ENGR10004 Engineering Systems Design 1 Design Project
Wind Turbine Specifications

1 Summary

This document presents the detailed specifications for the wind turbine module of the semester long team design project for Engineering Systems Design 1. This project involves the planning, design, construction, testing and reporting of a solution to a real-world design problem involving the pumping and delivery of water to a remote community using renewable energy resources.

The proposed project involves the planning, modelling, design and testing of a small wind-powered pumping station to supply drinking water to a remote community from an underground well - see Figure 1. Wind energy will be harnessed via a wind turbine, which converts the mechanical energy provided by the wind into electrical energy to drive the pump in the underground well. The water is pumped through a pipe and stored in an above-ground tank that has a spout and tap on the bottom to allow people to obtain water via gravity-driven flow. This configuration with an above-ground tank is important because if a pump fails or no power is available, water can still be obtained for some time simply via gravity. There are periods when there is little or no wind power and energy storage system will be employed, but this is being designed and sized by an external engineering firm that specialises in this area. To improve the quality of the drinking water, the water will be treated by a small ozone generation and disinfection system. The process for completing the wind turbine section of the design project will consist of :

- Experiment
- Modelling
- Design
- Testing

Note that this document is a only a sub-module of the complete water-pumping design project. Refer to the complete project specifications for an overview of the project and description of the overall subject requirements.

A check list of the tasks to be completed for this module of the design project are summarised at the end of this document.

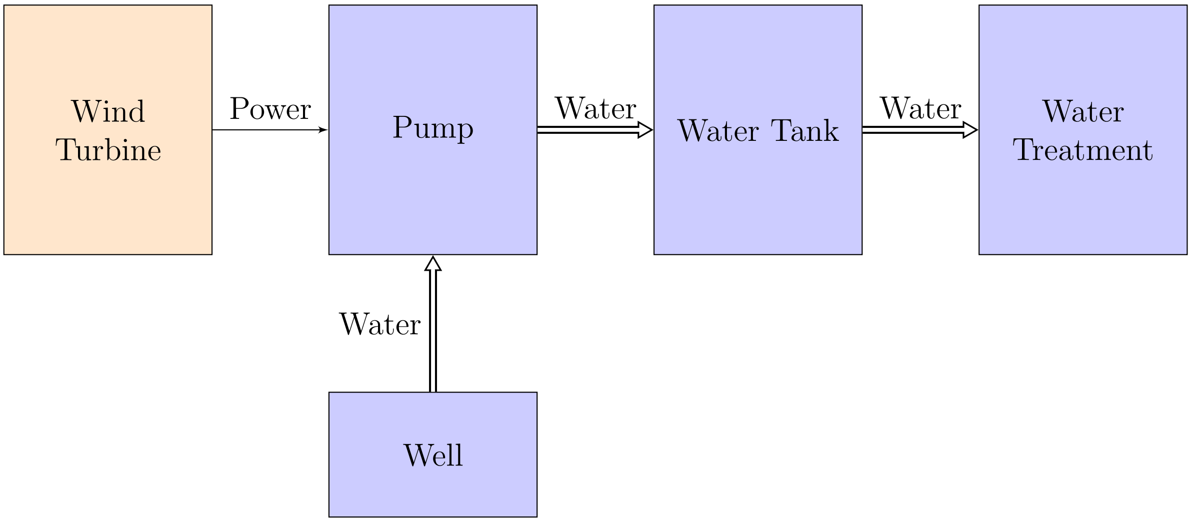

Figure 1: Wind Powered Pumping Station Systems Diagram

2 Introduction

The main principle behind wind turbines is very simple: the energy in the wind turns two, three or more blades around a rotor. The rotor is connected to a shaft, which spins a generator to create electricity. Wind turbines are mounted on a tower to capture the energy from the wind. The higher the blades are, the more they can take advantage of faster and less turbulent wind. A simple wind turbine consists of three main parts, the blades, shaft and generator, as shown in Figure 2.

Blades: The blade acts as barriers to the wind. When the wind forces the blade to move, some of the wind energy is transferred to the rotor.

Shaft: When the rotor spins, the shaft also spins, and transfers the mechanical energy into rotational energy.

Generator: A generator uses the difference in electrical charge (electromagnetic induction) to produce a change in voltage. Voltage can be thought of as a form of 'electrical pressure', the force that moves an electrical current. The voltage drives the electrical current (AC power) through power lines for distribution. In the case of this design project, the wind turbine is only powering the pumping system and the generator outputs Direct Current (DC) power.

Traditional windmills (drag type) have used flat blades or sails that would catch the wind and turn a drive shaft. Mechanical energy from the drive shaft would be transmitted through 90 degree gear arrangements and transferred to a point where the mechanical energy was desired, such as a grinding mill. Low wind forces are the choice for this flat-blade design, since grinding wheels and other mechanical parts would be (and have been) destroyed in higher winds. But for higher wind speeds drag is something to be avoided. Drag is defined as the force on an object that resists its motion through a fluid. When this fluid is a gas such as air, the force is called aerodynamic drag, or air

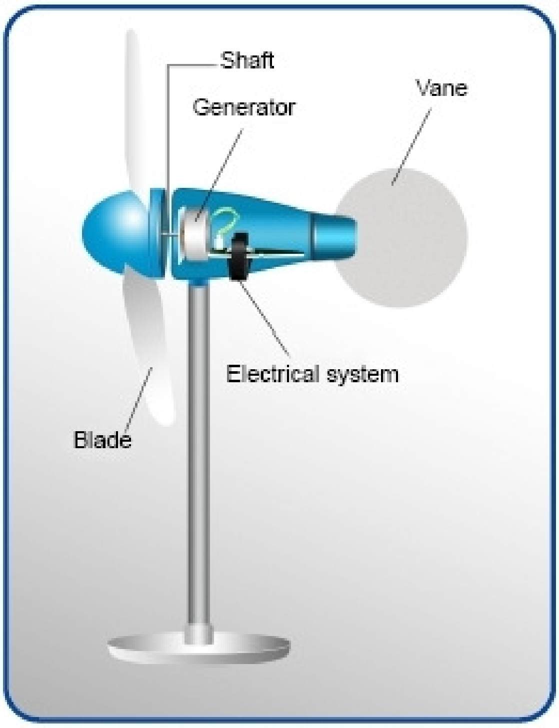

Figure 2: Internals of the wind trubine

resistance. Aerodynamics are an important consideration when studying wind turbines, as aerodynamic drag will decrease the efficiency of wind turbines. As turbine blades rotate with the wind and spin the motor drive shaft, the mechanical force that slows down the system can reduce the amount of power generated. Therefore, increasing the efficiency and reducing the drag on the moving blades is key to generating the maximum amount of power from wind turbines. These are the main ways to reduce drag in wind turbine systems:

- changing the pitch or angle of the blades
- using fewer blades
- employing light weight materials to reduce the mass of the blades
- using smooth surfaces on the blades as rough surfaces create more friction with the air
- optimising the shape of the blades to be more aerodynamic.

This last point is important since designing a blade that has lift rather than drag as its main component for turning a rotor will produce much more power in higher winds. In this module of the project you will be investigating some of these factors in order to accurately model blades of different profiles, construct your own scale model and design a full-scale wind turbine to satisfy the goals of the project.

3 Experiment

3.1 Modelling $C_P(\lambda)$ for a particular blade configuration

Include your experimental work from Workshop 5, including a description of the experimental procedure you used, your results and any required MATLAB plots showing a model of the power coefficient $C_P(\lambda)$ for the three supplied blades with a *fixed* pitch angle β.

3.2 Custom blades and measuring $C_P(\lambda, \beta)$

Include your design work from Workshop 6 and onwards, including a description of the design and testing procedure of your custom wind turbine blades. Provide a plot of $C_P(\lambda, \beta)$ for your custom designed blades.

Note : You must use your curve and values for $C_P(\lambda, \beta)$ obtained from experiment in order to calculate the expected power output of your real-world turbine blade design.

4 Designing the wind turbine system

After gaining a basic understanding of the the effects of wind speed, blade profile and pitch angle on the power output of the experimental rig's wind turbine your goal is now to design the blades for the full-scale wind turbine and provide an estimate of the typical output power of the turbine. You will need to scale up the blades you designed for the experimental rig in the workshops in order to adequately power the real-world water pumping system that you have been designing so far. You have free choice over the size of the turbine blades, however you must use the same blade profile (i.e. same $C_P(\lambda, \beta)$ charateristic) that you developed and tested on the experimental rig.

The following are constraints on the real-world wind turbine

- The turbine is designed to run for wind speeds in the range $2\,m/s \leq V_w < 20\,m/s$. Outside of these ranges, the wind turbine is stationary due to either insufficient wind or prevented from revolving due to high winds and thus produces no power.
- The Revolutions Per Minute (RPM) of the turbine hub is fixed through choice of the turbine's internal gearing and can chosen to be any constant value between 10 RPM and 25 RPM. Note that the RPM value you choose will affect the power output through the tip-speed ratio parameter λ and cannot be changed once selected.
- The real-world blades that you will design will have the same profile and $C_P(\lambda, \beta)$ characteristic as you determined on the experimental rig, but simply with a larger radius R.

One year's worth of hourly wind data from the site location of the project is given as a MATLAB file on the LMS under the "Project Material→Project Documents" link. The 365×24 matrix `WindDataRAW` lists the wind speeds in m/s, with the columns representing the hour of the day and the rows representing the day number of the year. It is expected that you will use this data to decide on the scale-up size of your turbine blade.

4.1 Design procedure

In order to estimate the power output of your real-world turbine, you will need to have taken enough data for yor custom blades to plot a surface for $C_P(\lambda, \beta)$ over a suitable range of λ and β values. The goal of the design procedure is to choose values for β, RPM and R in order to produce maximum power based on your measurement of C_P.

The steps you will need to take are

1. Choose a value for the pitch angle β for the real-world turbine. You should choose $\beta = \beta_0$ such that it gives the maximum $C_{Pmax}(\lambda_0, \beta_0)$ value for some λ_0 according to your experiments.
2. Analyse the wind speed data in the MATLAB matrix `WindDataRAW` to determine an average value of the wind speed $\bar{V}_w$ over the entire year.
3. Choose a fixed RPM value for the turbine between 10 RPM and 25 RPM and a radius R such that the average tip-speed ratio $\bar{\lambda} = \frac{\omega R}{\bar{V}_w} = \lambda_0$, which will mean that your wind turbine is operating most of the time with the maximum value of the power coefficient $C_{Pmax}(\lambda_0, \beta_0)$.
4. Calculate the average power produced by the wind turbine under typical wind conditions and ensure that it is enough to power the pump you decide to use.

4.2 Design requirements

You must include in your report

- A scale diagram of your designed blade for the full-scale wind turbine (clearly showing all dimensions and the radius value R).
- A plot of the power coefficient $C_P(\lambda, \beta)$ for your designed blade (obtained in Workshop 6).
- An estimate of the "typical" power output produced by your wind turbine.

Some things to think about when designing your wind turbine blades

- The power required by the water pumping system
- The visual impact of the size of the blades

5 Checklist

Use Table 1 to ensure that you have completed the necessary tasks for each part of the experiment and design process. Once you have completed these tasks, you should have enough information to compile your final group project report for the wind turbine module.

Phase	**Task**	**Completed**
Experiment	Perform $C_P(\lambda)$ modelling experiment	☐
	Design custom blades and model $C_P(\lambda, \beta)$	☐
Blade Design	Select appropriate scale-up size and pitch angle of custom blade	☐
	Provide scale diagram of scaled-up custom blade	☐
	Estimate the "typical" power output produced by the turbine	☐

Table 1: Checklist of required tasks in order to complete the wind turbine system module of the design project