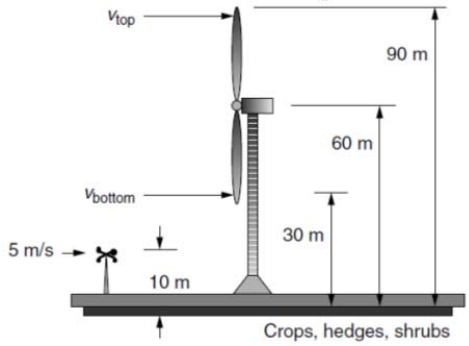
NATIONAL UNIVERSITY OF SINGAPORE
Department of Electrical Engineering

EE4511 RENEWABLE GENERATION & SMART GRID
Tutorial 2

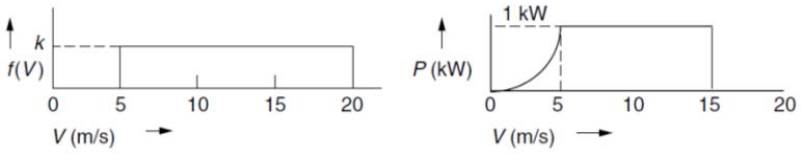
1. An anemometer mounted at a height of 10 m above a surface with crops, hedges and shrubs, shows a windspeed of 5 m/s. Assuming 15◦C and 1 atm pressure, determine the following for a wind turbine with hub height 60 m and rotor diameter of 60 m:



   a. Estimate the windspeed and the specific power in the wind (W/m2) at the highest point that a rotor blade reaches.
   b. Repeat (a) at the lowest point at which the blade falls.
   c. Compare the ratio of wind power at the two elevations using results of (a) and (b) and compare that with the ratio obtained using

$$\left(\frac{P}{P_0}\right) = \left(\frac{1/2\rho A v^3}{1/2\rho A v_0^3}\right) = \left(\frac{v}{v_0}\right)^3 = \left(\frac{H}{H_0}\right)^{3\alpha}$$

2. Suppose the wind probability density function is just a constant over the 5 to 20 m/s range of windspeeds, as shown below. The power curve for a small 1 kW windmill is also shown.



   a. What is the probability that the wind is blowing between 5 and 15 m/s?
   b. What is the annual energy that the wind turbine would generate?
   c. What is the average power in the wind?

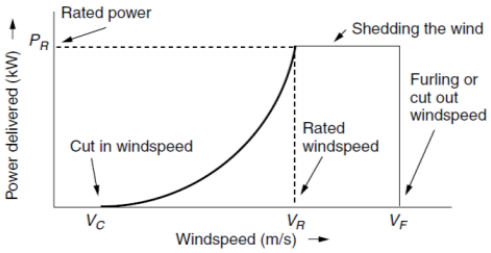
3. Suppose an anemometer mounted at a height of 10-m on a level field with tall grass shows an average windspeed of 6 m/s.
   a. Assuming Rayleigh statistics and standard conditions (15◦C, 1 atm), estimate the average wind power (W/m2) at a height of 80 m.
   b. Suppose a 1300-kW wind turbine with 60-m rotor diameter is located in those 80 m winds. Estimate the annual energy delivered (kWh/yr) if you assume the turbine has an overall efficiency of 30%.
   c. What would the turbine's capacity factor be?

4. Consider the Nordex 1.3 MW, 60-m wind turbine with power specifications given below, located in an area with 8 m/s average wind speeds.

Manufacturer:		Nordex
Rated Power (kW):		1300
Diameter (m):		60
Avg. Windspeed		
v (m/s)	v(mph)	kW
0	0	0
1	2.2	0
2	4.5	0
3	6.7	0
4	8.9	25
5	11.2	78
6	13.4	150
7	15.7	234
8	17.9	381
9	20.1	557
10	22.4	752
11	24.6	926
12	26.8	1050
13	29.1	1159
14	31.3	1249
15	33.6	1301
16	35.8	1306
17	38.0	1292
18	40.3	1283
19	42.5	1282
20	44.7	1288
21	47.0	1292
22	49.2	1300
23	51.5	1313
24	53.7	1328
25	55.9	1344
26	58.2	0

a. Find the average power in the wind (W/m^2) assuming Rayleigh statistics.
b. Create a spreadsheet to determine the energy delivered (kWh/yr) from this machine.
c. What would be the average efficiency of the wind turbine?
d. If the turbine's rotor operates at 70% of the Betz limit, what is the efficiency of the gearing and generator?

5. For Rayleigh winds with an average windspeed of 8 m/s:
   a. How many hours per year do the winds blow at less than 13 m/s?
   b. For how many hours per year are windspeeds above 25 m/s?
   c. Suppose a 31-m, 340-kW turbine follows the idealized power curve shown in Figure below. How many kWh/yr will it deliver when winds blow between its rated windspeed of 13 m/s and its furling windspeed of 25 m/s?



d. Using the capacity factor correlation given below, estimate the fraction of the annual energy delivered with winds that are above the rated windspeed?

$$\mathrm{CF} = 0.087\overline{\mathrm{V}} - \frac{P_R}{D^2}$$

6. Clara is an electrical engineer whose task is to perform feasibility study of two potential sites for wind farm, site A and site B. Both sites are located at the same altitude but with different terrain characteristics. Site A has terrain characteristic of tall grass on level ground where site B has terrain characteristic of high crops, hedges and shrubs. She measured a wind speed using anemometer mounted at a height of 10 m and found out that both sites provide the same wind speed at the height of 10 m. Assume the friction coefficient as shown in the table below.

Site	Terrain Characteristics	Friction Coefficient (α)
A	Tall grass on level ground	0.15
B	High crops, hedges and shrubs	0.20

   a. If she plans to install a wind turbine at the height of 25 meters above the ground at site A, in order to capture the same output power per swept area at what height should she install the wind turbine at site B?
   b. Clara has collected the wind speed data at the height of 10 meters for both sites for over a year. She found out that the wind statistics follow Rayleigh statistics with the average wind speed of 6.5 m/s. Find the average power in the wind per swept area at the height of 25 meters above the ground at site A. Assume standard air density of 1.225 kg/m3.
   c. Suppose that the company decides to choose site B as the location for wind farm and install fifty NEG Micon 750/48 (i.e. 750 kW generator, 48-m rotor) wind turbines at the height found from a. If the wind turbine efficiency is 30% and array efficiency of 90%, find the annual energy production from this wind farm. Assume that the capacity factor of an individual wind turbine can be approximated from the average wind speed in m/s $(\bar{v})$, rated power of a generator in kW (P_R) and rotor diameter in meter (D) using the formula, $CF = 0.087\bar{v} - \frac{P_R}{D^2}$.