KTH Electrical Engineering

# EG2040 Wind Power Systems
# Comments on Assignment 1 – Wind measurements and data analysis

## 1 Report

- Be careful about the instructions. For example, it was asked to plot histograms and not the continuous density functions. Also, it was not asked in question 2.2 to draw histograms for Visby.

- If you do something different from the instructions (such as drawing continuous density functions instead of histograms in this assignment), you must justify why you chose not to follow the instructions. Note that it does not mean that you will get full grade. The best choice is of course to see with the course assistant if you think something is wrong with the assignment.

- All symbols you use must be introduced, even if you used symbols that were used during the lectures or in the course material.

- When you derive formulas using assumptions, laws, theorems, etc, cite these assumptions, laws, theorems, etc, at the steps where you use them. Listing all assumptions, laws, theorems, etc in the beginning, and carrying out the derivation without referring to them makes it hard to follow your steps.

- Always justify your claims. For example, many of you claimed that the power in the wind increases with the density, which is correct, but you have to justify it (for example by giving the expression of the power in the wind).

- The figures are best placed in the flow of the text, not in the appendix. It is not convenient for the reader to go back and forth between the text and the appendix. In the appendix, you can put extra figures that were not required in the assignment.

- The figures must have a legend, and should be drawn thinking about the black-and-white issue (do not use colors if you print the report in black and white; instead, you can use different types of lines – continuous, dashed, ... – and up to a maximum of three types of grey).

- Be careful also about the quality of your figures. If you use Matlab to export your figures, you can use the following export formats for different text editors:
  - Latex using pdflatex: export to pdf.
  - Latex using latex+dvips+ps2pdf: export to eps.
  - Word: export to emf.
- Matlab code should be placed in the appendix, because the main point of the report is precisely to report and explain. Matlab code is a tool you use to come to conclusions, and should not be put within the text.
- Matlab code is **not** a substitute for explanations. You have to explain in equations and words, what you do in the code. You cannot paste the code, and expect from the reader to understand what you have done.
- It does not make sense to give numerical results with a large number of decimals. For example, an energy value of 334,257689083020 kWh would confuse the reader: why so much precision? 334,26 kWh would be enough.

# 2 Assignment

## 2.1 Part 1: density

- It is true as some have noticed that the density decreases with altitude, but also that the wind speeds are generally higher at higher altitudes. Therefore, it may be tempting to conclude that because the decrease in power with altitude due to the density is smaller than the increase in power with altitude due to higher wind speeds, the power in the wind will actually be higher at higher altitudes (even though the density decreases). The point in the assignment, however, was to compare situations where just the density changes, so that we compare situations with the same wind speeds but with different densities. This is what is done, for example, when calculating power curves: we want to know how much a turbine produces at a given wind speed. Because what the turbine produces is proportional to the power in the wind, and since the power in the wind is proportional to the density, what the turbine produces at a given wind speed will be proportional to the density. Therefore, a turbine's power curve will look a little different depending on the density of the air at the site where the turbine is installed.

## 2.2 Part 2: energy calculations

- The Weibull and Rayleigh distributions are calculated over a certain range of wind speeds. In practice, we calculate points of the density functions in Matlab: we choose some values of the wind speeds ($v = 0, 1, 2 \ldots, 25$ m/s for example), and calculate the value of the density function at these points. Therefore, we approximate the continuous density functions by discrete values at specified wind speeds. Then, we need to integrate the density functions to calculate the average wind power. The question here is how to calculate the integral of the continuous density functions, given the discrete approximation that we have. Let us call $v_i, i = 1, \ldots, N$ the wind speeds at which the density functions are calculated, and let us assume that $v_{i+1} - v_i = \Delta v$ for all $i$ (that is, we sample the range of wind speeds every $\Delta v$, and calculate the value of the density functions $f(v_i)$ at these points). Then an approximation of the average wind power per unit of swept area (see Equation (6)) is

$$P_{\text{mean}} = \frac{1}{2}\rho \int_{\mathbb{R}} v^3 f(v) dv \simeq \frac{1}{2}\rho \sum_{i=1}^{N} v_i^3 h_i, \tag{1}$$

where $h_i$ is the probability of having wind speeds between $v_i - \frac{\Delta v}{2}$ and $v_i + \frac{\Delta v}{2}$. Now, this probability can be approximated by the samples of the density functions, $f(v_i)$, that we have:

$$h_i \simeq f(v_i)\Delta v. \tag{2}$$

Note that if we choose $\Delta v = 1$ (that is we calculate the Rayleigh and Weibull distributions at $v_i = 0, 1, 2, \ldots, 25$ m/s for example), then $h_i$ is simply $f(v_i)$ and the average wind power is calculated as

$$P_{\text{mean}} \simeq \frac{1}{2}\rho \sum_{i=1}^{N} v_i^3 f(v_i). \tag{3}$$

- The power in the wind is proportional to the cube of the wind speed. To calculate the average power in the wind, it may be tempting to use the cube of the average wind speed. This is wrong, because the power in the wind is proportional to the average of the cube of the wind speed, $(v^3)_{\text{mean}}$, and not to the cube of the average wind speed $(v_{\text{mean}})^3$. These two values are different:

$$(v^3)_{\text{mean}} = \int_{\mathbb{R}} v^3 f(v) dv, \tag{4}$$

$$(v_{\text{mean}})^3 = \left( \int_{\mathbb{R}} v f(v) dv \right)^3, \tag{5}$$

where $v$ are the wind speeds, and $f(v)$ is the density function of the wind speed distribution. So the average power in the wind per unit of swept area is calculated from the average of the cube of the wind speed:

$$P_{\text{mean}} = \frac{1}{2}\rho (v^3)_{\text{mean}} = \frac{1}{2}\rho \int_{\mathbb{R}} v^3 f(v) dv, \tag{6}$$

and not from the cube of the average wind speed:

$$P_{\text{mean}} \neq \frac{1}{2}\rho(v_{\text{mean}})^3 = \frac{1}{2}\rho\left(\int_{\mathbb{R}} vf(v)dv\right)^3. \tag{7}$$

- Power and energy are two different concepts. Be careful not to mix them up. Power is an instantaneous quantity. Energy is power consumed, or produced, over a given period of time. Therefore, calculating energy requires the knowledge of the period of time of interest, and during which the energy consumption (or production) must be calculated. For wind power applications, the average energy production **over a specified period of time**, $E_{\text{mean}}$ can be calculated from the average power production:

$$E_{\text{mean}} = P_{\text{mean}}\Delta T, \tag{8}$$

  where $\Delta T$ is the specified period of time.

- Electrical energy is almost always expressed in Watt hours, Wh (or kWh, MWh , etc), **not in Joules**. One Watt hour is an energy consumption or production of 3600 Joules in one hour. In this assignment, when you calculate the mean power in the wind in Watt, you can get the yearly energy production in Watt hours by multiplying the mean power in the wind by the number of hours in one year.

- The data you were given consisted of average wind speeds, rounded to the closest integer. This means that the wind measurements are centered on $0, 1, 2, \ldots$ m/s: all measured values between 0 and 0.5 m/s have been rounded to zero, those between 0.5 and 1.5 m/s to 1 m/s, etc. Therefore, the most intuitive way of calculating the Weibull and Rayleigh distributions was to use these values $0, 1, \ldots$ m/s. Another way that some of you used was to assume that it was best to use $0.5, 1.5, \ldots$ m/s to calculate the theoretical distributions. Using either one leads to very close results in the energy calculations. The most noticable difference between these two ways is probably the disappearance of the probability at 0 m/s when using wind speed classes centered on integers (i.e. when using $0, 1, 2 \ldots$ m/s). Note also that the probability of having a wind speed of zero does not contribute directly to the power in the wind, because there is no power if the wind speed is zero. However, a higher probability of having zero wind speed means that a smaller part of the total distribution will spread over nonzero wind speeds, and thus that the average power in the wind may be lower than in the case where there is less probability weight over the zero wind speeds.