DO NOT SEPARATE EXAM BOOKLET
DO NOT WRITE ON EXAM BOOKLET

Yale University Science Olympiad
January 21, 2017

Wind Power

You may not open this exam until given permission by your proctors.

DO NOT WRITE ON THIS EXAM

Report all answers on the provided answer booklet. Scrap paper is provided at the end of the answer booklet.

DO NOT SEPARATE EXAM BOOKLET
DO NOT WRITE ON EXAM BOOKLET

Part I. Historical Wind Power Designs

1. List three things that turbines have been used for. [2]

2. Where (city and country), and in what year, was the first energy-producing wind turbine created? [2]

3. What is the name of a windmill design that consists of a four-bladed mill mounted on a central post? [2]

4. In the aftermath of World War II, what shortage spurred developments in wind turbine design? [2]

5. On July 9th, 2015, what country achieved a record by using wind turbines to generate 140 percent of the electricity it was consuming? What did it do with its excess 1 GW of electric power? [2]

Part II. Wind Power Rotor and Fan Blade Design

1. What does HAWT stand for? What does VAWT stand for? [2]

2. A wind turbine has a blade radius of 120m. Wind is blowing directly into the face of the turbine with velocity 13 m/s. Assume air density of 1.225 kg/m^3
    a. What is the cross-section area covered by the spinning turbine blades? [1]

    b. In kg/s, what is the air mass flow rate through the turbine [1] (Hint: Use dimensional analysis! Combine the quantities you have to get an answer with units of kg/s.)

    c. What mass of air passes through the turbine blades in one second? [1]

    d. What is the total original kinetic energy of the air mass that passes through the turbine blades in one second? [1]

    e. What is the power of the wind incident on the turbine? [1]

    f. What is the maximum power the turbine can actually extract from the wind? [1]

DO NOT SEPARATE EXAM BOOKLET
DO NOT WRITE ON EXAM BOOKLET

3. What is Betz' Law, and what is the percent associated with it? [2]

4. Are lift-based or drag-based wind turbines more effective at extracting wind power? [2]

5. The Wikipedia article "Wind turbine design" states "for a given survivable wind speed, the mass of a turbine is approximately proportional to the cube of its blade-length." This seems unintuitive: naïvely, you'd expect that the mass of a turbine would be directly proportional to its blade-length, because a blade twice as long weighs exactly twice as much (not eight times as much!). Explain why the naïve analysis is incorrect. [2]

Part III. Power Generator

1. If a turbine has a 7.5 ohm resistor and the voltage measured across the resistor is 100 mV what is the power generated by the motor? [2]

2. A turbine in Chicago contains the following dimensions: air density of 1.23 kg/m^3, wind speed of 6 m/s, and a turbine radius of 1 m. How much power is being produced by this turbine? You may or may not have to use all the information given. [2]

3. Using the information given in #2, calculate how much of this energy can actually be harnessed. What law or principle governs this generation? [2]

4. If a generator is turned with a torque of 50 N*m and is turning at a constant rate of 50 rpm, what is the total power generated? [2]

5. How is the load factor of a power station defined? [2]

Part IV. Power Storage

1. Why is AC energy commonly used for energy transportation? [2]

2. Circle which of the following are methods of energy storage. [2]

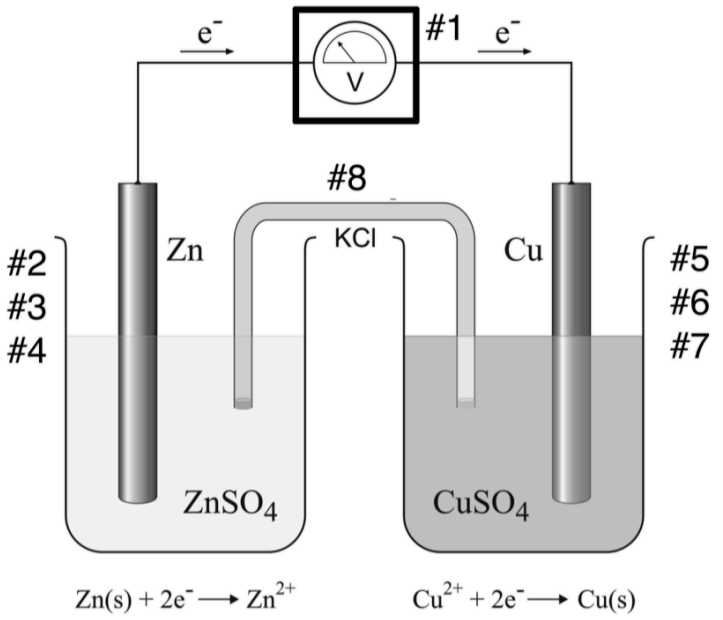
   Molten salt Tidal Flywheel Liquid Nitrogen Uranium

3. At what time of the day is energy most likely to be stored in an energy storage facility? [2]

DO NOT SEPARATE EXAM BOOKLET
DO NOT WRITE ON EXAM BOOKLET

4. Why is power storage ability more important for wind or solar power than it is for coal-burning plants? [2]

5. Answer the following questions based on the battery cell below.



a. Name item #1. Note that there are several acceptable answers; just provide one. [1]

b. Name item #8, the upside-down u-shaped structure connecting the two solutions. [1]

c. Is the side labeled with #2-4 the anode or the cathode? [1]

d. Is the side labeled with #5-7 undergoing oxidation or reduction? Why? [1]

e. Is the side labeled with #2-4 the positive or negative side of the battery? [1]

Part V. Power Transmission

1. If a power plant is generating 100 MW, running on a 20 KV line (20 kilometers long), loses 10 MW of power after running along the line, how much resistance does the line have? [2]

2. A wind turbine has a 5 ohm resistor connected in series with the CD motor, and the voltage measured across the resistor is 100 mV. Include units in your answer. What is the current flowing through the resistor? What is the power generated by the CD motor? [2]

DO NOT SEPARATE EXAM BOOKLET
DO NOT WRITE ON EXAM BOOKLET

3. A power plant in Chicago is generating 900 MW on a 700 KV line. Assuming the line is 100 kilometers long, with a resistance along the line of 0.2 ohms, answer the following:

    a. What is the current flowing along the line? [1]

    b. How much power is lost in the lines? [1]

4. At approximately what voltage is electricity transmitted in long-distance overhead power lines? [2]

5. What device is used to change the voltage to make it suitable for long-distance transmission? [2]