ANSWER KEY

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.

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Part I. Historical Wind Power Designs

1. List <u>three</u> things that turbines have been used for. [2]

   Crushing grain, making gunpowder, generating electricity, pumping water, draining lakes, cutting wood at sawmill.

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

   Glasgow, Scotland. 1887.

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

   Postmill

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

   Fossil fuel shortage

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]

   Denmark. They sold it to Norway, Sweden, and Germany ("sold to other countries in Europe" is acceptable)

Part II. Wind Power Rotor and Fan Blade Design

1. What does HAWT stand for? What does VAWT stand for?

   Horizontal Axis Wind Turbine, Vertical Axis Wind Turbine

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]

      45,200 m^2

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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.)

720,000 kg/s

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

720,000 kg

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

60,880,000 J

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

60,880,000 W

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

36,000,000 W

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

Betz' Law says that only a certain amount of energy can be harnessed from the wind. 59.3%

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

Lift-based

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]

A longer blade must be thicker/stronger to prevent deformation.

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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]

   100 mV * 13.3mA = 1330 mW = 1.33 W

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]

   0.5(area)(air density)(wind speed^3) = $0.5(3.14159 * 1^2)(6^3) = 56.55$ W

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]

   (watts)(Betz' Law) = (56.55)(59.3%) = (56.55)(0.593) = 33.53 watts
   Betz' Law

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]

   262 W

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

   Average load / peak load

Part IV. Power Storage

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

   AC energy can change the amounts of voltage being transported and easily changes direction.

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

   <u>Molten salt</u>   Tidal   <u>Flywheel</u>   <u>Liquid Nitrogen</u>   Uranium

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

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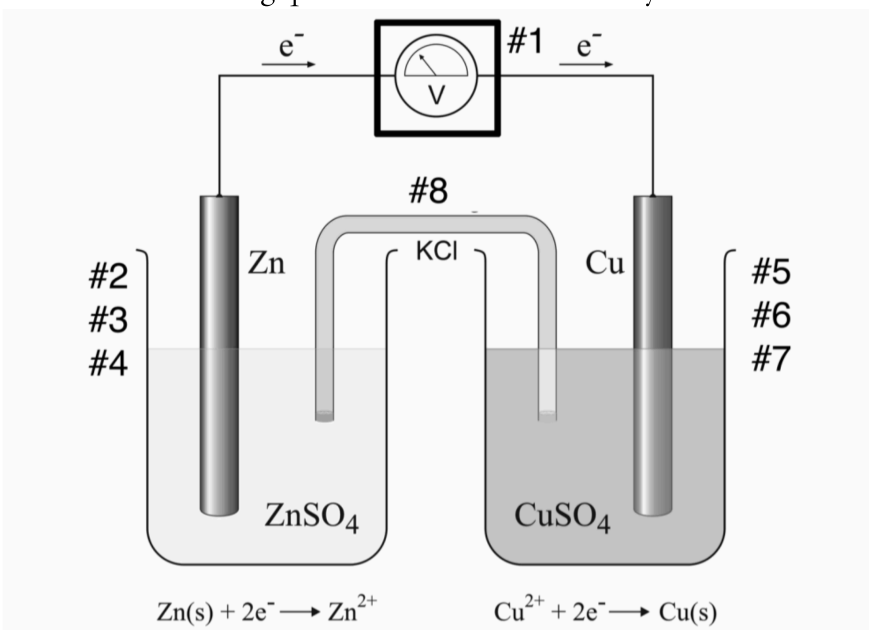
3 a.m. (accept any answer from midnight to 6 a.m.)

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

   Wind power is not as steadily available, so sometimes it produces a lot of energy when demand is low, or not a lot when demand is high.

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]

      Voltmeter or multimeter

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

      Salt bridge

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

      Anode

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

      Reduction, because gaining electrons

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

Negative

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]

   V = IR, P = VR
   Amps: 100 MW / 20 KW = 5000 A
   Ohms: V / I = 20 KV / 5 MA = <u>4 ohms</u> (← final answer)

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]

   100 mV / 5 ohms = 20 mA (current)
   100 mV * 20 mA = 2 mW (power)

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]

      900 MW= 90000000 watts 700 KV= 700000 volts
      90000000 watts / 700000 volts= 1286 amps

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

      Find Voltage drop: (amps)(ohms)
      Substitute: (1286 amps)(0.2 ohms)
      Calculate: 257.2 kV 4)
      Find power lost: (amps)(kV)
      Substitute (1286 amps)(257.2 kV)
      Calculate 330.76 MW

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

Accept any answer 50k – 500k

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

Transformer