IAM 550 Introduction to Engineering Computing, J. Raeder, Fall 2019

Homework 02

Wind Turbine

Due: Friday, October 25, 5pm, in the IAM550 drop box

Objectives:

- Be able to analyze and solve a problem start to finish.
- Be able to read data files.
- Be able to deal with large data sets.
- Structured code development.
- Learn how to properly document code with comments.

Deliverables:

- A homework report in the same format as a lab report summarizing your results and including all required files (scripts, plots), but **not any data files**. The report should address the structured development of the code as discussed in class in the “Methods” section. Make sure your name is on *all* pages of your report. Document your scripts profusely with comments. This will be emphasized when grading.

Wind Turbine:

Suppose you want to install a wind turbine in Durham. You find out that a 5 kW rated wind turbine costs $25,000 with installation. 5 kW sounds really good, but before you begin you want to find out if it ever pays off. The table below gives some basic data for the turbine.

Model	ASWT.6.4-5KW
Rated Power	**5KW**
Maximum Output Power (W)	7500
Battery Bank Voltage (Vdc)	240
System output voltage (Vdc)	110/220/380
Start-up wind speed (m/s)	2.5
Rated wind speed (m/s)	10
Working wind speed (m/s)	3-25
Survival wind speed (m/s)	50
Generator efficiency	>0.8
Wind energy utilizing ratio (cp)	0.4
Generator type	Permanent Magnet Alternator
Generator weight (kg)	147
Blade material / quality	GRP/3
Blade diameter (m)	6.4
Speed regulation method	Yawning + Electromagnetism braking (Optional hydraulic braking)
Shutting down method	Manual + Automatic

First, you need to make yourself familiar with the physics of a wind turbine. The turbine works by slowing down the wind and converting the wind's kinetic energy into mechanical energy, which is then converted into electrical energy by a generator. The most important parameter is the 'swept area', *A* covered by the blades. Obviously, the larger the area, the more energy can be extracted. Next comes the wind speed, but how much power is in the wind? If *w* is the speed, r = 1.27 kg/m^3 the mass density of the air, then the kinetic energy of 1 m^3 of air is $K=½ rw^2$.

But the amount of air flowing through the turbine is also proportional to the wind speed, so the power flux going through the turbine is proportional to Arw^3. However, not all of that power can be harnessed, because that would require to slow the wind speed down to zero. When the wind slows down going through the turbine, either the air must be compressed (which does not happen at realistic wind speeds), or the effective inflow area must decrease. That puts a limit on the amount of energy that can be extracted, which is called the Betz limit and has a value of 59%. Other aerodynamic losses further reduce what can be extracted, particularly for small turbines. Thus, the power generated should be $P(w) \sim wK = aw^3$, where a is a constant that is specific for each turbine. In addition, turbines have a 'cut-in' speed, where the turbine starts to spin (2.5 m/s for this turbine) and a 'cut-out' speed, where the blades are turned into the wind for safety (possible generator burnout and excessive centrifugal forces). For our turbine we assume that the cut-out speed is 13 m/s (a value rarely exceeded in Durham).

Task 1

Given the data above, calculate the power function of the turbine, that is, *P(w)*. For that you need to find the constant *a* for this turbine from the data given. Write a function for *P(w)* and plot *P(w).* Beware of units and the cut-in/out speeds!

Task 2

Write a second script that reads the June 2019 wind data that you calculated in homework 1, and calculate the power output minute-by-minute. Plot the power output as function of time. Discuss the relation between power output and wind speed. Integrate the power output (a simple Riemann sum will do) to find the total power in kWh generated in that month.

Task 3

Assume that each kWh generated is worth $0.15 and that you finance the capital cost with a z% APR (Average Percentage Rate) loan, where you keep z as a variable and payments are monthly. Assume that you use all revenue to pay off the loan and that each month produces the same amount of energy as June 2019. Make a table, starting from 0% APR in steps of 0.2% of z, of how many years it takes to repay the loan. It's a good idea to write a function for the repay time. Stop when z is so large that you would never repay the loan. You will find that the turbine in Durham would provide a pathetic return. Discuss why this is so.

Task 4

You remember that it is much windier at your summer mansion in Provincetown (on the Cape). Redo the calculation with the wind data from KPVC (the airport there). I already got the data for you and they can be downloaded from the web site as 'pvc.mat' and be used with the load() command. The data come as the arrays t1 (POSIX time) and w1 (wind speed in mph). However, the data are for the whole year of 2018, 5 minute resolution, and have some gaps. Use the trapezoidal rule to integrate the power. Discuss if this is economical, and how one could make it more economical to produce power there.

Task 5 (50 points extra credit)

Using the radiation data from homework 1, calculate the payback from a solar array on your roof. Assume a 7.5 kW (peak) array, costing $25,000. Your roof is facing due south and has a pitch that equals your latitude (the optimal angles). For the radiation, you need the insolation (solar radiation) in W/m^2, but the data are given in a different unit (moles of photons/m^2/s), which is not straightforward to convert. Also, the radiation data already include geometrical effects, such as the solar zenith angle. To simplify, the maximum in the data is ~2600 versus maximum insolation at ~1000 W/m^2, and the array is rated for a peak of 7500 W, which is sufficient to calculate the instantaneous array output. Is the solar array a better investment?

You need to understand the following concepts at a basic level:

- Numerical integration.
- Reading and writing files.
- Plotting 2d data sets.

Turbine failures:

This video collection shows examples of cut-out failures: https://www.youtube.com/watch?v=MVHzfUWul2Y, in particular #2 and #1 with a generator burnout. Note that the other turbines in that farm are already cut-out.

For large turbines the blade 'tip speed' is a significant fraction of the sound speed. Big turbines have a 'tip speed ratio' of ~7, that is, a 20 m/s wind corresponds to 140 m/s of the blade tip under normal operation. Once the tip speed becomes close to supersonic, forces on the blade become extremely large and the blade disintegrates.

METAR data from https://mesonet.agron.iastate.edu/request/download.phtml?network=MA_ASOS

Morse data info: http://www.weather.unh.edu/display.mp?FILE=about