Operational Manual

Team 25

Taller Wind Turbine for Low Wind Speed Regions

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ABSTRACT

In this report the team explains the general manual on the operation, assembly, and possible problems with the full-scale wind turbine being developed and the small-scale representation that has been developed in the Fall and Spring semesters. The small-scale representation is a smaller part of this report because the goal of the project is the design and development of a full-scale turbine. The major parts and dimensions for the turbine are shown, the assembly of the tower and blades is also explained. This report also explains the major problems that can be expected to occur during assembly and operations and how to resolve these issues to ensure the turbine remains in operation. The next report will be the final report which will combine all the work done over the last two semesters and will go into the full project in depth.

ACKNOWLEDGMENTS

There were several individuals that have helped us throughout this semester. Without help from these people the project would not have made as much progress as it has. We are very thankful for the time they took out of their busy schedules in order to instruct us and make sure we understood how to fix our problem before they let us go. Dr. Sungmoon Jung allowed the group to work on this very exciting project and always made time to attend biweekly meetings and answer any questions we had. Dr. Jung has always been extremely positive even when the team has been confused or stuck on a topic related to the project. Dr. Kunihiko Taira has been an excellent mentor and helped us with approaching the design of the wind turbine blades and always provided great ideas that we had not considered. Dr. Powell at the Center for Ocean and Atmospheric Studies helped us understand how to find the wind speed at different heights and good sites to build the turbine. Dr. Hollis has been very helpful in the modeling of the wind turbine blades in Pro Engineer. Dr. Atul introduced the team to the FAST software that is essential to determining the power output from our designed turbine. The senior design instructors, Dr. Shih and Dr. Gupta have provided guidance on deliverables and helpful feedback to make sure the team stays on track.

1. Functional Analysis/Functional Diagram

The wind turbine design has three main components, the tower which supports both the blades and nacelle and allows the blades to harness wind power at higher elevations, the nacelle is the connection point between the blades and tower and houses the generator and gearing system which takes rotation of the rotor and generates electricity, and the blades which use generate lift and spin the rotors.

1.1 Tower

The main purpose of the wind turbine tower is to support the blades and the nacelle. Without any of these parts, the system would fail to operate. Therefore, it is important for the tower to be able to withstand the forces created by the rotating blades. The tower consists of a steel lattice frame, reinforced by internal bracing and wrapped in an architectural fabric. Utilizing the high strength-to-weight ratio of the steel lattice structure and the internal bracing, the overall strength and weight of the tower is maintained with the increase in height when compared to a typical 80-meter steel tubular wind turbine. The design of the widened base prevents the large moment caused by the movement of the blades from overturning the tower. Furthermore, the fabric protects the steel and the internals of the tower, such as the generator and electrical components, from corrosion.

1.2 Nacelle

The design of a full-scale nacelle was not requested for the project so the team was provided with a nacelle to use in the design of the full-scale turbine. A representation of the nacelle is shown below in Figure 1.

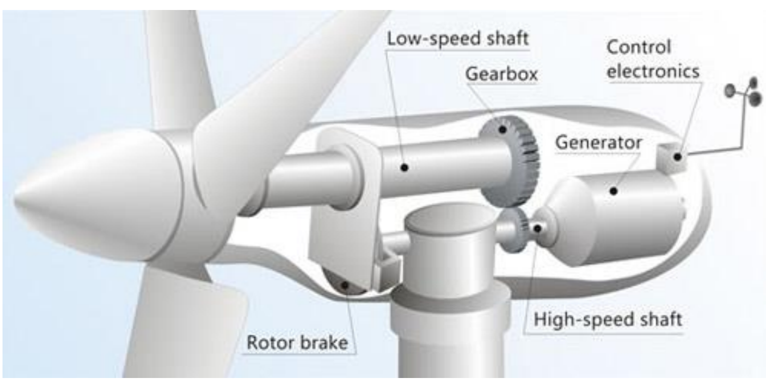

Figure 1. Interior of nacelle for wind turbine. [1]

High wind speeds generate lift on the wind turbine blades and cause them to spin which spins the rotor. The rotor shaft enters the nacelle and is connected to a gearbox which takes the low speed rotation and uses a high gear ratio to spin a generator shaft at high speeds. The spinning of the generator shaft creates electricity. Inside the nacelle is also the electronics to control the rotation of the nacelle and a rotor brake that stops the blades from spinning too fast for safety.

1.3 Blades

The team chose to maintain the same general shape of current wind turbine blades because an airfoil cross section was found to generate the most amount of lift at lower wind speeds. The blades designed are 61.5 meters in length and use a NACA 64 airfoil design which run the length of the blade. A further dimensioned blade will be located shortly in the report within the Product Specification section. The team was tasked with coming up with a method to innovate the blade and reduce weight while remaining cost efficient and strong enough to withstand the wind speeds in the southeastern United States. The team redesigned the internal spar that braces the beam from excess loads. The spar was designed to use minimal material and prevent plastic deformation on the blade under high loads. The full blade and a cross section is shown below in Figures 2 and 3, respectively.

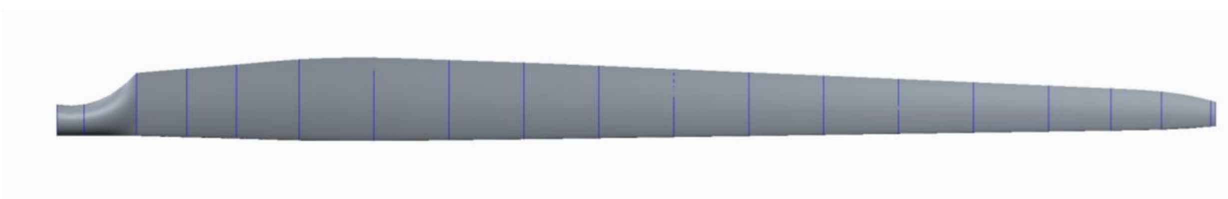

Figure 2. Blade designed for full-scale turbine.

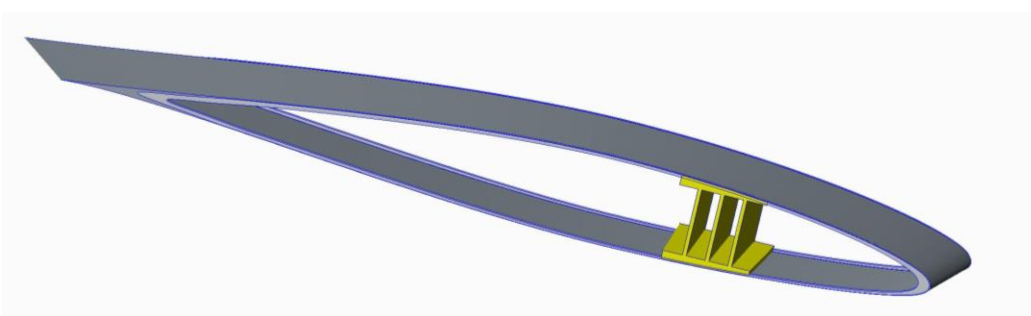

Figure 3. Blade cross section showing internal spar.

The internal spar of the wind turbine will be made out of Aluminum 6061 which offers a great combination of low density and high strength while still remaining reasonably priced. The shell of the blade is a sandwich structure of E-glass and epoxy resin to increase structural strength and Styrene Acrylonitrile (SAN) foam to reduce weight but maintain strength. Carbon fiber will also be included in the shell of the blade in the high stress areas, which will be located directly above and below the internal spar frequently.

Small-Scale Representation

The function of the small-scale representation of the final design is to show a physical representation of the major decisions of the final design including the blade shape and tower construction. The small-scale representation will function in a similar method as a regular wind turbines where the rotation of the blades will rotate a shaft that back drives and motor and generates power. The power will then be output onto a breadboard where an LED will be powered while the turbine is in motion.

2. Project/Product Specification

2.1 Tower

The hub height of the tower is 157.5 meters. This height allows the wind turbine to harness the wind speeds at a higher altitude to produce sustainable energy. Additionally, to improve efficiency the tower is divided into twenty sections of which the majority of the sections can be preassembled, prewrapped, and transported on standard semi-trailers. However, in order to transport the widened base in the standard semi-trailers, the three lower sections must be assembled on site. Although this increases the construction time and costs, the overall efficiency of the tower is maintained, partly through the ability to use standard semi-trailers for transportation. Another factor that offsets the increased construction costs is the low weight of the tower. The steel lattice tower design is about twice the height of a typical tubular tower, yet it is about the same weight. The key dimensions of the tower can been seen below in Figure 4.

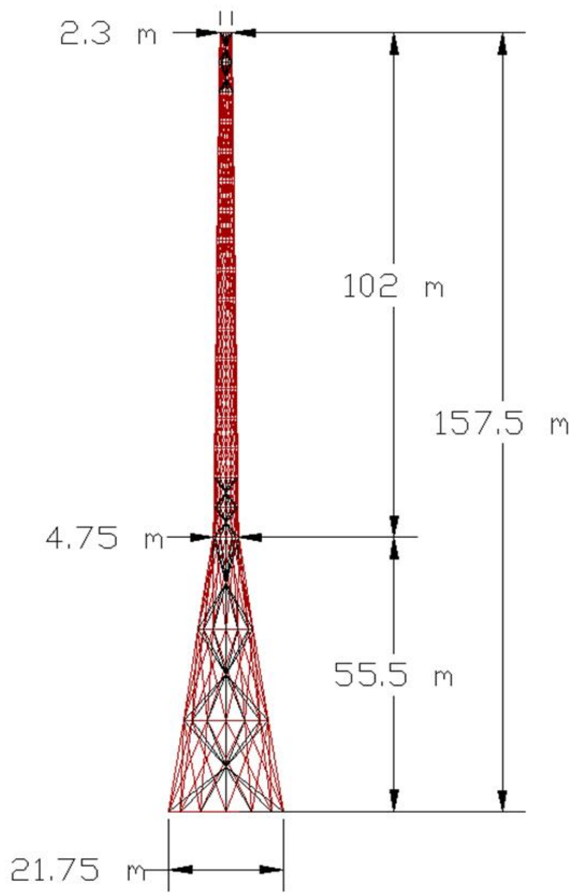

Figure 4. Full-Scale tower with dimensions

2.2 Nacelle

The power generation system in the nacelle is a low speed shaft connected to gear box and generator that creates electricity through rotation of the rotor. The generator that the project is designed for is a 5 MW generator with specifications obtained from the National Renewable Energy Laboratory (NREL). [2] The specifications for the generator are shown below in Table 1.

Table 1. Full-Scale wind turbine 5 MW generator.

Rated Rotor Speed	12.1 rpm
Rated Generator Speed	1173.7 rpm
Gearbox Ratio	97 : 1
Electrical Generator Efficiency	94.4 %

2.3 Blades

Blades that are longer than 62 meters are much more difficult to transport by road to the building site because the trucks needed to transport a single blade cannot be longer and still drive safely so the team used a length of 61.5 meters for the blades. The team also worked to reduce the weight of the blades as much as possible and still maintain the shape and strength that was required for safe operation of the wind turbine. The specifications for the blades are shown below in Table 2 and dimensions of the blade are shown below in Figure 4.

Table 2. Wind turbine blades for use in full-scale design.

Blade Length	61.5 m
Airfoil Shape	NACA64
Material (Internal Spar)	Al6061
Material (Blade Shell)	E-glass, epoxy, SAN foam, carbon fiber

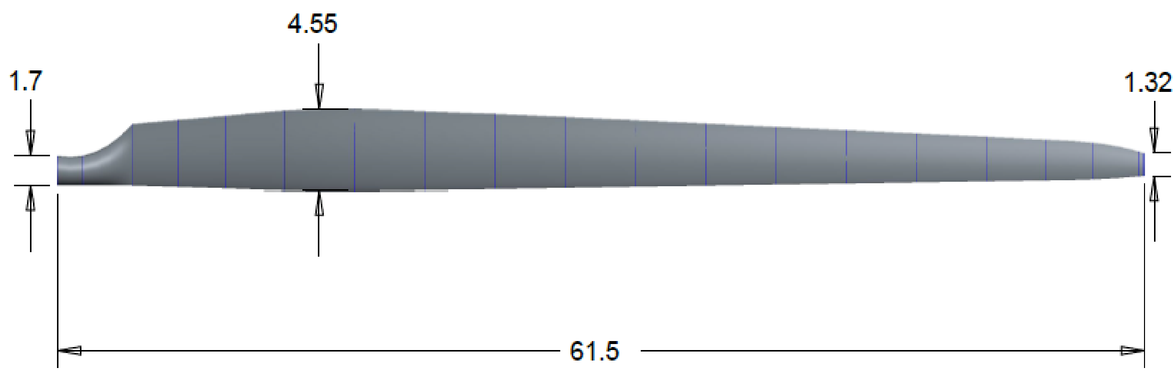

Figure 5. Full-Scale turbine blade dimensioned in meters.

3. Product Assembly

3.1 Tower

In the assembly of the tower, the material is transported to the construction site by standard semi-trailers. The upper seventeen sections are preassembled and prewrapped while the lower three sections will be assembled and wrapped in the architectural fabric onsite. Using a crane, the sections will be lifted into place on the tower. Using the male-to-female connections, the upper sections may rest on the section beneath until the connections are made.

Upon arrival at the site, segments will be inspected, wrapped in architectural fabric, and hoisted into place by a crane operator. The widened base requires the first three spans (one third of the height) to be completely assembled and wrapped on site before placement can begin with the use of a crane. This will require more workers to be present and longer hours to be worked. But such a process is necessary to meet primary design goals and this method of erection will only need to continue for however long it takes to assemble three spans, after which rapid assembly may begin with the remaining smaller 17 spans.

3.2 Nacelle

The nacelle will be built offsite and shipped to the construction site. The nacelle will be lifted by crane to the top of the tower where the nacelle will be attached with bolts. The electrical wires will be fed through the center of the tower to protect them from the outside environment. The low speed rotor shaft will be inserted into the front of the nacelle and connected to the gear box. The hub that connects the nacelle to the blades will be attached last to the rotor shaft with bolts. All connection points will be inspected before moving on to the next step in construction.

3.3 Blades

The blades will be manufactured offsite and transported to the construction site by flatbed truck. Once the blades arrive at the site they will be lifted by crane to the nacelle where they will be connected to the rotor with bolts. Workers will climb the center of the tower and tighten the bolts. All workers will be harnessed and safely connected while the blades are being connected. The connection will be checked before the tower is cleared to operate.

4. Operation Instructions

The operation of the full-scale design requires no input from users in order to function properly. Once clearance to build in an area has been approved the tower can be shipped to the site in sections and the blades can be transported by flatbed trucks.

Startup

Once the wind turbine construction is complete the tower is ready to start generating power. Wind sensors on the nacelle will allow the blades to rotate perpendicular to wind direction. Wind speeds above 3m/s will generate enough lift on the blades to spin the rotor and generate power. This can then be transported to a local substation for distribution.

Normal Operation

With wind speeds above 3m/s the wind turbine will generate power. It is important that the turbine monitor the direction of oncoming wind and the speed so it can adjust the rotation of the nacelle and pitch of the blades. The turbine will generate the maximum power at a wind speed of 11.9m/s up to 25m/s.

Shutdown

At extended wind speeds above 25m/s it is no longer safe for the wind turbine to operate. At these speeds the blade pitch will be changed for minimal lift and rotor rotation will be halted with internal brakes. The nacelle will rotate so the blades are parallel to the direction of wind flow. This will protect the blades from spinning too fast and excess deflection which can damage the blade and tower.

Maintenance

For any maintenance done on the wind turbine the system will be shut down and the rotor brakes will be applied until maintenance is complete and it is safe to resume normal operation.

5. Troubleshooting

<u>Crack created in blade outer shell during transportation to site</u>

Ensure that central spar is still clean of cracks and fractures. Contact blade manufacturer to repair crack before installation. If blade cannot be repaired, replace blade before operation of wind turbine.

<u>Deformation of bracing beam in lattice tower during installation.</u>

Replace bad beam with new beam making sure new welds are checked by proper safety staff before continuing assembly of tower.

<u>Male/female connections in tower rings do not match properly during installation.</u>

Check to see if connections can be adjusted without damaging ring structural strength. If connection cannot be completed without excess damage to ring, contact manufacturer and replace ring with new ring.

<u>Rotation of tower/blade pitch does not function properly.</u>

Ensure motors are installed properly and all connections are intact. If solution cannot be found, contact manufacturer for solution to issue.

<u>Nacelle does not rotate perpendicular to wind direction.</u>

Check controller electronics for proper operation and good communication between wind sensor and motor controller. Ensure sensor is not damaged in any way. If no solution can be found, replace sensor before operation of wind turbine.

6. Regular Maintenance

The small-scale representation wind turbine is not designed for regular use so only maintenance on the full-scale design will be covered in this section.

Every 6 months

- Check power generation system in nacelle for any signs of overheating or damage to the generator. Inspect gearing system for fractures or chips on the gear teeth to ensure smooth operation.
- Check turbine blades for cracks, fracture and any other defects that would negatively impact the lift capabilities of the blades. Connection between the blades and rotor must be inspected to ensure blades are balanced.
- Check systems used for blade pitch control and nacelle rotation.
- Grease/oil all fittings, bearings, and joints in movement as needed.

Yearly

- Inspect lattice tower for any signs of corrosion or fracture that could harm tower stability. Special inspections to male-female connections between sections must be done to ensure bolts are not rusted or sheared.
- Inspect fabric covering tower exterior for any rips.
- Check nacelle exterior for cracks and environmental damage.

Any signs of fatigue or failure to the tower, blades, or nacelle should be reported immediately and must be fixed before the turbine is allowed to return to regular operation.

7. Spare Parts/Inventory Requirement (if any)

After the wind turbine is assembled, there are very few spare parts that are necessary for extended operation. Below are some of the major parts that should be readily accessible to maintenance workers.

- Patching sheets of architectural fabric should be stored on site in case of damage.
- Spare bolts for all connections within tower, nacelle, and rotor in case of corrosion or shear of bolts.
- Paint for nacelle and blades to repair any patches caused by debris or environmental exposure.
- Harnesses for maintenance workers.

References

[1] "Nacelle." *Encyclopedia of Alternative Energy*. Web. 28 Mar. 2015. <http://www.daviddarling.info/images2/wind_turbine_nacelle.jpg>.

[2] J. Jonkman, S. Butterfield, W. Musial, and G. Scott. Definition of a 5-MW Reference Wind Turbine for Offshore System Development. Page 25, 2009.