KTH Electrical Engineering

EG2040 Wind Power Systems
Assignment 1 – Wind measurements and data analysis

Deadline for full credits: see the course webpage.

The assignments should be completed individually and the report containing all solutions should be submitted in the blue box marked EG2040, outside the student room at Teknikringen 33. If Matlab is used for completing the assignment the code should be included with the report.

Solutions to the assignments should be well motivated and explained in detail. All equations used should be written clearly and all variables clarified. Figures and tables should be properly scaled and have captions. Write your name and student number on the front page of the assignment.

The teaching assistant will be available to answer questions during the scheduled course assistance hours.

For this assignment, you must download a zip archive containing:

- a Matlab function, *calculateRho.m*, which you will use in section 1.2. It uses another function *saturationPressure.m*, also included in the archive.
- two data files containing wind measurements, *data_2010_Bromma.mat* and *data_2010_Visby.mat*, which you will use in section 2.

You can find the zip archive on the course webpage.

1 Power in the wind

1.1 Density of moist air

Moist air can be thought of as a composition of dry air and water vapor sharing the same volume; both of which can be considered as ideal gas. Thus, the ideal gas law holds for dry air and water vapor:

$$PV = \frac{m}{M}RT,$$

where P is the pressure in Pa, V the volume in m^3, m the mass in kg, M the molar mass in kg.mol^{-1}, R the universal gas constant – 8.3145 J.mol^{-1}K^{-1} – and T the temperature in Kelvin. The total mass of moist air is the sum of the masses of dry air and water vapor. Assume also that Dalton's law holds for moist air so that the pressure of moist air is equal to the sum of the pressure of dry air and the pressure of water vapor:

$$\text{Dalton's law: } P = P_a + P_w,$$

where P is the pressure of moist air, P_a that of dry air and P_w that of water vapor.

The pressure P in the expression of air density can be expressed as a function of altitude:

$$P = 101.29 - 0.011837 \cdot z + 4.795 \cdot 10^{-7} \cdot z^2. \tag{1}$$

For moist air, the relative humidity Φ is expressed, in percent, as

$$\Phi = \frac{P_w}{P_{\text{sat}}} \cdot 100,$$

where P_{sat} is the saturation pressure. The saturation pressure is given in millibar by

$$P_{\text{sat}} = 6.1078 \cdot 10^{\frac{7.5 \cdot t}{t+237.3}}, \tag{2}$$

where t is the temperature in degree Celsius.

Questions

1.1. Show that the density of moist air can be expressed as

$$\rho = \frac{1}{R_a T}\left(P + \left(\frac{R_a}{R_w} - 1\right)\frac{\Phi}{100} P_{\text{sat}}\right), \tag{3}$$

where $R_a = R/M_a$ and $R_w = R/M_w$ with M_a and M_w the molar masses of dry air and water vapor, respectively. Remember that the density of moist air is defined as the mass of moist air over the volume of moist air.

1.2. Explain **qualitatively** how the power in the wind changes with temperature, altitude and relative humidity, when air density is given by (3) (no advanced calculations are expected here; the idea is to get a feeling of how the density will vary with the different parameters).

1.2 Numerical examples

From the course web page, you can download a MATLAB file that calculates the air density for different values of the parameter. See the beginning of this document for a link to this file. In order to use the function, it must be located in the same folder as the Matlab file that you use for your calculations. It takes vectors of parameters as inputs and returns the air density. The syntax is:
density = calculateRho(t,z,phi), where:

t is an input vector of temperatures in degree Celsius,

z is an input vector of altitudes in meters,

phi is an input vector of relative humidities in percent,

density is an output array of densities in kg.m^{-3}.

The output vector *density* is built such that the element *density(i,j,k)* is the air density for a temperature defined by the i-th element of t, an altitude defined by the j-th element of z and a relative humidity defined by the k-th element of *phi*.

An example of how you can use the function to plot variations with different parameters while maintaining the other parameters constant is given below:

```
t = 5:9; % temperature in degree Celsius
z = 50:57; % altitude in meter
phi = 0:3:9; % relative humidity in percent

density = calculateRho(t,z,phi); % Run the function to get the density

figure
plot(t,density(:,1,2),'r') % plot density variations with temperature, for z=z(1)=50m, ...
    phi=phi(2)=3%

figure
plot(phi,squeeze(density(3,5,:)),'r') % plot density variations with relative humidity, ...
    for t=t(3)=7 C, z=z(5)=54m
```

Questions

1.3. Using the MATLAB function, continue your analysis from the previous section by showing with graphs how exactly the power in the wind varies with each parameter (consider temperatures between 0 and 40 C, altitudes between 0 and 200 m and relative humidities between 0 and 100 %). Which parameter has the strongest impact on the power in the wind?

2 Wind speed distributions

In this part of this assignment, you need to import in Matlab the data files in the zip archive (see the beginning of this document for a link to the files).

Importing the data files in Matlab

In the zip archive that you downloaded, you can find two data files containing wind speed measurements:

2.1. *data_2010_Bromma.mat*

2.2. *data_2010_Visby.mat*

Note that the data files must be in the same folder as the Matlab file that you use for your calculations. To import these files in Matlab, use the command *load* in your code:

`load('data_2010_Bromma.mat');` OR `load('data_2010_Visby.mat');`

This will create a new array called *windSpeedData* in your Matlab workspace. You can then use this array as any other array in Matlab.

Note also that the array name is the same for the two files (which means that if you try to load both files at the same time, the array from the second file will overwrite the array from the first file).

Assumptions

In the following, the air density is assumed to be equal to 1.225 kg/m^3, the shape factor of any Weibull distribution is assumed to be beween 1 and 10, and the wind speed range of interest is 0 – 25 m/s.

Suppose that you want to study the wind conditions at two sites: Visby (Gotland) and Bromma airport (close to Stockholm). In the questions below, we disregard the effect of altitude on the wind speeds.

Questions

2.1. Explain how to get the wind speed distributions in Bromma, when the information includes:

- Case 1: You are given the mean wind speed and the standard deviation at the sites, see table below.
- Case 2: You are given only the mean wind speed at the sites, see table below.
- Case 3: You are given three-hour wind speed measurements from 2010 at Bromma and Visby (files *data_2010_Bromma.mat* and *data_2010_Visby.mat* in the zip archive). See the instructions above for importing these files in Matlab.

2.2. Apply the method you explained in question 2.1 to draw the histograms of the three wind speed distributions (cases 1, 2 and 3) for Bromma. Gather the wind speeds in wind speed classes: 0 – 1 m/s, . . . , 24 – 25 m/s. The three distributions must be presented on the same graph.

2.3. Explain how to calculate the expected value of the yearly wind energy available at a site per unit of swept area (be careful: here, we do **not** ask for the yearly energy produced by a wind turbine, but for the yearly energy available in the wind).

2.4. Apply the equations derived in question 2.3 to calculate the expected yearly wind energy available per unit area and up to a typical cut-out wind speed for cases 1, 2 and 3 for Bromma. Comment on the differences.

2.5. In the following, we consider only case 3. Explain the differences between the two sites (Visby and Bromma) in terms of wind speed distribution and expected yearly wind energy available per unit of swept area. Comment on how these differences would influence the choice of wind turbine. Support your discussion with relevant plots. Which site would you choose if you were to invest in wind power?

	Visby	Bromma
Mean wind speed (m/s)	4.36	2.82
Standard deviation	2.41	1.72