ENSC 283 Project

Assigned date: Feb. 23, 2011 Due date: April 8, 2011

The project should be done individually. The report **should be typed** and be accompanied with a CD including your code and plots. It should not exceed 8 pages; appendices extra.

Total mark is 50, that is 5% of your final mark. Innovative ideas or engineering recommendations have 10 bonus marks.

The most common practical engineering application for fluid mechanics is the design of fluid machinery. The most numerous types are machines which *add* energy to the fluid (the pump family), but also important are those which *extract* energy form the fluid such as turbines.

Wind turbines have long been used as a source of mechanical power. The familiar four-bladed windmills of Holland, England, and the Greek islands have been used for centuries to pump water, grind grain, and saw wood. This renewable energy has exhibited the most rapid growth of all renewable energy sources over the last few years. The purpose of this project is to introduce the fundamentals of wind energy and to impart a quantitative understanding of wind energy.

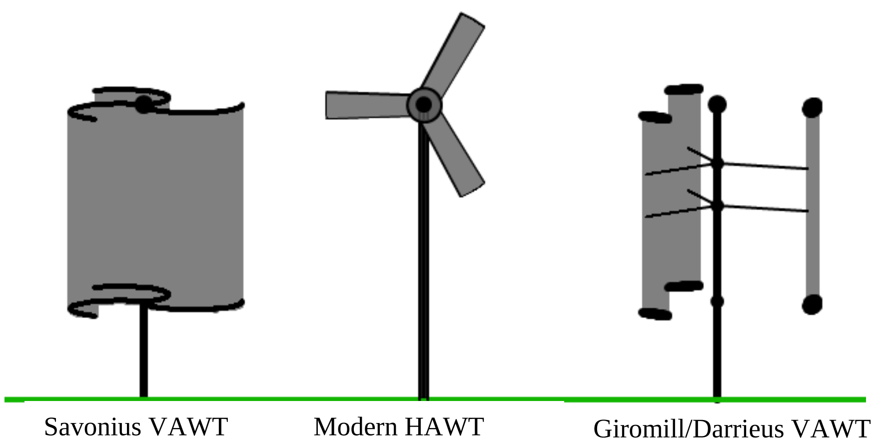
Figure 1: Typical wind turbines

Devices to harvest wind energy are available in many different configurations. Fundamental designations of a wind energy device include horizontal-axis wind turbine (HAWT) shown in

Figure 2-a and the vertical-axis wind turbine (VAWT) in Figure 2-b. The designation simply depends on the axis of rotation; HAWT devices rotate in horizontal plane and VAWT devices rotate in vertical plane. HAWTs are more common than VAWTs, but horizontal devices must have a mechanism -a yaw control- to keep them pointed into the wind. VAWTs on the other hand do not need a yaw control. More information on each turbine type can be found in your text book, Chapter 11.

(a)

(b)



(c)

Figure 2: Some examples of wind turbine designs: a) HAWT; b) VAWT; and c) schematic of both types

Theory:

The power available from a wind of speed V with mass flow rate $\dot{m}$ sweeping an area A is

$$\text{Power}_{\text{avail}} = \frac{1}{2}\dot{m}\,V^2 \qquad \text{Eq. (1)}$$

The power coefficient is defined as power extracted divided by the available power of the wind stream or

$$C_p = \frac{\text{Power}_{\text{ext}}}{\text{Power}_{\text{avail}}} \qquad \text{Eq. (2)}$$

The power coefficient is perhaps the most important single metric used in characterizing a wind turbine. Equation (2) is usually rewritten to specify the power extracted in terms of the power coefficient. Figure 4 presents the power coefficient for a two-blade HAWT wind turbine. The HAWT shows relatively high power coefficient over a rather wide range of advanced ratios.

The horizontal axis is the advanced ratio, which is defined as the rotor tip speed divided by the wind speed:

$$\Omega = \frac{r\omega}{V_{wind}} \qquad \text{Eq. (3)}$$

where r is the rotor radius and ω is the rotor rotational rate. For more detail on the theory of wind turbines, please refer to Chapter 11 of your textbook.

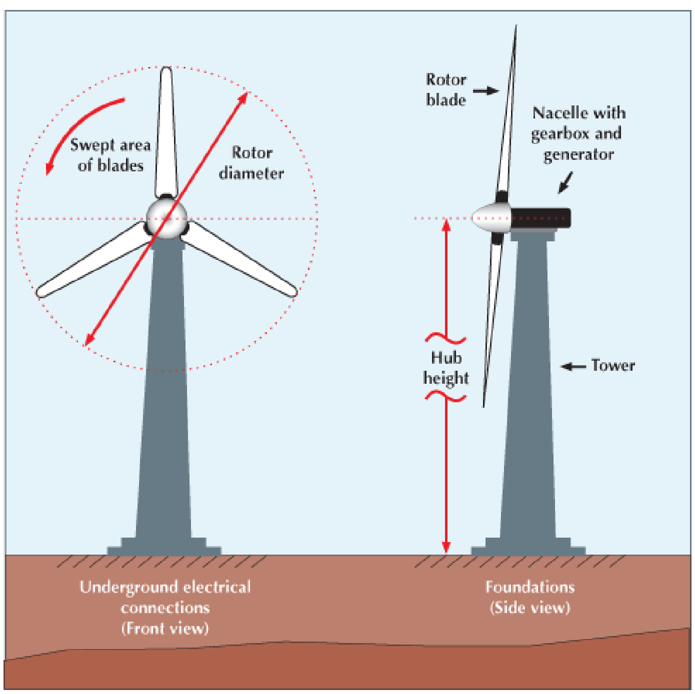


Figure 3: HAWT schematic and nomenclature (www.retscreen.net)

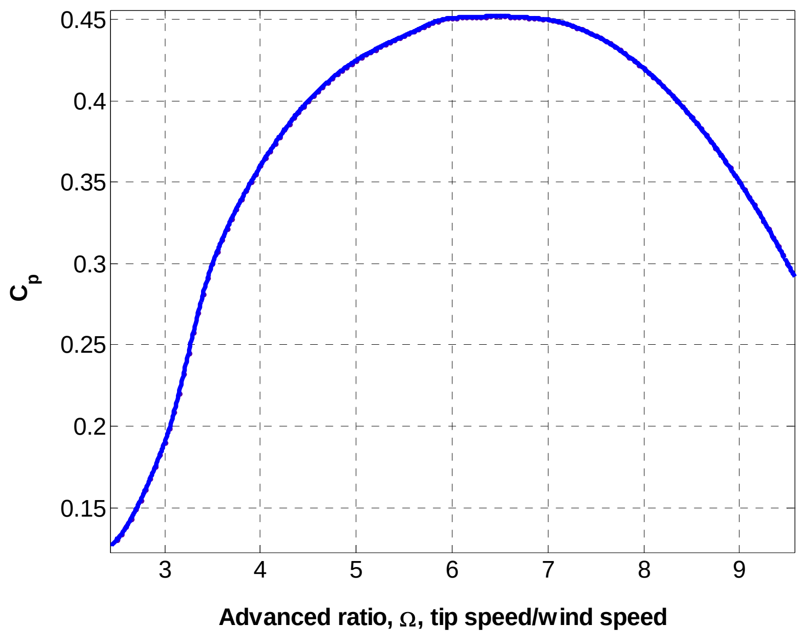


Figure 4: Power coefficient versus advanced ratio

Section 1 (15 Mark)

Effects of different parameters on the extracted power

A wind at a pressure of 1 atm and a temperature of 20℃ enters a two-bladed HAWT wind turbine, the power coefficient of which is presented in Figure 4. Use the data provided in this figure and

(a) Assuming the rotor radius = 2 m and the rotor speed = 25 Hz, vary wind speed from 6 m/s to 16 m/s and calculate the extracted power as a function of wind speed. Plot power vs wind speed and C_p vs wind speed.

(b) Assuming the rotor radius = 2 m and the wind speed = 12 m/s, vary rotor speed from 20 Hz to 50 Hz and calculate the extracted power as a function of rotor speed. Plot power vs rotor speed.

(c) Assuming the wind speed = 12 m/s and the rotor speed = 25 Hz, vary rotor radius from 1 m to 4 m and calculate the extracted power as a function of rotor radius, r. Plot power vs r.

Section 2 (30 Marks)

Design optimization

If the wind enters the turbine at a constant velocity of 12 m/s, use Figure 4 and find the rotor diameter and the speed that maximize the extracted power. Also use the following constraints:

$$20\ Hz < \omega < 35\ Hz$$

$$1\ m < r < 8\ m$$

Report the speed ratio for this optimum point.

Important note: the advanced ratio, Ω, should not exceed the range given in Figure 4.

Section 3 (5 Marks)

Discussions. Explain why the blade tip can move much faster than the wind?

Section 4 (optional, 5 bonus marks)

Innovative ideas or engineering recommendations.

Suggested approach for Section 2:

1. Read the C_p data from Figure 4 in points: $\omega = 2.5, 3, \ldots, 9.5$. You may use software (such as Grafula) to digitize the plot or read and enter the data manually for your code.

2. Interpolate the data in other points. Load a data file containing at least 100 points into your code.

3. Sweep ω by a step of *1 Hz*, sweep r by a step of *0.05 m*, and calculate the extracted power, $P(\omega, r)$, in different ω and r, using the interpolated data.

4. Pick the maximum value of P, and report r and ω for this optimum point.

Report Structure

This is an engineering report and should be prepared as per the following structure:

- Introduction: A brief review on how wind turbines work;

- Analysis and programming:

  - For section 2 you need to write a computer code (use the language of your choice).
  - Plots and tables.
  - Discuss your results and explain the trends observed.

- Formatting and presentation of the results:

A printed copy accompanied with a CD should be submitted individually. The CD should include a softcopy of the report and an executable computer code; do not print/attach the code to your report.

Print must be in black ink and of letter quality.

- The accepted font is Times New Roman regular 12 pts, or any comparable font – nothing smaller.
- Use white paper, 8 1/2 × 11 inches (21.5 cm × 28 cm), portrait format, with a single column.
- Enter your name and student ID at the top of every page, outside the set margins.
- Number your pages sequentially.
- Print on one side of the page only.
- The maximum number of pages allowed is 8 pages for the report; appendices are extra.