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Subject: Operation and Assembly Manual

The Collegiate Wind Competition Project Development Team has design a wind power plant to present to the Department of Energy in the coming month. Through this process, the team has created a layout of the site, turbine model and placement, substation, and transmission. In addition, a risk analysis has been performed on the local wildlife and structures and mitigation procedures have been planned. Functionally, the site has been broken down into four comprehensible sections that operate as a whole to keep the site running efficiently.

1 Construction/ Deconstruction

Constructing the site will take a planned period of eleven months to lay foundation, assemble turbines, place cable, and build all remaining structures. Deconstruction will take less, but the plans to reuse or recycle the remaining assets remain under discussion.

1.1 Construction

Site construction is divided amongst the turbines, cable, and operations structures. Each division consists of separate construction times. Each turbine will need a foundation dug and filled with steel-reinforced concrete and left for a minimum of 28 days to cure. From there, the tower and other components will be shipped and assembled on site. In order to abide by the schedule set by the project, crews will move from foundation to foundation as soon as concrete is poured. The total construction time for a single turbine will take approximately 32 days.

Cabling refers to both underground and transmission. Underground cable routes will be trenched to an optimal depth and laid with conduit before pulling the cable through. It’s estimated that a minimum 50 feet can be trenched in a day, assuming the majority of the project trenches through dirt and lays at a standard depth. Transmission lines will take longer to erect, but there will be fewer in both time and labor. Lines will connect from the substation to the active, local transmission lines.

Operations buildings refer to the substation, central hub, warehouse, and energy storage. Substation and energy storage structures will be situated nearby for ease of transfer, while central hub and warehouses are located near any local road. This will assist the day-to-day commute for personnel and centralize the maintenance crews.

1.2 Deconstruction

Prior to the end of the site’s lifespan, the project will connect with nearby recycling centers. The turbine components will be disassembled and brought to a disposal center. After grading, the cable will be cut and pulled from under the ground to be recycled. All structures will be demolished unless otherwise repurposed or sold.

In the event that the site begins a new lifespan, the turbines will be replaced. Cabling, substation, and other electrical components will be inspected and, if necessary, replaced.

2 Operations and Maintenance

The site team's project did not involve the team building anything; thus, the team thought about how a wind farm, in general, would operate by creating a black box model and a functional decomposition model. For the Collegiate Wind Competition (CWC), the team talked to a Vestas representative to gain insight into rough cost estimates, which included some information on Vestas' maintenance plans for the turbines.

2.1 Black Box Model

Figure 1 shows the site team's black box model, which depicts a wind farm's function and its different inputs and outputs. Wind and human personnel are the physical components that enter and leave the wind farm. Mechanical and kinetic energy enters the system through the wind, which is converted to electrical energy by the wind farm. Visual signals of the wind farm included cut-in and cut-out, which can be seen in the turbine blades starting to turn and stopping, respectively. The wind farm receives an externally sourced digital signal input. The turbines, when functioning, will produce a sound.

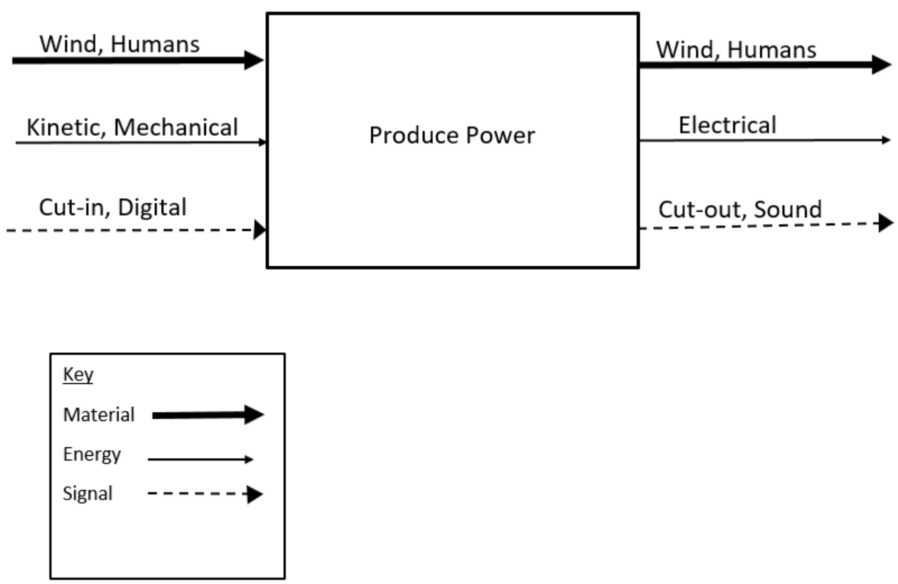

Figure 1: Black Box model for CWC Site Team

2.2 Functional Decomposition

Figure 2 show how a wind farms functions can be broken down into five sections: harvesting, converting, storing, transmitting, and controlling.

During the harvesting process the wind moves at a high velocity towards the turbines containing a substantial amount of kinetic energy. The energy is captured by the blades, which causing them to spin converting the kinetic energy into mechanical. Once the air passes through the blades and the rest of the wind farm that is the point where it leaves the functional decomposition as well.

Within the turbine's nacelle there is a series of rotating shafts, gears, motors, and generators. Through these parts in the nacelle the mechanical energy gets converted to an unrefined electrical energy. The electricity then travels down the tower. The electricity is then diverted to either be storage or transmission.

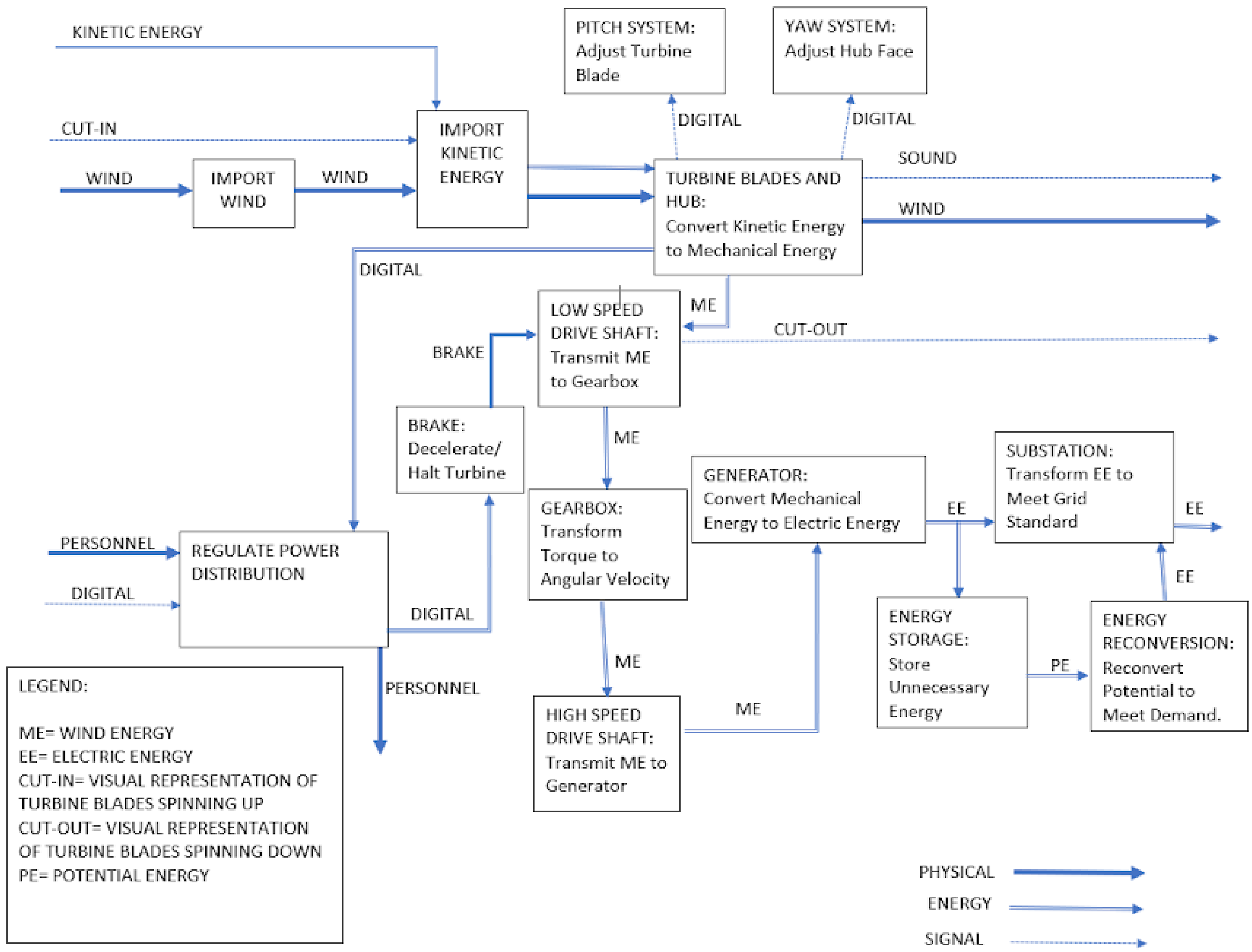

Figure 2: Functional Decomposition for a Wind Farm

The modern means of storage the electrical energy produced could range from air compression to electrolysis and chemical synthesis. These storage system options will hold the energy for peak hours to supply what is required from control.

The transmitting of the energy produced encompasses the substations and transmission lines. The electrical energy would be transformed to meet the voltage standard of the transmission lines and sent in a more refined package to supply power to consumers.

In control sector of the wind farm, an on-site staff will be communicating with external monitoring groups to determine the amount of power that exiting the plant or filling and emptying energy storage. The group must inspect, maintain, and control the wind farm daily.

2.3 Vestas' Maintenance Plan

The team's final selection for turbines was the Vestas V120-2.2 MW turbines. To prepare and gather more accurate information for CWC, the team talked to a Vestas representative about the V120. One of the topics that were discussed was the maintenance plan that Vestas offers to clients that buy their turbines. Vestas crews would enter the site and begin cycling checkup work on a set of designated turbines. The standard scheduled checkups included tightening, greasing, and cleaning the turbines and their parts. Additionally, Vestas requires that a small warehouse housed inventory and possible truck storage for them to use. The Vestas representative gave the team an estimated maintenance quote of $65,000 per turbine per year. Thus, the turbine maintenance cost alone per year is roughly $2,925,000. From the team's research, yearly maintenance mostly consists of the scheduled turbine maintenance. However, unscheduled turbine maintenance can happen throughout the year. Other maintenance that can happen on a wind farm but is significantly less of a factor in comparison are road, cable, and substance maintenance.

3 Risk Analysis and Mitigation

The siting team evaluated potential critical failures that could arise in the operation of the wind farm. From the collection, the failures were then ranked from most to least severe. Most severe indicates that the wind farm will need to halt operations and least indicates maintenance crew can operate on the issue during operating times. With these risks involved in the project, the team conducted an analysis to create alternatives and ways to mitigate these potential failures and risks, all can be found in Appendix A.

3.1 Potential Failures Identified

The team categorized their failures on the main components and divided them into sub-components that could cause a risk. Starting with the major component of the turbine, the blades, can encounter stress from high winds that cause shear stress. Blades also could encounter striking objects in the sky most likely birds. Next is the gear box within the turbine's nacelle, could face major shear forces if the gears are not aligned correctly with their ratios. The tower is another major component of the turbine that encloses all major cables, due to the high level of winds and possible weather disasters the tower can potentially cause the most damage. Generators is another potential risk, a part that converts the mechanical energy to electricity. Problems within the generators can lead to a disruption of the flow of the turbine which can put the maintenance crew in danger. Turbines' control systems are the center of information from transmitting to and from the turbines. A failure to the control systems lead to the less production of the turbines. Furthermore, these risks were identified further into sub-components which can all be found in the Appendix A.

3.2 Risk Mitigation

Many of the potential failures can be prevented with an educated workforce and regular inspection and maintenance. A few detailed mitigations include electrical cabling to be constructed underground to decrease exposure to wiring, blade inspections, preventative and maintenance protocols, monitor productivity and environmental compliance, and regular checks to maintain systems. Some risks listed in Appendix A have more severity than others, yet again with a proper maintenance schedule all components will be less likely to fail.

Appendix A: Shortened FMEA

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Potential Causes and Mechanisms of Failure	RPN (Maximum 75)	Recommended Action
Nacelle Housing	Impact	Flying debris	Flying Impacts	2	Scheduled Maintenance
Nacelle Housing	Wear	Flying debris	Poor Maintenance	1	Scheduled Maintenance
Blades	Impact	Flying debris	Flying Impacts	16	Scheduled Maintenance
Blades	Wear	Flying debris	Poor Maintenance	12	Scheduled Maintenance
Gear Box	Wear	Loss of Function	Overstressing; Poor Maintenance	75	Scheduled Maintenance
Gear Box	Fatigue	Loss of Function	Assembly Errors; Poor Tolerances	75	Scheduled Maintenance
Brake Systems	Wear	Erratic Operation	Poor Maintenance; Overstressing	16	Scheduled Maintenance
Transformers	Corrosion	Loss of Function; Fire	Over current	36	Scheduled Maintenance
Tower	Wear	Flying Debris, Loss of Function	Assembly Errors; Poor Maintenance	25	Scheduled Maintenance
Tower	Buckling	Flying Debris, Loss of Function	Assembly Errors; Poor Tolerances	15	Scheduled Maintenance
Generator	Fatigue	Loss of Function	Overstressing; Assembly Errors; Poor Maintenance	18	Scheduled Maintenance
Generator	Wear	Loss of Function	Poor Maintenance	18	Scheduled Maintenance
Generator	Galvanic Corrosion	Loss of Function; Potential Fire	Assembly Errors; Poor Maintenance	18	Scheduled Maintenance
Control System	Galvanic Corrosion	Loss of Function; Reduced Oversight Effectiveness	Electromagnetic Interreference; Poor Maintenance	18	Scheduled Maintenance

Control System	Short-Circuiting	Loss of Function; Reduced Oversight Effectiveness	Poor Maintenance	30	Scheduled Maintenance
Rotor	Impact	Flying Debris; Loss of Function	Flying Impacts	24	Scheduled Maintenance
Rotor	Wear	Flying Debris; Loss of Function	Assembly Errors; Overstressing	24	Scheduled Maintenance
Tower Cables	Wear	Flying Debris; Loss of Function	Assembly Errors; Overstressing; Poor Maintenance	8	Scheduled Maintenance
Main Shaft	Fatigue	Loss of Function; Disrupt Other Components	Assembly Errors; Poor Tolerancing; Poor Maintenance	8	Scheduled Maintenance
Main Shaft	Wear	Loss of Function; Disrupt Other Components	Overstressing	8	Scheduled Maintenance
Shaft Bearings	Wear	Loss of Function; Disrupt Other Components	Poor Maintenance	32	Scheduled Maintenance
Power Cables	Galvanic Corrosion	Loss of Function	Overcurrent	40	Scheduled Maintenance
Transmission Lines	Impact	Loss of Function; Fire	Flying Impacts	24	Scheduled Maintenance
Transmission Lines	Galvanic Corrosion	Loss of Function	Poor Maintenance	24	Scheduled Maintenance
Energy Storage (Hydrogen)	Corrosion; Brittle Fracture	Loss of Function; Leaking Combustible Gas	Overstressing	12	Scheduled Maintenance
Energy Storage (Hydrogen)	Electrical Exposure	Loss of Function; Fire; Flying Debris	Poor Maintenance	8	Scheduled Maintenance
Energy Storage (Flywheel)	High Cycle Fatigue	Loss of Function; Flying debris	Overstressing	8	Scheduled Maintenance

Energy Storage (Compressed Air)	Stress Rupture	Loss of Function; Flying debris	Overstressing	6	Scheduled Maintenance
Anemometer	Impact	Loss of Function; Flying debris	Flying Impacts	6	Scheduled Maintenance
Anemometer	Fatigue	Loss of Function; Flying debris	Overstressing	6	Scheduled Maintenance
Wind Vane	Impact	Loss of Function; Flying debris	Flying Impacts	6	Scheduled Maintenance
Wind Vane	Wear	Loss of Function; Flying debris	Overstressing	6	Scheduled Maintenance
Pitch System (Hydraulic)	Wear	Loss of Function; System Rupture	Overstressing	18	Scheduled Maintenance
Pitch System (Electric)	Wear	Loss of Function; System Rupture	Overstressing	18	Scheduled Maintenance
Turbine Blade Edge	Wear	Loss of Efficiency	Poor Maintenance	40	Scheduled Maintenance
Sensor	Corrosion	Loss of Function; Loss of Oversight	Assembly Errors; Extensive Use	12	Scheduled Maintenance
Hub	Fatigue	Loss of Function; Flying debris	Overstressing	8	Scheduled Maintenance
Hub	Impact	Loss of Function; Flying debris	Flying Impacts	18	Scheduled Maintenance
Hub	Wear	Loss of Function; Flying debris	Tolerance Issues	16	Scheduled Maintenance
Yaw System (Active)	Deformation Wear	Loss of Function; System Rupture	Overstressing; Natural Events	18	Scheduled Maintenance
Yaw System (Passive)	Stress Rupture	Loss of Function; System Rupture	Overstressing; Natural Events	18	Scheduled Maintenance