WIND PROFILES OVER FOREST FOR WIND ENERGY IN HIGH HUB HEIGHTS

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Summary

Many wind energy plants are planned and erected in or near forests. Lidar and mast measurements in forests help to estimate the influence of the forest on the production of the wind energy plant in high hub heights. Examples of met mast profiles over forests are prepared and presented.

1. Measurements of wind profiles over forests

RSC GmbH took several wind measurements in forest areas across Germany to improve the calculation of energy production of wind turbines with high hub heights. We present a small range of measured profiles. Wind measurements over forest can be taken by Lidar instruments or met masts equipped with anemometers in several heights. In this case only met mast profiles are used. For the data analysis the measured data is checked and implausible data is eliminated. Only profiles with data availability in all heights are used to calculate mean wind profiles. The shown profiles are measured in different forest areas and in different periods of time.

2. Theoretical background

To calculate the energy production of wind turbines with high hub heights in many cases wind speeds measured from lower levels are extrapolated to higher levels. In the Prandtl layer the equations in figure 1 can be used.

$$u_2 = u_1 \cdot \frac{\ln(z_2/z_0)}{\ln(z_1/z_0)} \qquad (a)$$

$$u_1(z_1) = \frac{u_*}{\kappa} \cdot \ln\frac{z_1}{z_0} \qquad (b)$$

$$u_2 = u_1 \cdot \left(\frac{z_2 - \left(\frac{2}{3} \cdot h\right) + z_o}{z_1 - \left(\frac{2}{3} \cdot h\right) + z_o} \right)^{\lambda} \qquad (c)$$

z_1 ... height 1
z_2 ... height 2
z_0 ... roughness-length
u_1 ... wind speed at height z_1
u_2 ... wind speed at height z_2
h ... height of trees
κ ... Karman-constant = 0,4
u_* ... friction velocity
λ ... power

Figure 1: *Equations for log profile (a), (b) and power profile (c).*

Typical values for z_0 over forests are 1 to 5 depending on the height of the trees [2]. Landscapes with a roughness-length of 1 have a regular coverage with large size obstacles with open spaces roughly equal to obstacle heights, suburban houses, villages, mature forests. Landscapes with a roughness-length of 2 or above are centers of large towns and cities, irregular forests with scattered clearings [3].

Typical values for λ are 0.3 for statically very stable air, 0.14 for statically neutral air and 0.05 for statically very unstable air [1].
Higher hub heights reach into the Ekman layer where the shown equations have no validity as the wind shifts with height.

3. Results

The analyzed mean wind speeds for four different measurement sites and different periods of time are shown in figure 2.

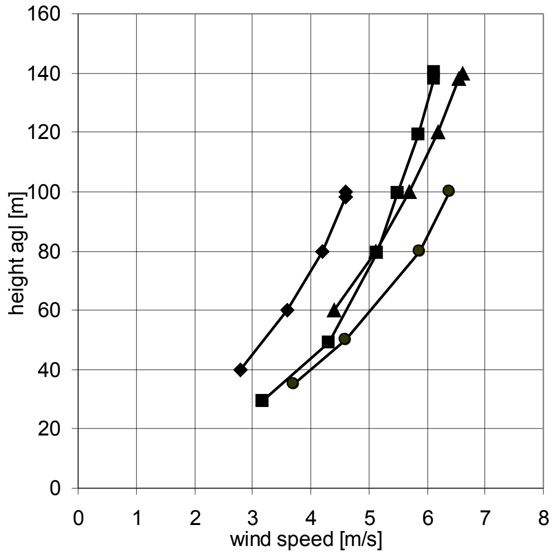

Figure 2: *Wind profiles measured at different sites in different periods of time over forest.*

The parameters in table 1 are used to fit the calculated wind profiles to the measured wind profiles for h = 30 m.

Table 1: *Parameters used to fit calculated wind profiles to measured wind profiles (h=30m).*

Profile	z_0 [m]	λ	u_* [m/s]
rhombi	9,0	0,40	0,77
triangels	10,0	0,43	0,99
squares	4,5	0,28	0,71
points	8,0	0,40	1,01

Figure 3 shows power profiles for different values of λ for two measured wind profiles and figure 4 shows log profiles for different values of z_0.

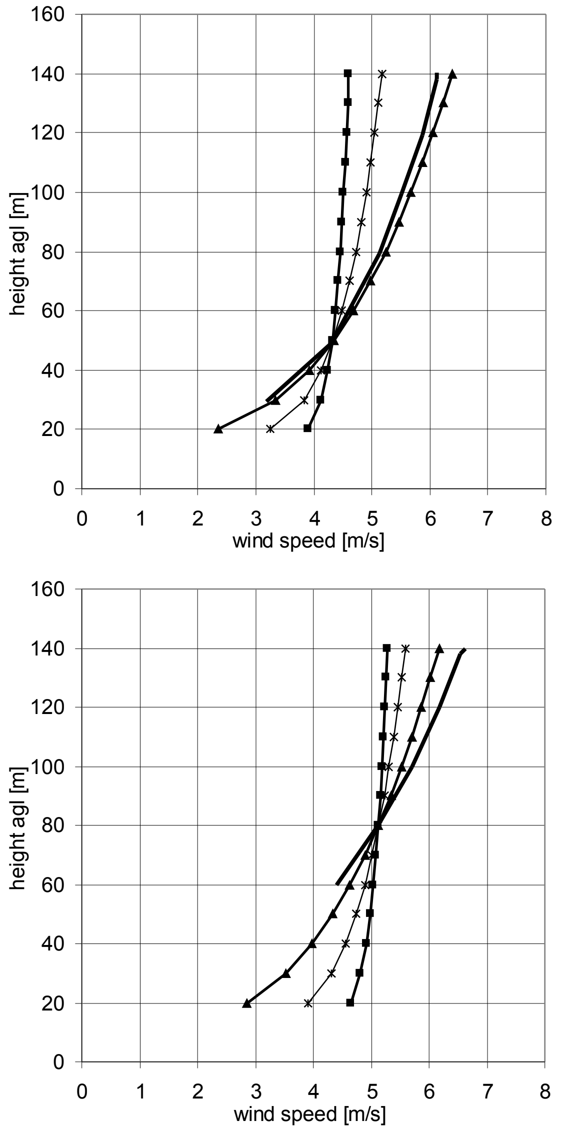

Figure 3: *Measured wind profile (bold) and calculated power wind profiles for different values of λ (squares: λ=0.05, stars: λ=0.14, triangles: λ=0.3) for two different measurements.*

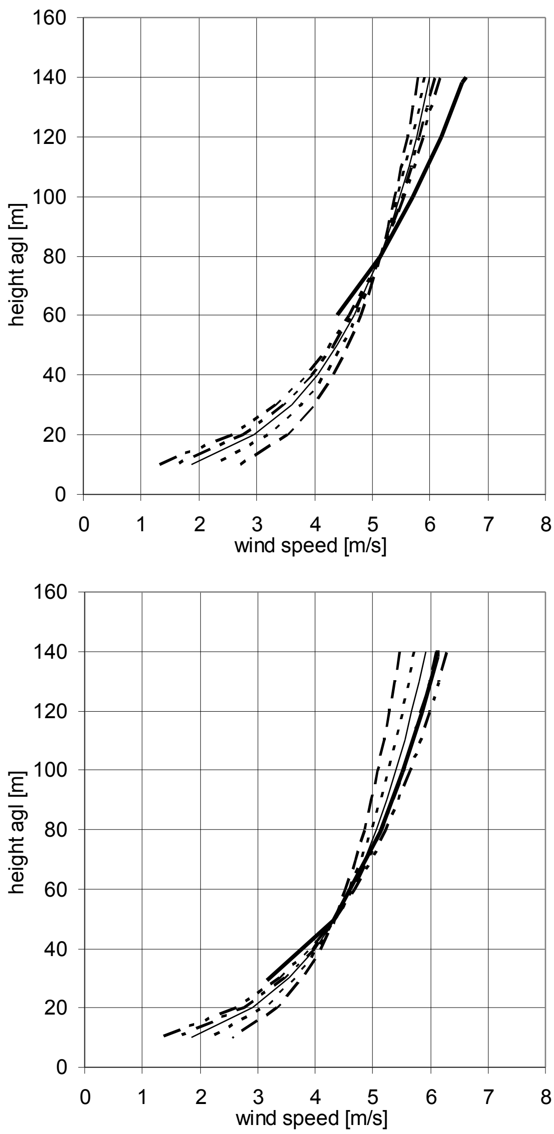

Figure 4: *Measured wind profile (bold) and calculated log wind profiles for different values of z_0 (dashed: z_0=1, pointed: z_0=2, lined: z_0=3, point-dashed: z_0=4, point-point-dashed: z_0=5) for two different measurements.*

In these cases the calculated profiles can hardly reproduce the measured profiles when common values for forest areas are used for the variables.

For one example the friction velocity is calculated for the measured heights (equation (b), figure 1) and depicted in figure 5. Different typical values for z_0 are used. For z_0= 5 (high forest) the highest friction velocity is at 50 m agl. Above 100 m agl the friction velocity is nearly constant. For z_0= 1 the friction velocity increases by height. If z_0= 1 a typical value for u_* is 0,44 [1]. In this example u_* is 0,44 at 50 m agl.

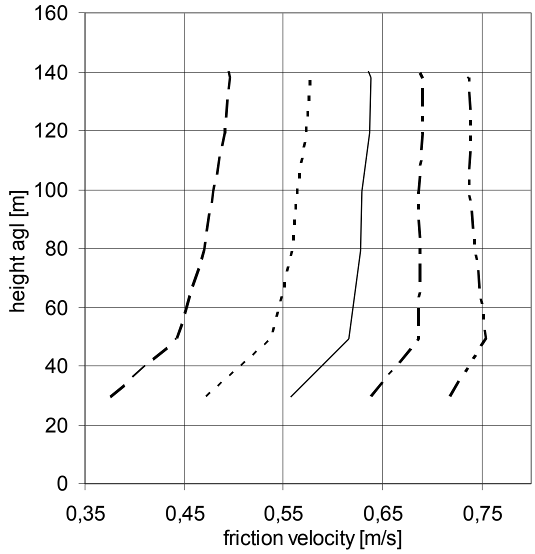

Figure 5: *Calculated friction velocity for measured wind speeds for different values of z_0 (symbols like fig. 4).*

4. Conclusion

For the calculation of the energy production of wind turbines rarely measured data higher than 100 m is used. Especially over forest only few is known about the wind field above 100 m agl. By concluding wind speeds in high levels from low levels assumptions have to be made and the equations for Prandtl layer don´t count for current hub heights. To calculate a reliable energy production more measurements have to be done especially over forests.

References:

[1] Etling, Dieter, 2002: *Theoretische Meteorologie (Eine Einführung).* Springer-Verlag.
[2] Kraus, Helmut, 2008: *Grundlagen der Grenzschicht-Meteorologie.* Springer-Verlag.
[3] Stull, Roland B., 2000: *Meteorology for Scientists and Engineers, second Edition.* Brooks/Cole.