EXERCISE SET 2: ESTIMATING WIND POWER

JULIAN HAIMOVICH, JIEHUA CHEN AND MATT ZEBIAK
ASSIGNMENTS WEBSITE

This problem set makes use of user-created MATLAB functions in order to estimate hourly power production from a set of 1.5 MW GE turbines. The turbines have a height of 80 m and blade diameter of 67.2 m. The first two columns of Table 1 (turbine power density vs. wind speed) are specifications from the manufacturer. The wind speed data that will be used is taken from satellite recordings of on-shore wind speeds measured at a height of 100 meters, and gathered every 10 minutes. You will be using data from WA_wind.xls, CA_wind.xls, and NV_wind.xls, which contain wind speed data for Washington, California, and Nevada respectively. Label the code for each part of the problem separately using comments. (Hint: in order to read excel files into matlab, use the xlsread function). Submit two files (write-up and code) to the appropriate folder in Courseworks Shared Files (name files: "LastName_FirstName_HW2").

1. Read California's wind speed data into an array.
2. Correct the wind speed data for roughness given that the wind data was collected at a height of 100 meters and the turbine hub is at a height of 80 m. Assume α to be 0.3. Place the corrected wind speeds in a new array. The function for roughness is given by Eq. (1):

$$W_{\text{height}} = W_{\text{initial height}} \left(\frac{\text{height}}{\text{initial height}} \right)^{\alpha} \tag{1}$$

3. Table 1 (this data is also provided in file Cpdata.xls) provides data on the performance of a sample wind turbine. However, the table gives power data only for discrete values. In order to generate the performance coefficient (C_p) for any wind speed value, we will need to first calculate the performance coefficient for the wind speeds in the table, then fit a curve to these discrete points. Write a function, p_coeff, that calculates the power coefficient for any given wind speed by fitting a 4th degree polynomial to the data given in the table. (Hint: think about how we define C_p). What are the coefficients for this polynomial? Plot your curve fit and the given data points in Table 1 on the same figure.

Date: June 28, 2012.

TABLE 1. Wind Velocity v. Power Density

V (m/s)	Wind Turbine Power Density (W/m^2)	Power Density in the Wind (W/m^2)
3.56	0	26.97
4.44	5	52.67
4.89	14	70.11
5.33	27	91.02
5.78	41	115.73
6.67	75	177.78
8.00	138	307.20
8.89	185	421.40
11.11	329	823.05
13.33	384	1422.22
15.02	407	2034.01
16	407	2457.60
18	407	3499.20
20	407	4800.00
21	407	5556.60
22	407	6388.80
23	407	7300.20
24	407	8294.40
25	300	9375.00
25.1	0	9487.95

4. In a separate m-file, write a function, power_func, that estimates the power output in Watts of a 1.5 MW wind turbine based on the power function for a turbine given by Eq. (2). Assume air density to be 1.2 kg/m^3. The Power Coefficient will be estimated by the p_coeff function. The sweep area is based on a turbine blade diameter of 67.2. Assume that wind speeds above 25 m/s and below 4 m/s yield no power, and wind speeds between 14 and 25 output 1.5 MW. Otherwise, the power is given by:

$$P(W) = 0.5 \times \rho_{\text{air}} \times \text{sweep area} \times C_p(W) \times W^3 \tag{2}$$

   Plot your power function for windspeed values 1:30 m/s.

5. Using the power function, power_func, calculate the estimated hourly power output, in MW, of six 1.5 MW turbine with hub height of 80 meters, located in California experiencing the height-corrected wind speeds. Assume that each turbine is exposed to the same wind and acts independently. In other words, the total power output of a six turbine farm will be the sum of the power produced by each individual turbine. Estimate the power generated every ten minutes, and average the six estimations per hour to generate an estimated power output per hour for each hour of the year.

   For the California's 6 turbine system:

   - Plot the histogram of the height-corrected annual ten-minute wind speed data. (Note: you should have about 6 * 8760 data points).
   - Print the first ten values of the annual hourly power output in MW (January 1st, hours 0 to 9).
   - Plot the histogram of the annual hourly power output in MW for the entire year.

- Calculate the capacity factor for the system.

6. Repeat part 5 for both the Nevada and Washington data. (Do not forget to account for roughness).
7. Repeat the estimation for two-3 turbine farms acting in parallel in Washington and California. Assume that the power output of the multi-farm system is the sum of the power created by both farms. Continue to assume that the total power output of one of these farms is the sum of the power created by each of the three turbines. Use the same approach as in part 5. That is, estimate the power generated every ten minutes, and average the six estimations per hour to generate an estimated power output per hour for each hour of the year.

   For the 2 location system:
   - Print the first ten values of the annual hourly power output in MW.
   - Plot the histogram of the annual hourly power output in MW.
   - Calculate the capacity factor.
8. Repeat the estimation for three-2 turbine farms acting in parallel in Washington, California, and Nevada.

   For the 3 location system:
   - Print the first ten values of the annual hourly power output in MW.
   - Plot the histogram of the annual hourly power output in MW.
   - Calculate the capacity factor.
9. Plot the Cumulative Distribution Function of the annual hourly power output in MW for each of the single location systems (part 6 & 7) as well as the two (part 8), and three-location systems (part 9) on the same plot (use the hold function when plotting). Discuss their similarities & differences. Be sure to color the lines differently and include a legend identifying each of them. (Hint: use the ecdf function)
10. Which of the following systems was most effective? Why? Your arguments should be based on the mean, variance, and sum of the power estimations for each location.
11. *lademand.xls* contains the annual hourly demand data for LA. Plot the absolute value of the hourly standardized demand data together with the absolute value standardized CA wind power data (daily standardized power available from 6 turbines in California), for the first week of the year (the first 168 data points) and discuss any trends you see. To standardize a value in a data set, subtract the mean from the value and divide by the standard deviation. For example, for the i-th value x_i in a data set x, the standardized value $x_{s,i}$ is

$$x_{s,i} = \frac{x_i - \bar{x}}{\sigma} \tag{3}$$

   where $\bar{x}$ is the mean and σ is the standard deviation of set x. Assume that the mean power $\bar{x}$ is the mean for the entire year.