Matthew Love

ME 4470 Wind and Tidal Energy

Dr. Naughton

October 7th, 2015

Homework 2, Problem 1

**Given/Find**: Provide a short answer to the questions below, and provide a reference from reading the 2014 Wind Technologies Market Report Summary (page number and line number).

1. Which country has the largest installed capacity of wind turbines? Who produces the most energy from their installed capacity?
2. Based on your reading, what would the range of cost for a 2 MW turbine have been in 2014 based on recent price data?
3. What is the capacity capability for building wind turbine components in the U.S.?
4. Although wind represents a significant amount of the electrical generating added capacity in the U.S., in which regions of the country did wind have the highest percentage of installed capacity?
5. Provide significant evidence that the ability to transport wind generated electricity from where it is made to where it is needed is increasing.

**Solution**:

1. “While the United States is the world’s number one producer of wind energy, in terms of total installed capacity, the United States remains second to China. (Wind Technologies p. 2, lines 11-13)
2. “Recently announced transactions feature pricing in the $850–$1,250/kW range.” (Wind Technologies p. 4, line 10)
3. “Domestic nacelle assembly capability stood at roughly 9 GW in 2014, and the United States also had the capability of producing approximately 7 GW of blades and 7 GW of towers annually.” (Wind Technologies p. 5, lines 5-7)
4. The interior region had the highest percentage of installed capacity, at 54%. (Wind Technologies p. 6, line 12)
5. “Solid progress on overcoming transmission barriers continued in 2014. Approximately 2,000 miles of transmission lines came online. The wind industry has identified 18 near-term transmission projects that could carry 55-60 GW of additional wind capacity. At the end of 2014, there were 96 GW of wind power capacity within the transmission interconnection queues reviewed for this report. Wind power represented 30% of all generating capacity within these queues, higher than all other generating sources except natural gas. (Wind Technologies p. 7, lines 1-5)

Matthew Love

ME 4470 Wind and Tidal Energy

Dr. Naughton

October 7th, 2015

Homework 2, Problem 2

**Given/Find**: Provide a short answer to the questions below, and provide a reference from reading the Executive Summary section ES.3 (Cost, Benefits and Other Impacts of the Study Scenario) from Wind Vision to support your claims (page number and line number).

1. Depending on the improvements of wind energy technology, what range of installed wind capacity is anticipated to reach the 35% goal in 2050?
2. What are some means of addressing increased variability on the electrical grid as wind penetration increases?
3. To reach the goal of 35% in 2050, how much transmission would need to be added per year? Is this reasonable?
4. What is the effect of adding wind generation to retail prices in the Central Study Scenario?
5. What are the estimated monetary benefits of reduced CO2 production under the central study scenario?

**Solution**:

1. “In the Central Study Scenario, total installed wind capacity increases from the 61 GW installed at year-end 2013 to approximately 113 GW by 2020, 224 GW by 2030, and **404 GW by 2050**.” (Wind Vision p. xl, column 1, lines 27-30)
2. “Such challenges can be mitigated by various means including increased system flexibility, greater electric system coordination, faster dispatch schedules, improved forecasting, demand response, greater power plant cycling, and—in some cases—storage options.” (Wind Vision p. xlii, column 2, lines 4-9)
3. “Through 2020: incremental 350 circuit miles/year needed; 2021–2030: incremental 890 circuit miles/year; 2031–2050: incremental 1,050 circuit miles/year” (Wind Vision p. xliii, Figure ES.3-3) This is reasonable, given that the historical average is 870 circuit miles/year. (Wind Vision p. xliv, Table ES.3-1)
4. “0.06¢ / kWh cost by 2020, 0.03¢ / kWh cost by 2030, 0.028¢ / kWh savings by 2050, (Wind Vision p. xlv, Table ES.3-2)
5. “Based on the U.S. Interagency Working Group’s Social Cost of Carbon estimates, these reductions yield global avoided climate change damages estimated at $85–$1,230 billion, with a central estimate of $400 billion (2013–2050 discounted present value).” (Wind Vision p. xlvi, column 1, lines 19-24)

Matthew Love

ME 4470 Wind and Tidal Energy

Dr. Naughton

October 7th, 2015

Homework 2, Problem 3

**Given/Find**: You will continue to analyze the 10 year data record of wind at the Laramie Airport used in the previous homework.

1. Using the 10 years of wind data provided on the web site, determine the probability density function (pdf) for the wind velocity for each month as well as for a year. Plot your results for January, April, July, October, and for the year.
2. Using the probability density function, determine the mean wind velocity and the velocity variance for all periods given above. Provide table of these values. How did these compare with the values you calculated in last week's homework?
3. Overlay the Weibull and Rayleigh distributions on the pdfs determined for the five different time periods. Determine and tabulate the parameters that provide the best fit and discuss how you obtained them (don't just guess; see the book for a starting value). Conclude whether each of these distributions is a good approximation to the actual wind distribution or not.

As with the last homework, convert wind speeds to an 80 m tower height before analyzing. Use a power law estimation with a roughness coefficient of a=0.19for this purpose.

**Solution**:

1. Calculate and plot pdf(u):
   1. Extract and organize desired data using *Love\_Matthew\_Extract\_Data()* or load previously saved variables into work space (this function uses the power law to convert wind speeds to a height of 80 m using ).
   2. Create histograms for wind speeds from 0 to 36 m/s, creating 19 bins, of all the data points for the desired time periods using MATLAB *hist()* built-in function.
   3. Calculate the probability density functions:
      * + is wind speed bin centers,
        + is number of data points,
        + is histogram bin width
   4. Plot pdf(u) as a function of wind speed (see plots on following page).



1. Calculate the mean velocities and variances of desired time periods:
   1. Calculate mean velocities:
      * + is the bin center of the ith bin
   2. Calculate variances:
   3. Tabulate mean velocities and variances, and compare to Homework 1:
2. Calculate and plot Rayleigh and Weibull distributions of wind speed:
   1. Calculate Rayleigh distributions:
   2. Calculate Weibull distributions:
   3. Tabulate parameters for best fit:
   4. Overlay Rayleigh and Weibull over the standard pdf’s (see plots on next page)
   5. Conclude whether each distribution is good approx. to real wind distribution:
      * The standard pdf data is certainly noisy in that a point-by-point analysis does not provide a smooth distribution between measured data points.
      * The Rayleigh distribution more accurately represents the most prevalent wind speeds than does the Weibull, but has a steeper slope coming down.
      * The Weibull more accurately represents wind speeds towards the tail-end of the distribution, but undercuts the most common wind speeds.



Matthew Love

ME 4470 Wind and Tidal Energy

Dr. Naughton

October 7th, 2015

Homework 2, Problem 4

**Given/Find**: The wind turbine power curve for a commercial wind turbine is provided in tabular form on the web site. Assume that the wind turbine will be installed at 80 m.

1. Using the Weibull fit to the probability density function (pdf) for the wind velocity for five different time periods (annual, January, April, July, and October) that you determined in the problem above, determine and tabulate the average power and energy produced by the wind turbine for each of these periods. For the purpose of this exercise, assume that the power curve has been adjusted for the density of Laramie.

**Solution**:

1. Import the wind speed and power curves provided.
2. Based on the Weibull distribution determined in Problem 3, Part c), interpolate the power data such that it matches the Weibull distribution of wind speed.
   * Use MATLAB’s *interp1(wind speed curve, power curve, Weibull)* to calculate power, P.
3. Calculate the power for each period of the Weibull distribution:
4. Tabulate results:

Matthew Love

ME 4470 Wind and Tidal Energy

Dr. Naughton

October 7th, 2015

Homework 2, Problem 5

**Given/Find**: A commercial wind turbine has the turbine power curve given in the file available on the homework web site. In another file, the rotation rate of the wind turbine is also given at different wind speeds. The wind turbine has a rotor disk diameter of 52 m.

1. Determine the coefficient of performance for this wind turbine at the velocity values listed in the data file. Assume that the data provided was acquired at sea level.
2. Most often, the coefficient of performance is plotted versus the tip speed ratio (blade tip velocity divided by the incoming wind velocity). Using the rotation rate information given, re-plot the coefficient of performance as a function of tip speed. Plot the Betz and Glauert limits on this second plot. A file with the Glauert limit tabulated is provided.
3. Comment on the result.

Issues:

* + You may use whatever software you want for performing these calculations.
  + When determining bin spacing, remember to use the spacing consistent with the data given in the file (which you convert to m/s and then further convert to 80 meter height) or you can get noisy results.

**Solution**:

1. Coefficient of performance:
   1. Import and organize all data given on course webpage.
   2. Calculate rotor disk swept area:
   3. Multiply given power curve by 1000 to achieve power in Watts.
   4. Calculate the coefficient of performance, :
      * where = air density at sea level
   5. Plot coefficient of performance as a function of wind speed (see plot on following page):



1. Coefficient of performance vs. tip speed ratio:
   1. Define wind speed vector from 0 to 30 m/s and 0.5 m/s intervals.
   2. Interpolate the provided rpm data from the wind turbine to match the new wind speed vector.
   3. Calculate linear blade tip velocity from the rpm data:
   4. Calculate the tip speed ratio, :
   5. Determine power corresponding to newly defined wind speed vector by interpolating the power curve provided.
   6. Calculate the coefficients of performance for the new wind speed vector using the same equation as in part a):
   7. Plot the new coefficients of performance as a function of tip speed ratio, and overlay the Glaurt and Betz limits on the same plot (see next page):



1. Comment on the result:
   1. One can see that the Betz limit is the theoretical upper limit for the coefficient of performance, independent of tip speed ratio. The Glaurt limit, on the other hand, is the upper limit for the coefficient of performance while taking into account the tip speed ratio. The plot shown is far from the upper limit in either case, starting with a very poor coefficient of performance at tip speed ratios of 3 to 5, where the coefficient of performance begins to improve markedly until it reaches its peak at about 0.3.