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Extended RR2 Analysis

Power Curve Working Group Meeting,
Aarhus, 013-09-19

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- Results of shear and turbulence correction of binned PC for all 3 sites
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Time Series Approach 2.0, 2.1

Exercise 2.0 (Base Case)

- Interpolate given PC with HH cup wind speed for each 10-minute period

Exercise 2.1 (Shear Correction)

- Calculate shear correction factor f_r from lidar data for each 10-minute period
- Multiply f_r with HH cup wind speed for each 10-minute period:

$$v_{eq} = f_r \cdot v_{H,cup}$$

- Interpolate given PC with rotor equivalent wind speed for each 10-minute period

Time Series Approach 2.2

Exercise 2.2 (Turbulence Correction)

- Calculate zero turbulence PC $P_{I=0}$ from given PC by assuming the given PC being valid for I=0.1 and ρ=1.225kg/m³
- For each 10-minute period:

$$P_{corrected} = P_{given\_PC}\left(v_{H,cup}\right) - P_{simulated,I=0.1}\left(v_{H,cup}\right) + P_{sumulated,I-measured}\left(v_{H,cup}\right)$$

$$P_{simulated} = \int_0^{\infty} P_{I=0}\left(v\right) f\left(v\right) dv$$

where f(v): Gaussian distribution determined by $v_{H,cup}$ and I

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Exercise 2.3 (Turbulence and Shear Correction)

- Use zero turbulence PC $P_{I=0}$ from exercise 2.2
- For each 10-minute period:

$$P_{corrected} = P_{given\_PC}\left(v_{eq}\right) - P_{simulated,I=0.1}\left(v_{cup,HH}\right) + P_{sumulated,I-measured}\left(v_{cup,HH}\right)$$

$$P_{simulated} = \int_0^\infty P_{I=0}(v) f(v) dv$$

where f(v): Gaussian distribution determined by $v_{H,cup}$ and I

Results Time Series Approach

Site	Exercise	SEP	SEP relative exercise 2.0
[-]	[-]	[kWh]	[%]
1	2.0	1569064	0.00
1	2.1	1577124	0.51
1	2.2	1569433	0.02
1	2.3	1577493	0.54
2	2.0	2473424	0.00
2	2.1	2466090	-0.30
2	2.2	2493317	0.80
2	2.3	2485983	0.51
3	2.0	953948	0.00
3	2.1	949636	-0.45
3	2.2	942217	-1.23
3	2.3	937905	-1.68

- Small shear effects
- Shear and turbulence effects interfere linearly

Distribution Approach 2.4, Sub Exercises 2.0 and 2.1

v_H	P	f_H	fXP
[m/s]	[kW]	[h]	[kWh]
0	0	1.2	0
1	0	23.2	0
2	0	48.2	0
3	0	104.5	0
4	91	154.3	14044
5	200	186.8	37367
6	362	210.3	76141
7	588	214.8	126322
8	889	178.7	158835
9	1256	142.2	178561
10	1637	100.2	163973
11	1904	80.2	152637
12	1988	74.3	147775
13	1999	76.7	153257
14	2000	63.8	127667
15	2000	48.5	97000
16	2000	26.7	53333
17	2000	16.2	32333
18	2000	10.0	20000
19	2000	5.7	11333
20	2000	4.3	8667
21	2000	2.7	5333
22	2000	1.2	2333
23	2000	0.7	1333
24	2000	0.0	0
25	2000	0.0	0
SEP [kWh]			**1568245**

Sub Exercise 2.0 (Base Case)

- Calculate HH wind speed distribution
- Multiply frequency of HH wind speed with power bin by bin
- sum product over bins

Sub Exercise 2.1 (Shear Correction)

- As sub 2.0, but use frequency distribution of v_{eq}

Distribution Approach 2.4, Sub Exercise 2.2

Sub Exercise 2.2 (Turbulence Correction)

- Bin turbulence intensity against v_{cup_HH}
- Turbulence correct given PC bin by bin:

$$P_{corrected} = P_{given\_PC}\left(v_{H,cup}\right) - P_{simulated,I=0.1}\left(v_{H,cup}\right) + P_{sumulated,I-measured}\left(v_{H,cup}\right)$$

$$P_{simulated} = \int_0^\infty P_{I=0}\left(v\right) f\left(v\right) dv$$

where $f(v)$: Gaussian distribution determined by $v_{H,cup}$ and I

$v_{H,cup}$: bin averaged HH wind speed, cup

I: bin averaged turbulence intensity

$P_{I=0}$: zero turbulence power curve as determined for 2.2

- Sum of product of frequency of $v_{H,cup}$ and turbulence corrected PC

Distribution Approach 2.4, Sub Exercise 2.3

v_eq [m/s]	P_Icor [kW]	f_eq [h]	fXP [kWh]
0	0	0.5	0
1	0	22.3	0
2	0	49.0	0
3	4	103.2	434
4	97	152.0	14715
5	202	187.8	38022
6	368	206.5	75971
7	596	216.7	129196
8	900	180.2	162127
9	1258	145.7	183311
10	1617	99.0	160108
11	1868	81.8	152899
12	1973	73.7	145359
13	1988	75.8	150785
14	1998	65.7	131186
15	1999	49.5	98971
16	2000	26.2	52334
17	2000	14.7	29335
18	2000	10.8	21668
19	2000	6.2	12334
20	2000	3.7	7333
21	2000	2.5	5000
22	2000	1.2	2333
23	2000	0.7	1333
24	2000	0.2	333
25	2000	0.0	0
SEP [kWh]			**1575089**

Sub Exercise 2.3 (Shear and Turbulence Correction)

- As sub 2.0, but use frequency distribution of v_{eq} and turbulence corrected PC

Results Distribution Approach

Site	Exercise	SEP time series	SEP distribution	SEP dist. relative time series
[-]	[-]	[kWh]	[kWh]	[%]
1	2.0	1569064	1568245	-0.05
1	2.1	1577124	1574924	-0.14
1	2.2	1569433	1568431	-0.06
1	2.3	1577493	1575089	-0.15
2	2.0	2473424	2473161	-0.01
2	2.1	2466090	2466472	0.02
2	2.2	2493317	2494110	0.03
2	2.3	2485983	2487636	0.07
3	2.0	953948	953118	-0.09
3	2.1	949636	949453	-0.02
3	2.2	942217	941291	-0.10
3	2.3	937905	937765	-0.01

- Distribution approach and time series approach lead to nearly equal results

Exercise 2.5, Direct Shear Correction of PC

- Bin shear correction factor $f_{r,site}$ against $v_{H,cup}$
- Principle of Annex P, CD IEC61400-12-1, Ed.2: The same rotor equivalent wind speed can be reached by different combinations of shear correction factors and hub height wind speeds:

$$v_{eq} = f_{r,site} v_{H,site} = f_{r,ref} v_{H,ref}$$

$$\Leftrightarrow v_{H,site} = \frac{f_{r,ref}}{f_{r,site}} v_{H,ref}$$

- Here $f_{r,ref}=1$ as given PC refers to v_{eq}
- Get shear corrected PC as valid for $v_{H,site}$ by dividing the given PC bin by bin with the site specific shear correction factor $f_{r,site}$
- SEP: sum of product of frequency of $v_{H,cup}$ and shear corrected PC

Exercise 2.6, Direct Shear and Turbulence Correction of PC

- Shear and turbulence corrected PC: combine shear corrected wind speed from exercise 2.5 ($v_{H,site}$) with turbulence corrected power ($P_{corrected}$) from 2.4, sub exercise 2.2
- SEP: sum of product of frequency of $v_{H,cup}$ and shear and turbulence corrected PC

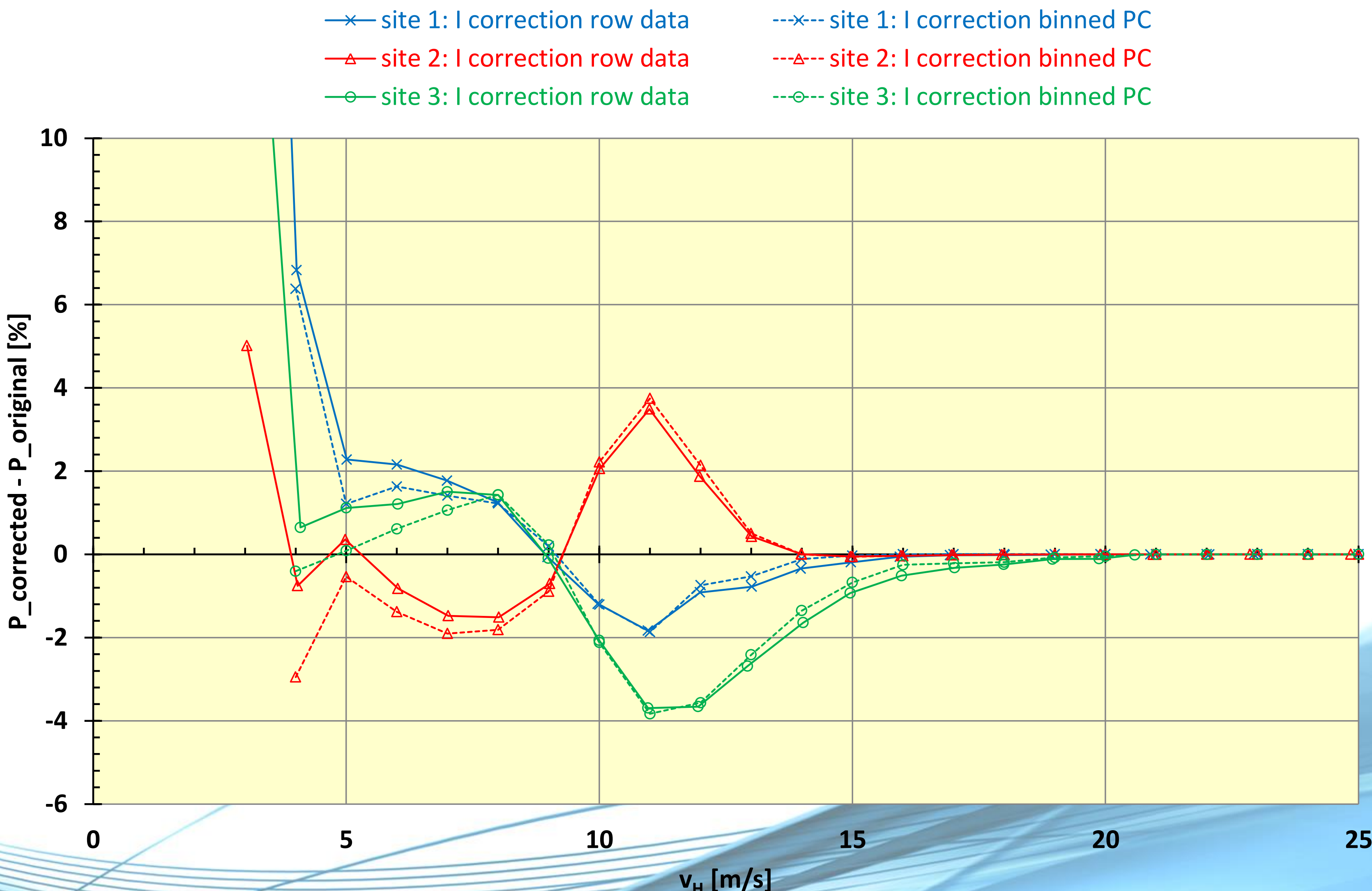
Results Direct PC Correction

Site	Exercise	SEP time series	SEP distribution	SEP dist. relative time series
[-]	[-]	[kWh]	[kWh]	[%]
1	2.5	1577124	1576959	-0.01
1	2.6	1577493	1577132	-0.02
2	2.5	2466090	2465361	-0.03
2	2.6	2485983	2486414	0.02
3	2.5	949636	948509	-0.12
3	2.6	937905	936824	-0.12

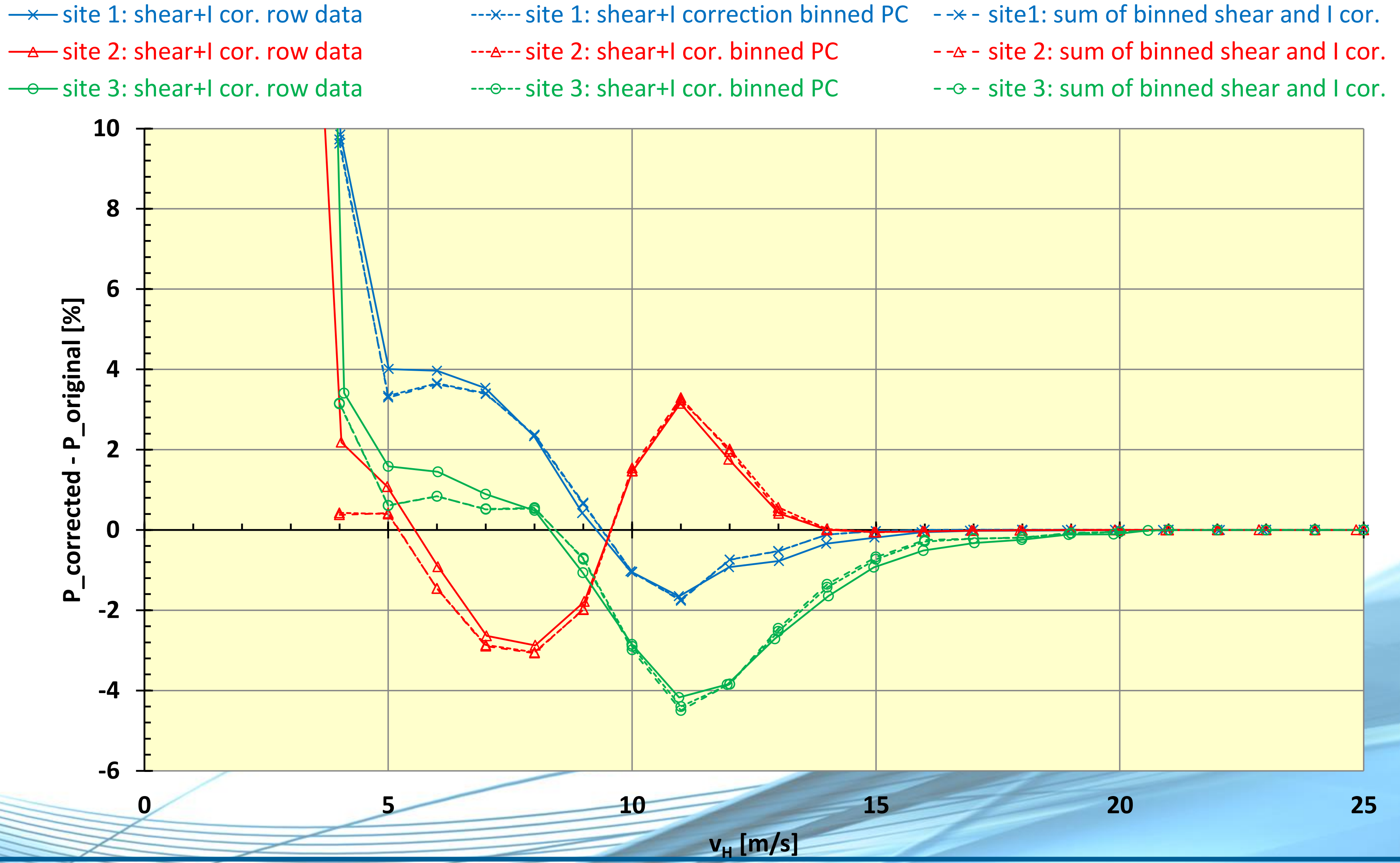
- Shear and turbulence correction of binned PC leads to same results as time series approach
- It is sufficient to consider wind shear conditions and turbulence conditions wind speed dependent
- It is unimportant to consider the distribution of shear conditions and turbulence conditions within wind speed bins

Shear Correction in Terms of Power

Turbulence Correction in Terms of Power



Shear + Turbulence Correction in Terms of Power



Shear, Turbulence Correction Results in AEP

PC's from site	Exercise	AEP v-mean=6.0m/s	AEP v-mean=7.5m/s	AEP v-mean=9.0m/s
[-]	[-]	[% relative to exercise 2.4: subcase 2.0]	[% relative to exercise 2.4: subcase 2.0]	[% relative to exercise 2.4: subcase 2.0]
1	2.4: subcase 2.0 (no correction)	0.0	0.0	0.0
1	2.5 (shear)	0.8	0.5	0.4
1	2.4: subcase 2.2 (turbulence)	0.2	-0.1	-0.2
1	2.6 (shear & turbulence)	1.1	0.4	0.2
2	2.4: subcase 2.0 (no correction)	0.0	0.0	0.0
2	2.5 (shear)	-0.5	-0.4	-0.3
2	2.4: subcase 2.2 (turbulence)	0.2	0.5	0.6
2	2.6 (shear & turbulence)	-0.3	0.1	0.3
3	2.4: subcase 2.0 (no correction)	0.0	0.0	0.0
3	2.5 (shear)	-0.3	-0.4	-0.3
3	2.4: subcase 2.2 (turbulence)	-0.8	-1.2	-1.3
3	2.6 (shear & turbulence)	-1.2	-1.6	-1.6

Conclusions for 3 Investigated Sites

- Relatively small shear and turbulence effects on SEP and AEP
- Significant deformation of power curve by shear and turbulence effects
- Shear and turbulence correction of binned power curve leads to same results as time series approach
- Wind shear and turbulence correction must be treated wind speed dependent
- Distribution of shear conditions and turbulence conditions within wind speed bins unimportant
- Shear and turbulence effects add up linearly in terms of SEP, AEP and power curve