

NPRE 475

Wind Power Systems

Spring 2018

Number	Date Assigned	Due Date	Description
1	1/17	1/24	<p>1. List the components of the envisioned Internet of Things (IoT) for a future energy system.</p> <p>2. Automobile internal combustion engines are designed to operate for about 5,000 hours over their operational time. Compare this to the required number of design operational hours for a wind turbine operating at an intermittency or capacity factor of 30-50 percent for a design lifetime of 20 years.</p> <p>3. The USA's goal for wind power production is from presently 2 percent up to 20 percent of electrical energy production by 2030.</p> <p>To accomplish this goal, the USA would need to add 1,700 Gigawatts (1 Gigawatt, GW = 1,000 Megawatts, MW) of wind power installed rated capacity per year.</p> <p>One megawatt (MWe) of electrical power supplies the electrical use of 240-300 average American homes with a family of four.</p> <p>Estimate the number of people that wind power would serve per year by the year 2030, assuming a wind intermittence factor of 40 percent, and a conversion efficiency of 70 percent.</p>
2	1/19	1/26	<p>Wind power, being an industrial process, poses challenges and concerns to be surmounted for its sustainable implementation.</p> <p>List the environmental concerns encountered in its development.</p>
3	1/22	1/29	<p>List the perceived advantages of wind power generation.</p> <p>List the components of a modern Horizontal Axis Wind Turbine (HAWT).</p>
4	1/24	1/31	<p>Briefly explain:</p> <ol style="list-style-type: none"> Coriolis force, Beaufort wind speed scale, Correlation between solar activity and wind activity hypothesis. <p>One percent of the solar radiation power of 1.7×10^8 GW is converted to wind power.</p> <p>The floral or plant global Net Primary Production (NPP) in all the links of the food and energy chain is:</p> <p>$NPP = 4.95 \times 10^6$ [cal / (m².year)].</p> <p>The Earth's surface area is: $A_{Earth} = 5.09 \times 10^{14}$ m².</p> <ol style="list-style-type: none"> Estimate the power stored as biomass in Watts. What is the ratio of wind to biomass power generated from solar radiation? <p>Discuss the implication regarding wind and biomass power generation.</p> <p>Use: 1 calorie = 4.186 Joule, 1 year = 3.1536×10^7 sec, 1 Watt=1 Joule/sec.</p>
5	1/26	2/2	<p>For the random variable representing the points obtained in throwing a single die:</p> $\xi_{die\ throw} : \begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 \\ \frac{1}{6} & \frac{1}{6} & \frac{1}{6} & \frac{1}{6} & \frac{1}{6} & \frac{1}{6} \end{pmatrix}$ <p>Calculate:</p> <ol style="list-style-type: none"> The mean value, first moment, mathematical expectation, or average value, The second moment or mean of squares, The variance as the "mean of squares minus the square of the mean". <p>The probability density function (pdf) of the two parameter Weibull distribution used in modelling wind duration curves is:</p>

			$W(v) = \frac{k}{C} \left(\frac{v}{C} \right)^{k-1} e^{-\left(\frac{v}{C} \right)^k}$ <p>where: $k = \text{shape parameter or slope}$ $C = \text{scale parameter or characteristic wind speed}$</p> <p>As special cases, deduce the forms of:</p> <ol style="list-style-type: none"> The Rayleigh distribution, The Exponential distribution. <p>Consider the exponential probability density function (pdf):</p> $p(v)dv = \frac{1}{C} e^{-\frac{v}{C}} dv$ <ol style="list-style-type: none"> Apply the normalization condition to prove that it is indeed a probability density function (pdf). Derive the expression for its cumulative distribution function (cdf). Derive the expression for its complementary cumulative distribution function (ccdf). Use a plotting routine to plot the pdf, cdf, and ccdf for a value of $C = 2$.
6	1/29	2/5	<p>To develop maximum power, a wind generator must be mounted as high as possible. Several authors have suggested the following simple power law for the variation of wind speed V with height H:</p> $\frac{V}{V_0} = \left(\frac{H}{H_0} \right)^n$ <p>where V_0 is the observed speed at a reference height of H_0 meters above ground, and V is the wind speed at altitude H. The value of V_0 is usually given at 10 m height at airports meteorological towers, and the coefficient n takes values over the range 0.1 – 0.4. The wind speed at 20 meters height at the Eiffel Tower, Paris, France is about 2 m/s, and it is about 7-8 m/s at 300 meters above ground. What range of values of the coefficient n best fits the Eiffel Tower situation?</p>
7	1/31	2/7	<p>A Japan Steel Works (JSW) J82-2.0 / III wind turbine has a rotor blade length of 40 m. Estimate the wind speed at the tips of its rotor blades at the maximum and minimum heights they attain, if the hub height is:</p> <ol style="list-style-type: none"> 65 meters. 80 meters. <p>Assume the turbine is built within an area with a roughness class of 2.5, for a wind blowing at $V_{ref} = 8 \text{ m/sec}$ at a height of $z_{ref} = 20 \text{ m}$.</p> $V(z) = V_{ref} \frac{\ln \frac{z}{Z_0}}{\ln \frac{z_{ref}}{Z_0}}, Z_0 = 0.2 \text{ m.}$
8	2/2	2/9	<ol style="list-style-type: none"> Consider the average wind speed at the Champaign Willard airport location from the graph in the lectures as about 5 m/s. Determine its wind class classification. Plot the corresponding Rayleigh probability density function. Using the power curve for the Gamesa G52-850 kW wind turbine, generate the graph of the potential energy production as a function of wind speed. Estimate the yearly total energy production.

			f) Compare the total potential energy production for this wind class site to that obtainable from a wind class 7 location as shown in the example in the lecture notes.
9	2/5	2/12	Compare the wind speed at a height of 50 m on the surface of water to that in rough city terrain using: 1. The power law, 2. The logarithmic law. Use: Average wind speed is 5 m/s at a measurement height of 10 m. Adopt average values of the equations parameters n and z ₀ .
10	2/7	2/14	The Suzlon S.66/1250, 1.25 MW rated power at 12 m/s rated wind speed wind turbine design has a rotor diameter of 66 meters. For the same rated wind speed, what would the rated power be, if: 1. The rotor diameter is halved to 33 meters. 2. The rotor diameter is doubled to 132 meters. 3. The wind speed is half the rated wind speed at 6 m/s. 4. The wind speed is double the rated wind speed at 24 m/s.
11	2/9	2/16	The Suzlon S.66/1250, 1.25 MW rated power at 12 m/s rated wind speed wind turbine design has a rotor diameter of 66 meters and a rotational speed of 13.9-20.8 rpm (revolutions per minute). Calculate the range of the tip of its rotor's speed in m/s, km/hr and miles/hr. Discuss the implication regarding the possible ice formation on the blades. Use: $v = \omega r$, $\omega = 2\pi f$, f=frequency in Hz. 1 Hz= 1 revolution/sec.
12	2/12	2/12	Class Quizz: 1. Write down the expression for the power content of a wind stream of density ρ , constant speed V , and diameter D , expressing the units of each variable. 2. If the diameter is doubled, what is the effect on the power content? 3. If the wind speed is doubled, what is the effect on the power content?
13	2/12	2/19	List the basic principles of energy conversion and extraction from the environment and their corollaries.
14	2/14	2/21	Write a one paragraph description of the "Desertec" project. By differentiation of the expression of the power coefficient: $C_p = \frac{P}{W} = \frac{1}{2}(1-b^2)(1+b)$ with respect to the interference factor b, determine analytically the value of the Betz' limit for wind machines. Explain its physical meaning. Plot the power coefficient as a function of the interference factor and identify on the graph the location and value of the optimal value of b.
15	2/16	2/23	By differentiating the expression for the power in a wind stream: $P = \frac{1}{4}\rho S(V_1 + V_2)^2(V_1 - V_2)$ with respect to the downstream velocity V_2 for a constant upstream velocity V_1 , derive Betz's Equation for the maximum amount of power extractable from a wind stream. Compare your result to the original equation introduced by Betz.
16	2/19	2/26	The pioneering Smith-Putman wind turbine had a rotational speed of 29 rpm, and its electrical generator operated at 600 rpm. 1. Estimate the gearing ratio in its gearbox or transmission. 2. Identify the design flaw learned from its operation. A wind turbine that operates in an area with a wind power flux resource of 200 Watt/m ² (measured at 50 m height) has the following operational parameters:

			<p>1. Rotor blade radius $R = 30$ m. 2. Coefficient of performance $C_p = 40$ percent. 3. Transmission (gearbox) efficiency: 97 percent. 4. Electrical generator efficiency: 98 percent. 5. Intermittency factor (capacity factor): 30 percent.</p> <p>Calculate:</p> <ol style="list-style-type: none"> The rotor swept area. The rated power of the turbine. The transmission power. The electrical generator power. The overall electrical power production in MWe. <p>Compare the values of the calculated parameters to those in an area with a wind power flux resource of 600 Watts/m².</p>																																																		
17	2/21	2/26	<p>Calculate the “gearing ratio” of the transmissions or gearboxes from the electrical generator and rotor technical specifications of the following wind turbine designs:</p> <table border="1" style="margin-left: 40px;"> <tr> <td>Rotor</td> <td>S.64/1250 (50 Hz)</td> <td>S.64/1250 (60 Hz)</td> <td>S.66/1250 (50 Hz)</td> <td>S.66/1250 (60 Hz)</td> </tr> <tr> <td>Blade</td> <td colspan="4">3 bladed horizontal axis</td> </tr> <tr> <td>Swept area</td> <td>3217 m²</td> <td>3217 m²</td> <td>3421 m²</td> <td>3421 m²</td> </tr> <tr> <td>Rotational speed</td> <td colspan="4">13.9 / 20.8 rpm</td> </tr> <tr> <td>Regulation</td> <td colspan="4">Pitch regulation</td> </tr> </table> <table border="1" style="margin-left: 40px;"> <tr> <td>Generator</td> <td>S.64/1250 (50 Hz)</td> <td>S.64/1250 (60 Hz)</td> <td>S.66/1250 (50 Hz)</td> <td>S.66/1250 (60 Hz)</td> </tr> <tr> <td>Type</td> <td colspan="4">Asynchronous 4/6 poles</td> </tr> <tr> <td>Rated output</td> <td colspan="4">250 / 1250 kW</td> </tr> <tr> <td>Rotational speed</td> <td>1006/1506 rpm</td> <td>1208/1807 rpm</td> <td>1006/1506 rpm</td> <td>1208/1807 rpm</td> </tr> <tr> <td>Frequency</td> <td>50 Hz</td> <td>60 Hz</td> <td>50 Hz</td> <td>60 Hz</td> </tr> </table>	Rotor	S.64/1250 (50 Hz)	S.64/1250 (60 Hz)	S.66/1250 (50 Hz)	S.66/1250 (60 Hz)	Blade	3 bladed horizontal axis				Swept area	3217 m ²	3217 m ²	3421 m ²	3421 m ²	Rotational speed	13.9 / 20.8 rpm				Regulation	Pitch regulation				Generator	S.64/1250 (50 Hz)	S.64/1250 (60 Hz)	S.66/1250 (50 Hz)	S.66/1250 (60 Hz)	Type	Asynchronous 4/6 poles				Rated output	250 / 1250 kW				Rotational speed	1006/1506 rpm	1208/1807 rpm	1006/1506 rpm	1208/1807 rpm	Frequency	50 Hz	60 Hz	50 Hz	60 Hz
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18	2/23	2/26	<p>Read then write a short summary of the book chapter: Adam M. Ragheb and Magdi Ragheb (2011). "Wind Turbine Gearbox Technologies," Fundamental and Advanced Topics in Wind Power, Rupp Cariveau (Ed.), ISBN: 978-953-307-508-2, InTech, http://www.intechopen.com/articles/show/title/wind-turbine-gearbox-technologies</p> <p>The relationship between the electrical generator rpm, the number of generator poles n, and the current/voltage frequency f is given by Eqn. 6 in the book chapter as: $f = (n * rpm) / 120$ [Hz]</p> <p>What would be the number of generator poles needed in the USA and in Europe/Asia for:</p> <ol style="list-style-type: none"> An off-shelf generator with an rpm of 1800 connected to a wind turbine by a gearbox/transmission? A gearless wind turbine with a gearing ratio of unity and an rpm of 18? 																																																		
19	2/28	3/7	<p>1. Euler’s equation applies to a steady incompressible inviscid fluid flow with no body forces. It relates the change in velocity along a streamline dV to the change in pressure dp along the same streamline: $dp = -\rho V dV$</p> <p>From Euler’s equation, derive Bernoulli’s equation. Explain its physical meaning in terms of the static and kinetic (dynamic) pressures.</p> <p>2. A wind rotor airfoil is placed in the air flow at sea level conditions with a free stream speed of 10 m/s. The density at standard sea level conditions is 1.23 kg/m³ and the pressure is 1.01 x 10⁵</p>																																																		

			Newtons/m^2 . At a point along the rotor airfoil the pressure is $0.90 \times 10^5 \text{ Newtons/m}^2$. By applying Bernoulli's equation estimate the speed at this point.
20	3/2	3/12	<p>For an air density of 1.23 kg/m^3, a wind speed of 10 m/s, a rotor cross sectional area of 10 m^2, and a rotor effective area in the drag direction of 5 m^2, estimate:</p> <ol style="list-style-type: none"> 1. The lift force L in Newtons, 2. The drag force D, 3. The thrust force T. <p>If the angle between the thrust and the incoming undisturbed air flow is 45 degrees, estimate:</p> <ol style="list-style-type: none"> 1. The perpendicular component of the force leading to translation of the rotor, 2. The force parallel to the undisturbed air flow, 3. The bending moment in the air stream on a <i>three</i> bladed turbine nacelle with a tower height of 50 meters. <p>Hint: $C_L = \frac{(L/A_L)}{\frac{1}{2}\rho V^2}$, $C_D = \frac{(D/A_D)}{\frac{1}{2}\rho V^2}$.</p> <p>Use: Lift to drag ratio $C_L/C_D = 18$, Drag coefficient $C_D = 0.06$.</p>
21	3/5	3/12	List the major components of gear-driven wind machines.
22	3/7	3/14	<p>Construct a table comparing the characteristics, advantages and disadvantages of:</p> <ol style="list-style-type: none"> 1. Horizontal Axis Wind Turbines, HAWTs, 2. Vertical Axis Wind Turbines, VAWTs.
23	3/12	3/26	Briefly describe the characteristics and the justification regarding the capacity factor of the Haliade-X, 12 MW of rated power GE turbine for offshore applications.
24	3/14	3/26	<p>Compare small wind turbines to utility level wind turbines as to:</p> <ol style="list-style-type: none"> 1. Their applicable power range, 2. Their fields of applications, 3. Their rotational speeds, 4. The use of transmissions.
25	3/15	3/26	

Assignments Policy

Assignments will be turned in at the beginning of the class period, one week from the day they are assigned. The first five minutes of the class period will be devoted for turning in, and returning graded assignments. Late assignments will be assigned only a partial grade. Please try to submit them on time since once the assignments are graded and returned to the class, late assignments cannot be accepted any more. If you are having difficulties with an assignment, you are encouraged to seek help from the teaching assistants (TAs) during their office hours. Questions may be emailed to TA's, but face-to-face interaction is more beneficial. Although you are encouraged to consult with each other if you are having difficulties, you are kindly expected to submit work that shows your individual effort. Please do not submit a copy of another person's work as your own. Copies of other people's assignments are not conducive to learning, and are unacceptable. For further information, please read the detailed assignments guidelines.