Förnyelsebar elproduktion och eltransporter (DAT460)

Wind Energy Assignment Part 1:
Wind Energy Potential

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1. Introduction

This exercise is given to provide a basic knowledge on how to make wind energy estimations. In order to present your results, prepare a document with your answers and necessary plots which will be used when the assignment is presented to the tutor. The document shall contain figures and answers to all questions.

Your answers should be short and straight to the point, but at the same time contain enough information so that you can still re-read the answers after one year, and the information shall be able to explain and motivate the answers to an engineer who hasn't participated in the course.

The assignment can be done in groups of maximum 2 persons.

2. Working with Office Excel

The Excel file can be downloaded from the course web page. There are four sheets in the Excel file:

- Parameters
- Calculation1
- Calculation2
- Plots

When doing this assignment, you need to adjust parameters, do necessary calculation, or check plots to answer different questions.

3. Wind Speed Distribution

Wind speed distribution throughout a year can be estimated with a Weibull function:

$$f(w) = \left(\frac{k}{C}\right)\left(\frac{w}{C}\right)^{k-1} exp\left[-\left(\frac{w}{C}\right)^{k}\right] \tag{1}$$

The equation above expresses the probability $f(w)$ to have a wind speed w during the year, where k is the shape factor ($K > 1$), C is the scale factor and calculated from:

$$C = \frac{\bar{w}}{\Gamma\left(1+\frac{1}{k}\right)} \tag{2}$$

where $\bar{w}$ is the average wind speed, and G is the gamma function.

Firstly, assume an average wind speed of 6 m/s.

Q1: Observe the plot 1 in the Excel file "Plots", Is the most frequently occurring wind speed the same as the average wind speed (6m/s)? Explain your answer.

Q2: Prove that the wind speed distribution given in Weibull function has an average value of 6 m/s (You can use the Excel file "Calculation1: column I").

4. Wind Power Density

The power contained in the wind can be calculated as:

$$P(w) = 0.5\rho w^3 A \tag{3}$$

where ρ is the air density and A is the area.

In order to estimate the distribution of wind energy at different wind speed, or so-called wind energy distribution, the following formula is used:

$$E(w) = f(w)P(w)T \tag{4}$$

where T is the hours per year.

Q3: Use the equation (3) to calculate the power contained in different wind speeds per area (You can use the Excel file "Calculation1: column J").

Q4: The wind energy distribution has already been calculated in Excel file "Calculation 1: column K" and will show up after Q3 is finished. Observe the plot 2 in the Excel file, which wind speed gives the most energy?

Compare this with the most frequently occurring wind speed. Is there any difference? If yes, Why?

For which wind speed would you like to have your wind turbine most efficiently working? Why?

The wind power density, measured in kW/m^2, indicates how much power is available at the site for conversion by a wind turbine. The wind power density is calculated as:

$$\bar{P} = \frac{1}{T}\int_0^\infty E(w)\,dw \tag{5}$$

where T is the hours per year.

Q5: The wind power density has already been calculated in Excel file "Calculation1: Column L, Line 275". Compare this result with the wind power calculated based solely on the average wind speed (6m/s).

Q6: Change the average wind speed in the Excel file "Parameters: Column D, Line 3" into 7m/s.

Compare the wind power density under different average wind speeds (6m/s and 7m/s), explain why the energy is increased so much?

5. Wind shear

Wind speed at hub height is normally significantly higher than wind speed at the anemometer height. Just to give an idea, normally an anemometer height is 10 m and a wind turbine hub height is between 80-120 meter.

One model to estimate the wind speed at hub height, using wind speed data obtained from anemometer height, is described by the following expression:

$$\frac{\overline{w_{hub}}}{\overline{w_{ane}}} = \left(\frac{h_{hub}}{h_{ane}}\right)^{\alpha} \tag{6}$$

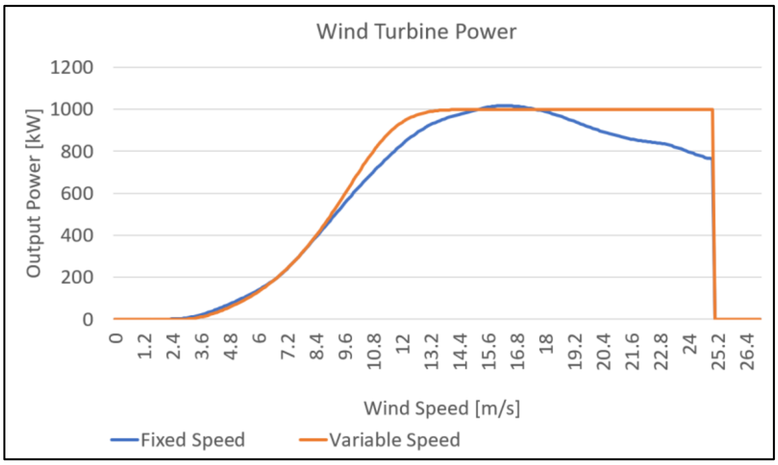
where $\overline{w_{hub}}$ is the average wind speed at hub height h_{hub}, $\overline{w_{ane}}$ is the average wind speed at anemometer height h_{ane}, and α is the wind shear exponent.

Q7: When the anemometer height is 20m, the average wind speed at the anemometer height is 6m/s, and the wind shear exponent is 0.2, the average wind speed under different hub height is calculated in the Excel file "Calculation 2: Column F". Plot 3 shows how the average wind speeds change with the hub height.

What are the average wind speeds at the hub height of 120m and 20m? What are the average wind energies per square meter (kWh/m^2) at the hub height of 120m and 20m? Compare the difference.

6. Wind turbine power curve

Regarding the rotational speed, wind turbines can be categorized into fixed-speed and variable-speed wind turbines. The typical power curve of the two wind turbine types is shown in the following figure:



The annual energy production of the wind turbine can be calculated with the following equation:

$$\bar{E} = T \int_0^{\infty} P_T(w) f(w)\, dw \tag{7}$$

where $\bar{E}$ is the annual energy production of the wind turbine, T is the hours per year, $P_T(w)$ is the wind power which will change with wind speed, $f(w)$ is the wind speed distribution.

Q8: The annual energy production of the fixed-speed and variable-speed wind turbine is calculated in the Excel file "Calculation1: Column O, Line 275" and "Calculation1: Column P Line 275" respectively.

Change the average wind speed in the Excel file "Parameters: Column D, Line 3" into hub speed at 120m (calculated in Q7). Compare the annual energy productions in percent, between the fixed-speed and variable-speed wind turbine.

Q9: Change the average wind speed in the Excel file "Parameters: Column D, Line 3" into (3m/s, 6m/s, 9m/s, 12m/s, 15m/s, 15m/s, 18m/s, 21m/s, 24m/s, 27m/s, 30m/s), and record the annual energy productions of the fix-speed wind turbine.

Why does the annual energy production of the fix-speed wind turbine decrease for the average wind speed higher than 15m/s?
Hint: How does the wind speed distribution look like for the different average wind speeds e.g. 10m/s and 20m/s? What happens with the fix-speed turbine when the average wind speed is higher than 25m/s?

Q10: Q9 is rather unrealistic, why?

Q11: If you would like to buy a wind turbine, what do you desire when it comes to turbine:

- Height?
- Sweep area?
- Type (fixed-speed or variable-speed)?

Give a short motivation to each choice and one possible problem with realizing that choice.