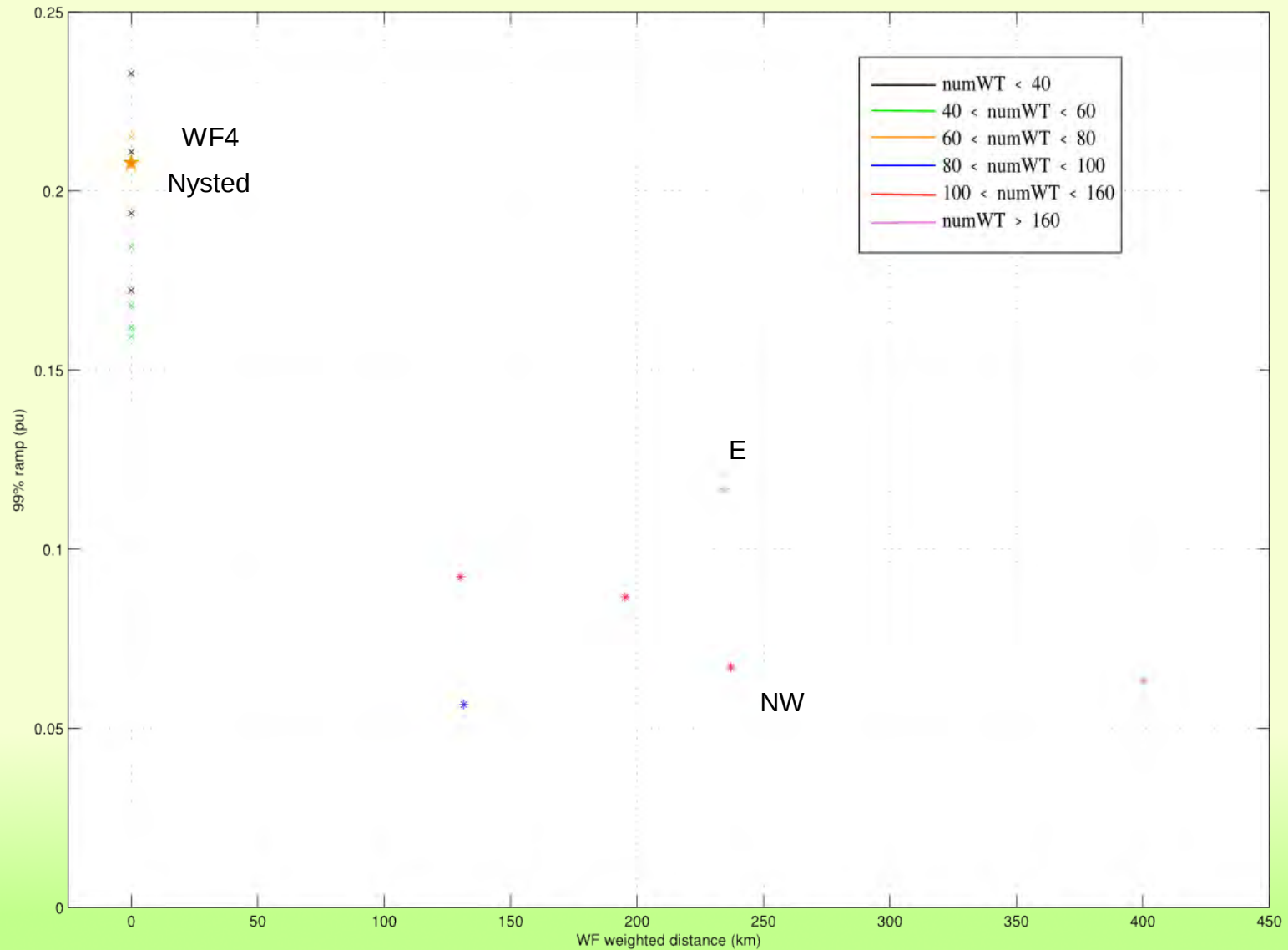
$T = 30 \text{ min}$



Power Fluctuations

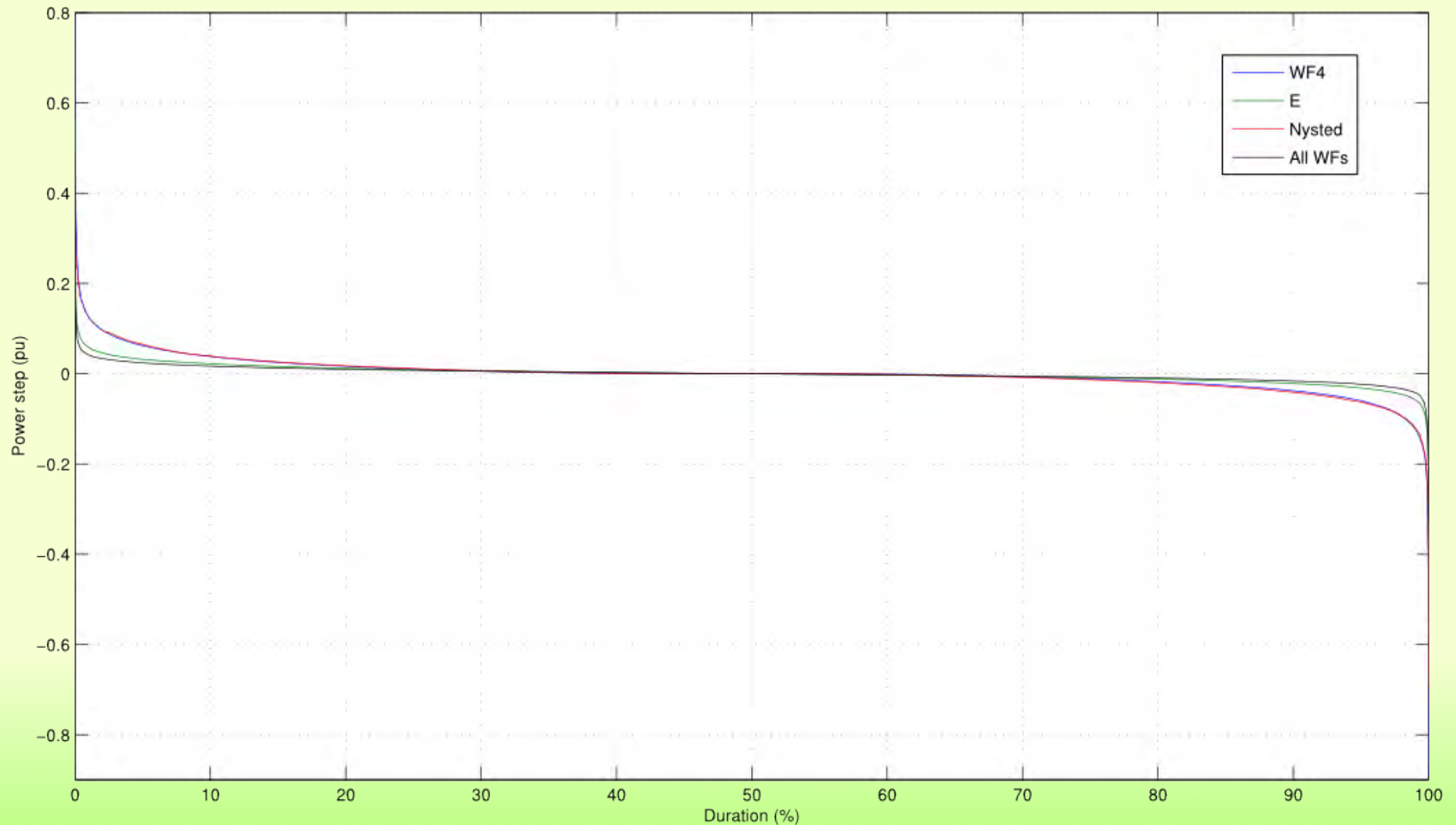
- 99% of ramping rates

$T = 30 \text{ min}$



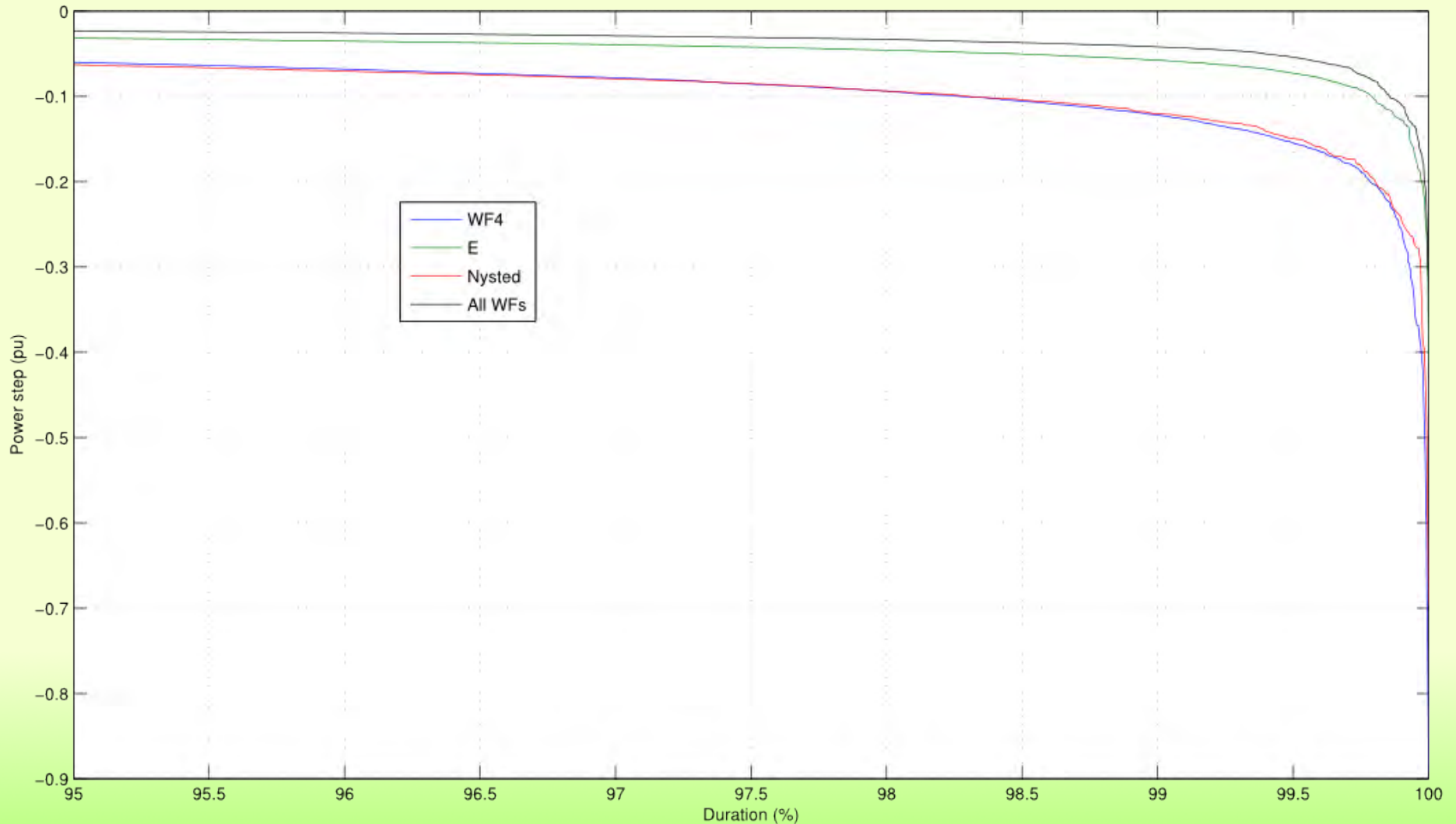
Power Fluctuations

- Ramping rates - Duration curve $T = 10 \text{ min}$



Power Fluctuations

- Ramping rates - Duration curve $T = 10 \text{ min}$



Power Fluctuations

- **Comparison between the Fluctuations in Nysted and other onshore WFs**

	T= 30min	
Wind farm	Std(ramps) (%)	99% ramping rates (pu)
<i>Nysted</i>	7.0	0.21
WF4	7.1	0.22
E	3.5	0.12
NW	3.2	0.07

	T= 10min	
Wind farm	Std(ramps) (%)	99% ramping rates (pu)
<i>Nysted</i>	4.2	0.12
WF4	4.1	0.12
E	2.2	0.07
NW	2.1	0.04

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Conclusions

- P.F. WF4 \sim P.F. Nysted
- P.F. \downarrow when considering aggregated WFs and when $d \uparrow$
- P.F. Nysted $>$ most of the single onshore WFs
- Offshore power fluctuations can be greater than onshore ones due mainly to:
 - Geographical concentration
 - Smooth orography

Open Problems and collaborations

- 1) Comparison the offshore and onshore aggregation effects for determining empirically the importance of each component

	NWTs1	N_WTs2	Pn1 (MW)	Pn2 (MW)	Dist. (km)
<i>Nysted+HornsRev</i>	72	80	165.5	160	275

	NysWTs	HornsWTs	Dist. (km)
WF6-WF4	17	25	259
WF8-WF4	14	25	289
WF7-WF5	16	12	295

$\sim Pn$
 $\sim d$
 $\neq N_{WT}$

$\neq Pn$
 $\sim d$
 $\sim N_{WT}$

	NysWTs	HornsWTs	Dist. (km)
WF6-WF4	45	75	259
WF8-WF4	37	75	289
WF7-WF5	57	37	295

Open Problems and collaborations

2) Extending the onshore analysis

- Looking for agreements with EDP
- Obtaining wind speed series
- Comparing with simulations (*WPTS*)
- Developing aggregated & simplified models

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