Modelling Impact of Non-Standard Conditions

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Content

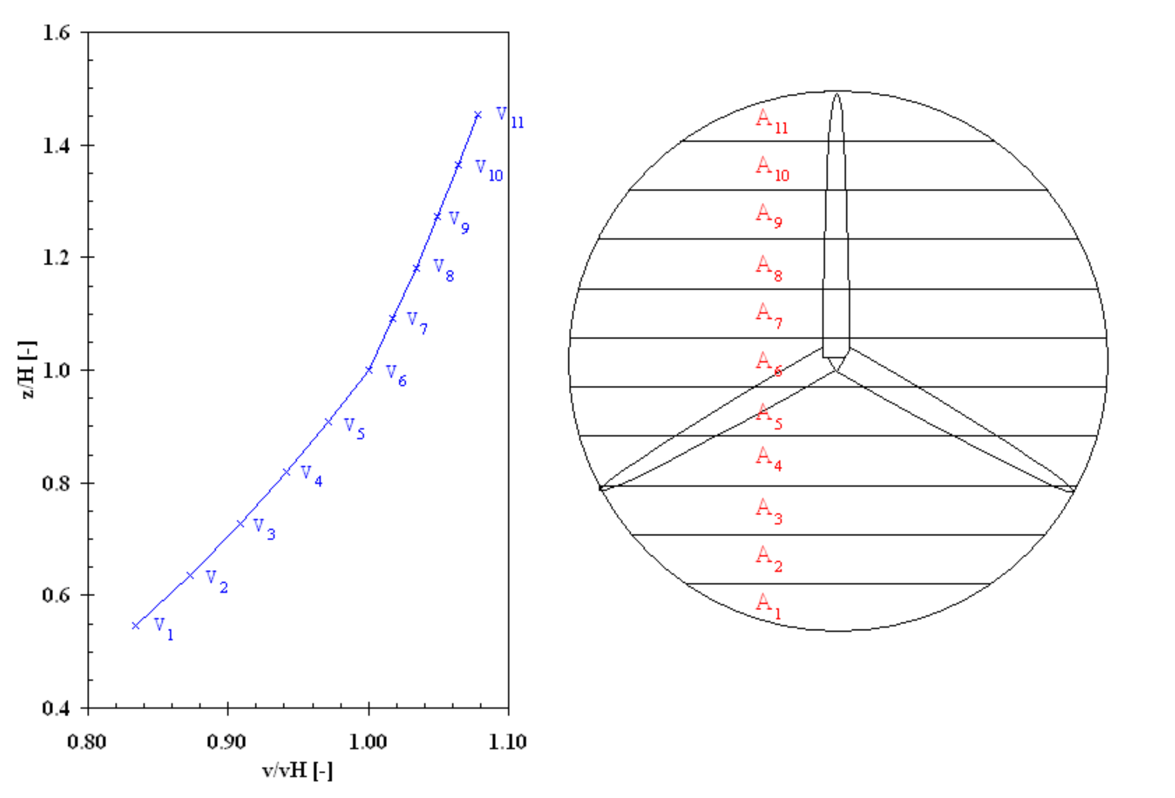
- Modelling of effect of environmental conditions on power curves according to the draft revision of IEC 61400-12-1, Ed.2
- Implications on power curve warranties and wind resource assessments

Status of Revision of IEC 61400-12-1

- Includes methods for taking care of wind shear, wind veer and turbulence effects on power curves
- Committee Draft (CD) Edition 2 available since September 2011
- Integration of national comments completed
- Committee Draft for Voting (CDV) expected at end of 2012
- Final revision expected in 2013
- Release of standard expected in 2014

Rotor Equivalent Wind Speed: for Taking Into Account Wind Shear Effects

$$v_{eq} = \left(\sum_{i=1}^{n} v_i^3 \frac{A_i}{A} \right)^{\frac{1}{3}}$$



H	D	α_l	α_u	fr
[m]	[m]	[-]	[-]	[-]
60	60	0.2	0.2	0.997
60	60	0.3	0.2	0.988
100	60	0.3	0.2	0.993
100	120	0.2	0.2	0.996
100	120	0.3	0.2	0.985
140	120	0.3	0.2	0.990

- Wind shear effect is described by Shear Correction Factor: $f_r = \frac{v_{eq}}{v_H}$

Wind Shear Normalisation: to Get a Hub Height Wind Speed Power Curve for Defined Wind Shear Conditions

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- The same v_{eq} can be reached by different combinations of f_r's ans v_H's:

$$v_{eq} = f_r v_H = f_{r,ref} v_{H,ref}$$

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

- If reference profile is a power law:

$$v_{H,ref} = \frac{\left(\sum_{i=1}^{n} \left(\frac{v_i}{v_H} \right)^3 \frac{A_i}{A} \right)^{\frac{1}{3}}}{\left(\sum_{i=1}^{n} \left(\frac{z_i}{H} \right)^{3\alpha_{ref}} \frac{A_i}{A} \right)^{\frac{1}{3}}} v_H$$

H	D	α_l	α_u	fr	α_{ref}	$v_{H,ref}/v_H$
[m]	[m]	[-]	[-]	[-]	[-]	[-]
60	60	0.2	0.2	0.997	0.2	1.000
60	60	0.3	0.2	0.988	0.2	0.990
100	60	0.3	0.2	0.993	0.2	0.994
100	120	0.2	0.2	0.996	0.2	1.000
100	120	0.3	0.2	0.985	0.2	0.988
140	120	0.3	0.2	0.990	0.2	0.991

Extended Rotor Equivalent Wind Speed: for Taking Into Account Wind Shear and Wind Veer Effects

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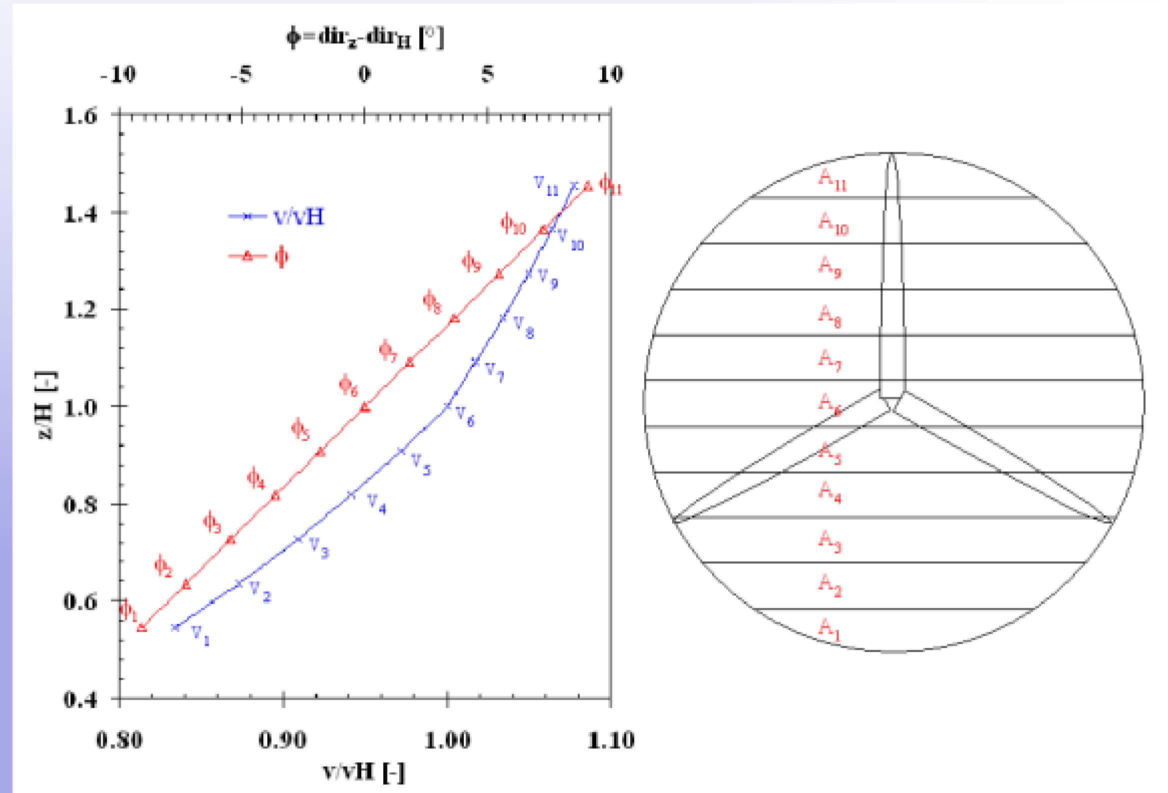
$$v_{eq} = \left(\sum_{i=1}^{n} \left(v_i \cos(\phi_i) \right)^3 \frac{A_i}{A} \right)^{\frac{1}{3}}$$

D	α_l	α_u	veer	f_r
[m]	[-]	[-]	[°/m]	[%]
60	0	0	0.0	1.000
60	0	0	0.2	0.999
60	0	0	0.4	0.995
120	0	0	0.0	1.000
120	0	0	0.2	0.995
120	0	0	0.4	0.979
180	0	0	0.0	1.000
180	0	0	0.2	0.988
180	0	0	0.4	0.954



- Combined shear and veer effect is described by: $f_r = \frac{v_{eq}}{v_H}$
- Normalisation to reference shear and veer conditions possible as in case of just normalising shear effects

Turbulence Normalisation

- Only the effect of data averaging over 10-minute period is considered
- Key assumption: turbine output follows instantaneous changes of wind speed, i.e. turbine always follows a certain power curve $P_{I=0}$.

$\Rightarrow$ mean power output over 10 minutes:

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

f(v): wind speed distribution measured over 10 minutes

- Zero turbulence power curve $P_{I=0}$ is determined from measured power curve under consideration of measured turbulence intensity
- Turbulence Normalisation:

$$\overline{P_{I_{ref}}(v_{meas})} = \overline{P_{meas}(v_{meas})} - \overline{P_{sim,I_{meas}}(v_{meas})} + \overline{P_{sim,I_{ref}}(v_{meas})}$$

- Example:

WT with 382 W/m²

I	cp_{max}	effect on cp_{max}	$AEP/AEP_{I=10}$ v_{avg}=6.0m/s	$AEP/AEP_{I=10}$ v_{avg}=7.5m/s	$AEP/AEP_{I=10}$ v_{avg}=9.0m/s
[%]	[-]	[%]	[-]	[-]	[-]
0	0.450	-2.9	0.998	1.006	1.008
5	0.454	-2.2	0.999	1.005	1.007
10	0.464	0.0	1.000	1.000	1.000
15	0.480	3.6	1.002	0.993	0.990
20	0.504	8.7	1.006	0.985	0.977

Treatment of Uncertainties

- Uncertainty of all corrections is taken into account:
  - air density correction
  - wind shear correction
  - wind veer correction
  - turbulence correction
- Only the air density correction is obligatory, but:
- Added uncertainty if no correction according to
  - wind shear
  - wind veer
  - turbulence intensity

Conflict WT Owner, WT Supplier

- Owner wants site specific power curve for his economic considerations
- Supplier has problems to warrant site specific power curve:
  - site conditions often not well known
  - supplier cannot be hold liable for possible special atmospheric conditions at power curve verification (takes only 1 to 6 months)
  - warranty on site specific power curve more difficult to manage than generic power curve

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Current Situation

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PC Warranty

- Generic PC, often valid only for idealised conditions

Economics, Wind Resource Assessment

- Owner uses generic PC for economic calculations;

⇒ yield expectations often too high!

- Often neither owner, nor sales people from suppliers, nor wind resource experts are aware of the problem

PC Verification

- special filtering:

⇒ sometimes long extension of verification

Immediate Improvement

PC Warranty

- Generic PC, often valid only for idealised conditions

Economics, Wind Resource Assessment

- PC adjusted to mean site conditions by methods of IEC 61400-12-1, Ed. 2
- Add uncertainties of corrections according to IEC 61400-12-1, Ed. 2 (can be high)
- Minimum: use generic PC and add uncertainties for not correcting PC to site conditions (can be high)

PC Verification

- special filtering:

$\Rightarrow$ sometimes long extension of verification

Future Improvement, Generic PC

PC Warranty

- Generic PC
- Based on equivalent wind speed
- Alternative: valid for reference shear and veer profiles
- Valid for reference turbulence
- Valid for reference air density

Economics, Wind Resource Assessment

- Use equivalent wind speed
- or adjust PC to mean shear and veer conditions by methods of IEC 61400-12-1, Ed. 2
- Adjust PC to mean turbulence and air density conditions by methods of IEC 61400-12-1, Ed. 2
- Add uncertainties of corrections according to IEC 61400-12-1, Ed. 2 (can be high)

PC Verification

- Use equivalent wind speed
- or adjust PC to reference shear and veer conditions by methods of IEC 61400-12-1, Ed. 2
- Adjust PC to reference turbulence and air density conditions by methods of IEC 61400-12-1, Ed. 2
- Add uncertainties of corrections according to IEC 61400-12-1, Ed. 2 (can be high)

Future Improvement, Site Specific PC

PC Warranty

- PC specific for mean site conditions

Economics, Wind Resource Assessment

- Take PC as it is
- Assess added uncertainty due to distribution of wind shear, wind veer, turbulence and air density conditions in analogy to IEC 61400-12-1, Ed. 2

PC Verification

- Use equivalent wind speed
- or adjust PC to mean shear and veer conditions by methods of IEC 61400-12-1, Ed. 2
- Adjust PC to mean turbulence and air density conditions by methods of IEC 61400-12-1, Ed. 2
- Add uncertainties of corrections according to IEC 61400-12-1, Ed. 2

If PC Verification Possible Only Based on Hub Height Measurement

PC Warranty

- See previous slides

Economics, Wind Resource Assessment

- See previous slides

PC Verification

- Adjust PC to mean turbulence and air density conditions by methods of IEC 61400-12-1, Ed. 2
- Add uncertainties of turbulence and air density corrections according to IEC 61400-12-1, Ed. 2
- Add uncertainty for not correcting PC in terms of wind sheer and veer according to IEC 61400-12-1, Ed. 2 (can be high)