REWS

EWEA Power Curve Working Group

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REWS
Introduction

- As rotors grow more and more, horizontal wind speed at hub height is no longer as representative for a power curve as it used to be

- The efficiency of a wind turbine should measure how much power the machine can extract from the current available power in the wind

- The available power to be extracted from the wind depends on
  - The area considered
  - The spatial distribution of the wind speed vector in the considered area
  - The orientation of the considered area in the wind vector field

REWS

Introduction

- The Rotor Equivalent Wind Speed (REWS) can be defined as the uniform wind speed vector perpendicular to the rotor area that has the same potential power than the current considered wind vector field in the considered area

  - Rotor area is considered as the circle of diameter the size of the machine's diameter, positioned at hub height, oriented at the direction measured at hub height and tilted backwards a determined angle

- The representation of the wind turbine's power output against the Rotor Equivalent Wind Speed is a better indicator of the machine's efficiency, rather than Horizontal Hub Height Wind Speed (HHHWS), as it measures how much of the available energy it is capable of extracting

REWS

Inclusion of upflow angle

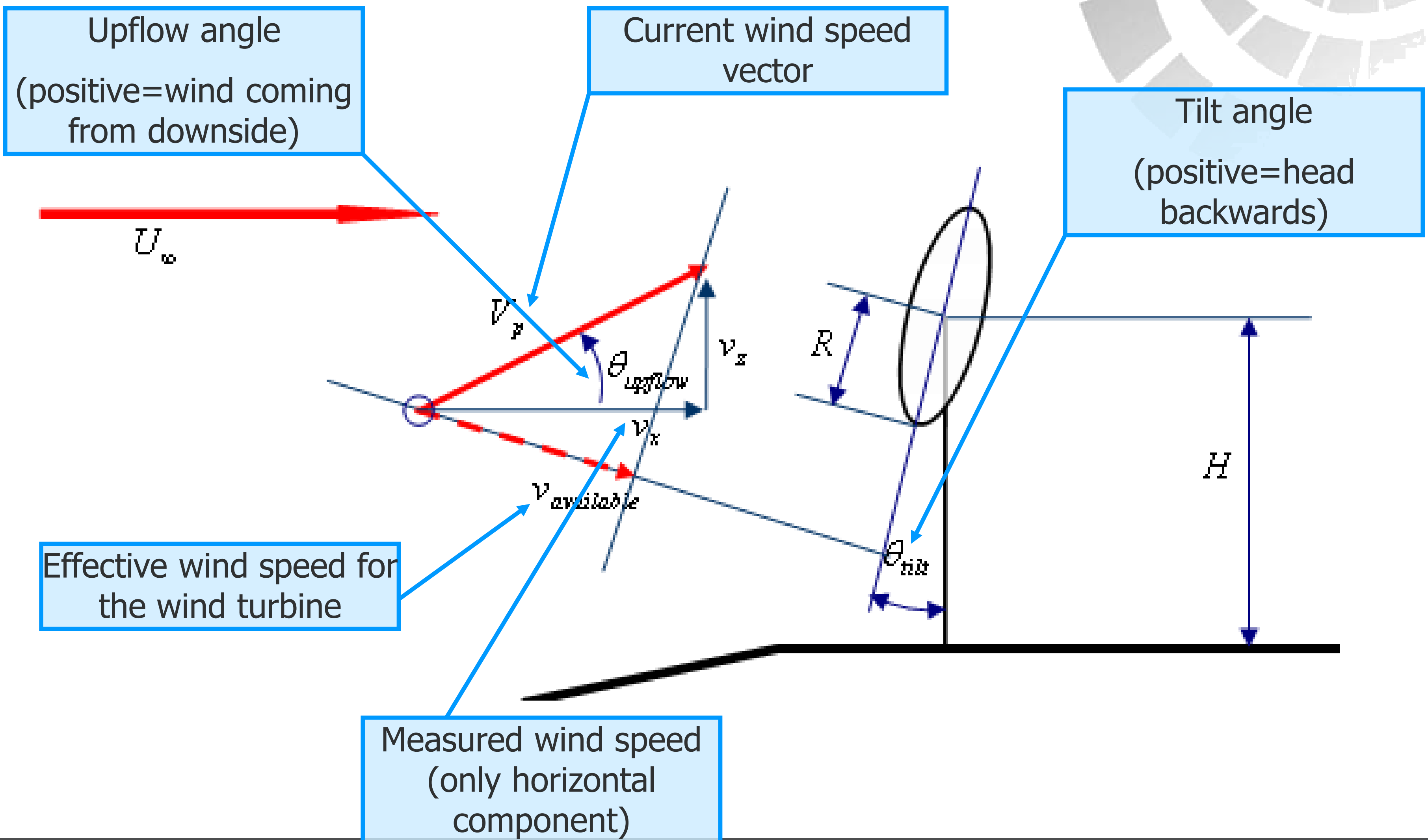
- Upflow angle must be included in the definition of the REWS, as wind turbines are tilted backwards and no tilt orientation is possible

- Flat terrains do not create a great variation of upflow angles, but it is very common in complex terrains to work under very different upflow angles depending on current wind direction

- If REWS do not include upflow angle projection, different wind directions in complex terrains can have similar REWS with very different power outputs

REWS

Inclusion of upflow angle



REWS

Wind spatial distribution

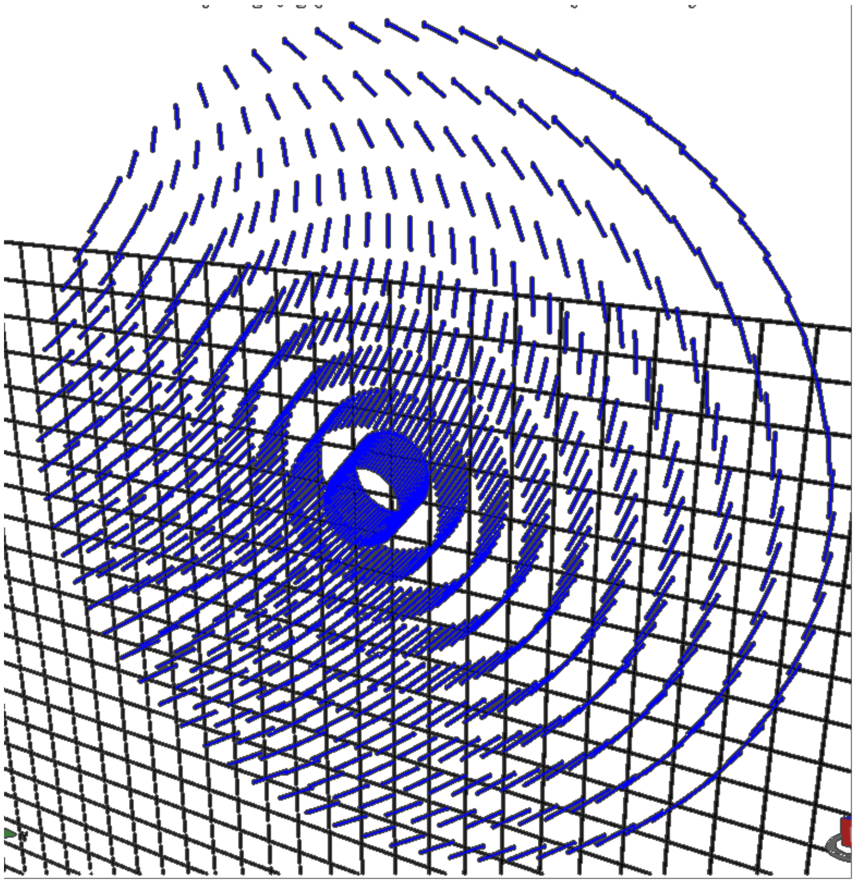
- Wind vector (measured as 10 minutes average) usually changes with height. Dependence with height is highly correlated with atmospheric stability.

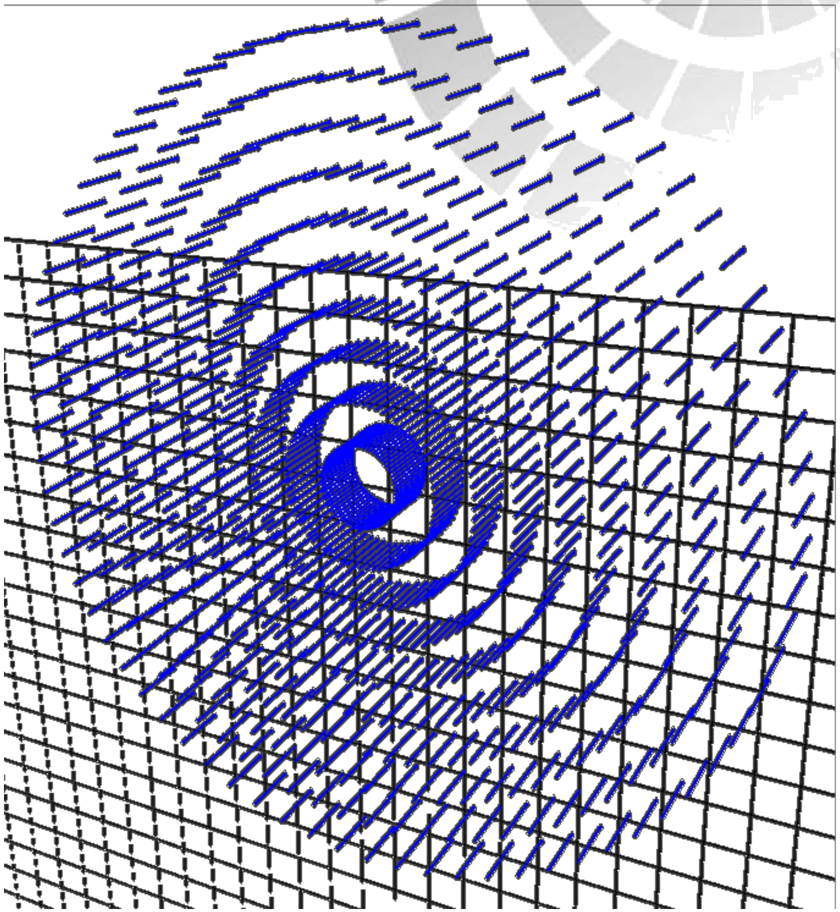
- To characterize the wind speed vector field, three variables must be measured at different heights:

  - Horizontal wind speed magnitude. Its variation with the height is known as wind shear
  - Wind direction. Its variation with the height is known as wind veer
  - Vertical wind speed magnitude. It is more common to refer to the upflow wind speed angle

REWS

Wind spatial distribution





From this: different wind vectors in the rotor area (real)

Same potential power

To this: wind vector is constant in the whole rotor area (ideal)

REWS

Ideal REWS calculation

- Ideally, the REWS can be calculated as:

$$rews = \sqrt[3]{\frac{1}{A}\int \left(v_x(h)\cdot\cos(\beta(h))\cdot\frac{\cos(\theta(h)+\theta_{tilt})}{\cos(\theta(h))}\right)^3 dA}$$

Power of three

Differential area (depends on height)

Averaged for the whole rotor area

Horizontal wind speed magnitude, depending on height

Wind direction depending on height, relative to hub height wind direction

Angle projection caused by the tilted rotor area, depending on height

REWS

REWS calculation

- If measurements above hub height are available:

$$rews = \sqrt[3]{\frac{1}{A}\sum_{i=1}^{N}\left(v_x(h_i)\cdot\cos(\beta(h_i))\cdot\frac{\cos(\theta(h_i)+\theta_{tilt})}{\cos(\theta(h_i))}\right)^3 A_i}$$

Measured (or evaluated) at N discrete points

Representative area slice

Horizontal wind speed magnitude measured at different heights

Wind direction relative to hub height wind direction measured at different heights

Upflow angle measured at different heights

REWS

REWS proxies

- If measurements above hub height are not available, the following proxies can be used:

  - Horizontal wind speed magnitude at different heights (wind shear):

    1. If wind speed at different heights are measured, the horizontal wind speed can be approximated at any height with the following:

$$v_x(h) = v_{hub}\left(\frac{h}{h_{hub}}\right)^{\alpha}$$

    2. If only one horizontal wind speed is measured (at hub height), a constant representative value of the wind shear exponent ("alpha") can be used. CFD calculations of wind shear exponent for each direction can be admissible also

Horizontal wind speed magnitude estimated at different heights

Horizontal wind speed measured at hub height

Wind shear exponent can be calculated with two or more horizontal wind speed measurements and a power law adjust

- Certain very complex sites may have different profiles other than power laws. For those types of terrain, a more thorough specific measurement may be necessary

REWS

REWS proxies

- If measurements above hub height are not available, the following proxies can be used:

  - Wind direction gradient with height (wind veer):

    1. If wind directions at different heights are measured, the wind direction relative to hub height wind direction can be approximated at any height with the following:

$$\beta(h) = \psi\left(h - h_{hub}\right)$$

Wind direction relative to hub height wind direction at different heights

Wind direction linear gradient calculated with two or mode wind direction measurements

    2. If only one wind direction is measured (only at hub height), a constant representative value of the wind direction gradient ("chi") can be used. CFD calculations or wind assessment tool approximations may be valid for determining a representative value of this parameter

- Certain very complex sites may have different wind direction gradients other than linear laws. For those types of terrain, a more thorough measurement may be necessary

REWS

REWS proxies

- If measurements above hub height are not available, the following proxies can be used:

    - Wind flow inclination angle with height (upflow):

        1. A single measurement at hub height can be representative for most of the sites (based on experience)

        2. If no upflow is measured, representative values for each wind direction can be calculated with most CFD programs or site and wind assessment tools

- An approximation of the upflow angle with height can be obtained by a potential model of the wind in a 2D field, but a single value is representative enough

REWS

REWS in complex terrain

- Calibration of complex terrains:

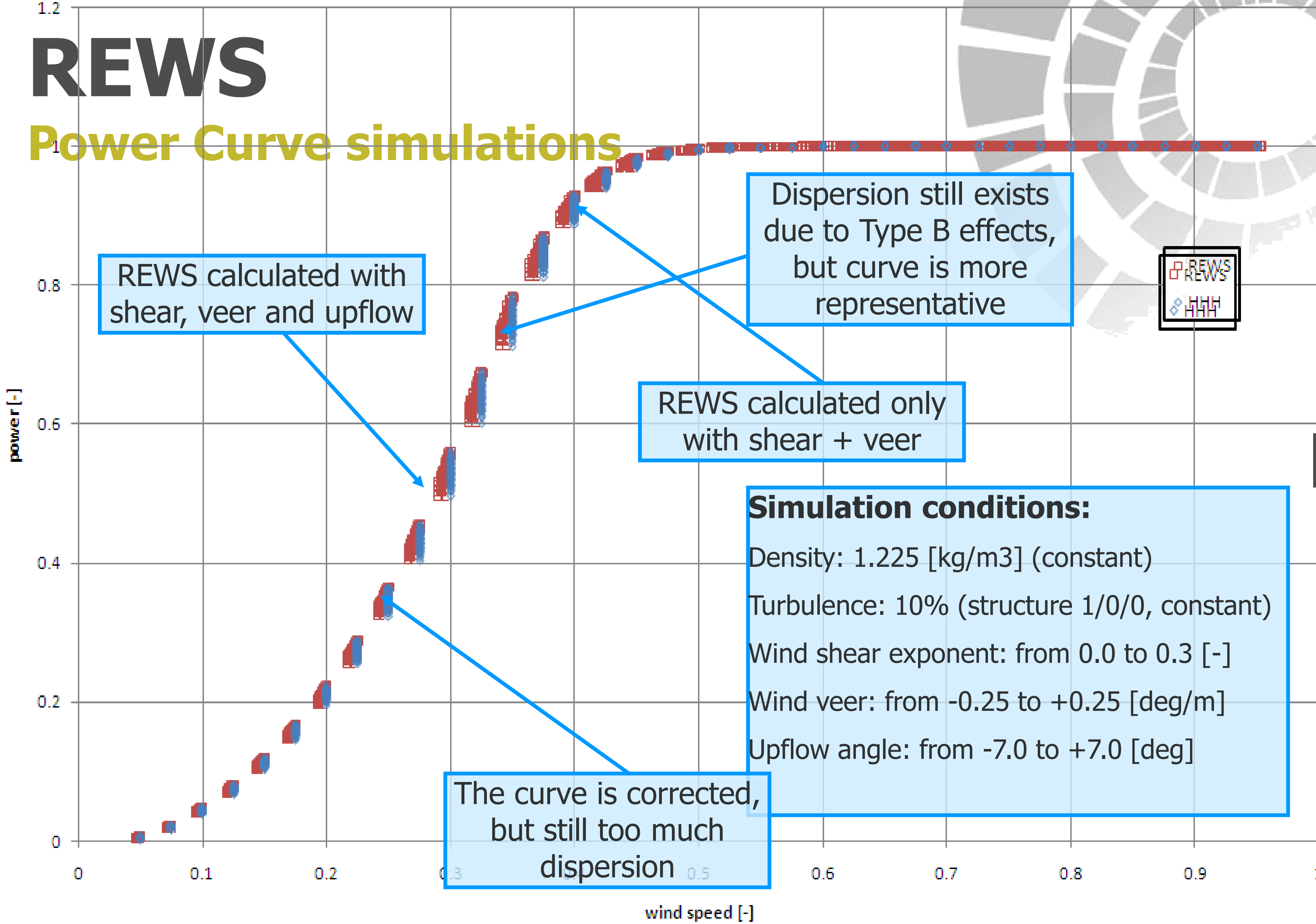
  - Calibration can be done as depicted in the current Norm or the upcoming draft, using REWS at both masts instead of HHHWS (instead of modeling wind shear, wind veer and upflow): Ratios or linear adjustments can be used. So far we have little experience in this field but previous cases point that it could be a good method

  - The instrumentation and configuration must be the same in both masts for the calibration to be accurate

  - Representative values for the REWS variables that cannot be measured or estimated must be accorded prior to the calibration procedure

REWS

Power Curve simulations



Simulation conditions:

Density: 1.225 [kg/m3] (constant)

Turbulence: 10% (structure 1/0/0, constant)

Wind shear exponent: from 0.0 to 0.3 [-]

Wind veer: from -0.25 to +0.25 [deg/m]

Upflow angle: from -7.0 to +7.0 [deg]

REWS
Conclusion

- The addition of the upflow correction in the REWS method leads to a more representative curve of the power function

- This correction can be used for:

    1. Resource evaluation

    2. Performance verification


Thank you

Q & A