Chapter 1
Wind Turbine Components

I Introduction

Wind Turbines can be classified in two main categories based on their physical structure. Vertical axis wind turbines have a main shaft that stands perpendicular to the direction of the wind stream. Horizontal axis wind turbines have a main shaft that lies along the direction of the wind stream. The experiments and operational theories contained in this handbook generally pertain to horizontal axis wind turbines. In particular, a SpectraQuest Wind Turbine Simulator (WTS) will serve as the experimental platform.

Horizontal axis wind turbines are composed of the following general systems:

System	Function
Yaw	Track incoming wind direction
Pitch	Control blade position
Drivetrain	Shift torque and speed characteristic
Generator	Convert from mechanical energy to electrical energy
Power System Connection	Interface generator to power grid or load systems
Supervisory Controls and Data Acquisition (SCADA)	Monitor performance and control

Throughout the course of this handbook, experiments will be performed in each of these areas to illustrate theories regarding wind turbine operation, and to enhance the understanding of wind energy conversion systems.

II System Functions

The purpose of the wind turbine is to convert the kinetic energy contained in the wind to electrical energy. It is desirable to capture as much energy as possible from the wind stream, and to lose as little energy as possible during the conversion process. Each of the major systems has some dependency on the other systems. Therefore, it is necessary for the turbine to have a system-wide controller which communicates with and controls various aspects of the turbine.

The main wind turbine controller monitors the health of the entire system, as well as the health of the individual subsystems. Based on information collected from the various sensors, the main controller can set operating conditions, verify performance metrics, and communicate with external parties, such as park-wide SCADA systems.

Yaw

To keep the wind turbine pointed into the wind, signals from a wind vane (or other wind direction measuring device) are monitored to check the incoming wind direction. With this information, the controller can actuate the yaw motors to turn the nacelle as necessary. However, many turbine designs are restricted in their yaw movement. Cables that carry power and/or control signals down tower are generally bundled together, and allowed to twist as the nacelle rotates. If those cables are twisted too many times, they can be pulled off of their anchors resulting in potentially extreme damage. Often times, a limit switch is used to notify the controller when the twist limit has been reached.

Pitch

Wind turbine blades provide a lift force, similar to an air-plane, which creates a torque on the main shaft. As wind passes over the blades, this force makes the shaft rotate. If there was no energy extracted from the system via the electrical generator, and the entire system were lossless, the turbine shaft would accelerate indefinitely.

In a real system, turbulence is created around the blades as they cut through the air mass. When the speed of the shaft increases, the amount of drag force increases. Additionally, as the rotor speed increases, the blades may begin to cut into the turbulent air created by the previous blades. As the magnitude of the drag forces increases beyond that of the lift force, the blades will “stall”. This phenomena can be taken advantage of, in that wind turbines can be designed so that they stall when the wind speed provides more power than the generator is capable of handling.

More advanced wind turbine designs allow for individual pitch control, via electric motors or hydraulic rams. Having the ability to control the pitch angle allows the designer to maximize the energy captured from the wind. Experiments can be performed to measure the performance coefficient (a measure of wind turbine efficiency) across the desired wind speed range to find a desired tip-speed ratio ($\lambda = v_{tip}/v_{wind}$). The tip-speed ratio defines the speed at which the blade cuts through the air at a given wind speed, and influences the torque vs. speed curve for the wind turbine. By defining the tip-speed ratio, a specific toque vs. speed curve can be created, one that maximizes the efficiency of the gearbox and generator. Experiments will be performed later in this handbook to illustrate this concept.

Gearbox

A gearbox is sometimes used to increase the speed of the shaft connected to the generator. The generator’s characteristics will influence the choice of gear ratio. For doubly-fed induction generators (DFIGs) the gearbox ratio is generally chosen so that the desired operating wind speed range aligns with a desired generator operating speed range. For squirrel-cage induction generators, the gear ratio can be chosen so that wind speed range is beyond the synchronous speed, putting the squirrel-cage machine in the power generating region. For permanent magnet generators, the gear ratio can be chosen to increase the speed of the shaft, which has a direct influence on the operating voltage and efficiency of the generator. Alternatively, a wind turbine with permanent magnet generator can be operated as a direct-drive unit, in which the gearbox is omitted and the generator shaft is directly coupled to the main rotor shaft; this can reduce the size and weight of the nacelle, increase overall efficiency, and reduce the number of moving parts and potential for failure.

Generator

All wind turbine generators have a generator of some kind. Although there are many different types of machines that can do the job, each offer different advantages and disadvantages. Some machines require precise control of the terminal voltages and currents, while others do not. Some machines are capable of operating over a wide range of conditions, while others are severely limited. In general, the use of power electronics is essential to maintaining efficient operation of the generator. The generator supplied with the WTS used to illustrate this handbook is a shunt-field synchronous machine (basically a car alternator). This is a common machine type, and is very popular among amateur wind turbine experimenters. However, it is interesting to note that the efficiency of the turbine can be greatly affected by the way this generator is operated. Several experiments will be performed later in this handbook, to illustrate these variations, among other topics. Also, a permanent magnet generator will be used in some experiments; it is interesting to see the tradeoffs associated with each machine type.

Power System Interconnection

Wind turbines can be operated as part of an existing power distribution network, or in a standalone "island" power system. In either case, it is important that the power generated by the turbine is made available for use by the system. This generally requires the use of power electronic controllers, transformers, filters, and additional protective devices. Furthermore, the wind turbine must be capable of limiting its power output, and must have the capability of withstanding various fault conditions.
For instance, when connecting a wind turbine to an existing power distribution network, it is important that the terminal voltage and frequency match that of the power system. When used in a standalone setting, the wind turbine may play a large role in the nature of the power system dynamics, and additional requirements or control capabilities may be imposed to maintain the integrity of the system. Experiments will be performed later in this handbook to illustrate issues associated with system interconnection.

Supervisory Control and Data Acquisition

Supervisory control and data acquisition (SCADA) systems are an important item to consider. SCADA systems can collect information from wind turbines, substations, loads, and system operators, and can control turbine set-points to maintain reliable operation. When power generation signals are provided by a system operator, such as Mid-Continental Independent Service Operator (MISO), the SCADA system adjusts the set-points of individual turbines, and can shut down turbines in the case of excessive energy production.

SCADA systems also provide the operator with visual information regarding turbine status and health. Interfaces are usually provided to see system details and to provide the ability to remotely control the wind turbine.

Experiment 1.1: Component identification and functionality tests

Goals: Understand wind turbine functionality by simply observing each of the systems independently, and study how they interact to create the energy conversion system.

Procedure:

1. Identify the major components that make up each of the wind turbine systems, and how they are connected to each other.

2. Run the wind turbine with the prime mover. Use the WindQuest software to check that all of the data acquisition equipment is working and properly tuned. View analog signals on an oscilloscope.

3. Check operation of all systems, and familiarize yourself with the machine.

Deliverables:

1. Describe the function of the three turbine components you believe most crucial? Are there sensors, controllers, or actuators in the system? What are they and why are they needed?

2. Describe the physical characteristics of the wind turbine. What are the relative sizes of the system components? What areas of the turbine seem vulnerable to failure, and why? How would you design a wind turbine that minimizes that vulnerability?

Experiment 1.2: Wind Turbine Operation

Goals: Control the wind turbine simulator by manual manipulation of the system, including actively pitching, yawing, and changing the electrical load. This experiment will illustrate operation of the wind turbine control systems.

Procedure:

1. Move the wind turbine simulator into a natural wind stream. Keep the blades pitched to 90° to prevent the machine from accelerating out of control.

2. Yaw the turbine into the wind and pitch the blades to zero degrees. As the rotor accelerates, adjust the generator field and electrical load to make the machine operate at a steady-state condition.

3. Pitch the blades to 10 ° and see how your control action changes. Try to keep the speed between 200 and 400 rpm.

Deliverables:

1. Create a desired power vs speed curve for this turbine, assuming an ideal performance coefficient; be sure to measure the radius of swept area.

2. Are you able to achieve a steady-state condition? What difficulties do you encounter in controlling the turbine?

3. What do you find most interesting about controlling a wind turbine?