Wind Energy

The purpose of this document is to provide the reader with a general understanding of wind energy and the harnessing of its power in the state of Illinois. This is not a new concept, and in many rural areas the original water pumping windmills can still be seen. Most modern windmills are designed for generating electricity. They are usually referred to as “wind machines” or “wind turbines”. The long thin impeller blades and height give them a distinctively different look from the old time windmills.

Estimating wind speed in your area

The first issue to address when determining the feasibility of wind power is the average wind speed at the proposed location. This can be found by viewing the wind energy resource atlas map published by the National Renewable Energy Laboratory (NREL). An updated and more detailed map of Illinois from the same source can be found here. Table 1 is a clearer view of the legend for these maps.

Industry generally considers wind power to be economically viable if the area is rated at a power class of 3 or higher. Although very few areas in Illinois have a power class of 3 or higher, the remainder of this document will help you decide if wind power is right for you.

Analyzing available wind

Table 1 shows the class ratings of wind power. This system of class ratings was derived by Battelle Pacific Northwest Laboratories and holds much more information then first meets the eye.

Table 1 Classes of wind power density at 10 m and 50 m[a].

Wind Power Class*	10 m (33 ft)		50 m (164 ft)	
	Wind Power Density (W/m^2)	Speed[b] m/s (mph)	Wind Power Density (W/m^2)	Speed[b] m/s (mph)
1	0 100	0 4.4 (9.8)	0 200	0 5.6 (12.5)
2	100 150	4.4 (9.8) 5.1 (11.5)	200 300	5.6 (12.5) 6.4 (14.3)
3	150 200	5.1 (11.5) 5.6 (12.5)	300 400	6.4 (14.3) 7.0 (15.7)
4	200 250	5.6 (12.5) 6.0 (13.4)	400 500	7.0 (15.7) 7.5 (16.8)
5	250 300	6.0 (13.4) 6.4 (14.3)	500 600	7.5 (16.8) 8.0 (17.9)

6	300	6.4 (14.3)	600	8.0 (17.9)
	400	7.0 (15.7)	800	8.8 (19.7)
7	400	7.0 (15.7)	800	8.8 (19.7)
	1000	9.4 (21.1)	2000	11.9 (26.6)

(a) Vertical extrapolation of wind speed based on the 1/7 power law.

(b) Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, speed increases 3%/1000 m (5%/5000 ft) elevation.

Everyone knows from experience that wind does not blow at a constant speed. It will vary according to season, time of day, and the effect of other objects in close proximity. The wind classes include this information, but first a few concepts must be understood.

Wind speed is related to the power output of a wind turbine by equation 1.

Equation 1. The relation of wind power to wind speed[4]

$$\frac{P_2}{P_1} = \left(\frac{V_2}{V_1}\right)^3$$

Where $P_{1,2}$ are power densities at $V_{1,2}$ wind speeds.

As an example, assume Champaign Illinois has an average wind speed of 10 mph (4.47 m/s) and a wind turbine with a 1m^2 swept area is being used. Also assume that the wind blew at 20 mph (8.94 m/s) for 12 hours and blew at 0 mph (0 m/s) for the other 12 hours which resulted in the 10 mph (4.47 m/s) average. If we assume 24 hours at 10mph (4.47 m/s) we get 101Watts * 24 hours or 2424kWh. The actual power would be 20mph (8.94 m/s) or 808 Watts * 12 hours + 0 Watts * 12 hours which yields 9696kWh. If the average speed had been used, the output estimate would be off by 7272kWh for one day.

Table 1 gives us additional information about how the averages are calculated in footnote b. Here the wind speed average is described as based on a Rayleigh distribution. The Rayleigh distribution tells us what percentage of the total time is spent at each wind speed. Equation 2 is the formula for this distribution.

Equation 2. Rayleigh distribution[4]

$$f(V_R) = dV\left(\frac{\pi}{2}\right)\left(\frac{V}{V_{avg}^2}\right)\exp\left[-\frac{\pi}{4}\left(\frac{V}{V_{avg}}\right)^2\right]$$

Where
$f(V_R)$ is the ratio of the amount of time wind will occur at speed V
dV is the granularity of the wind speed (ex. dV of 2 would calculate ratios at 0, 2, 4, 6, 8, … etc.)
V is the speed the time ratio is requested at
V_{avg} is the average wind speed from Table 1

The Rayleigh distribution will give approximate results for most of North America. Large differences from this approximation can occur based on local terrain. Calculated values are shown in Table 2.

Now that we have an estimate of the wind speed throughout the day, we can apply it to a specific wind turbine. Manufacturers supply power curves for their wind turbines. These allow a person to determine the amount of power a wind turbine will make at a certain wind speed. An example power curve is shown in Figure 1 for a wind turbine with a blade diameter of 23 feet.

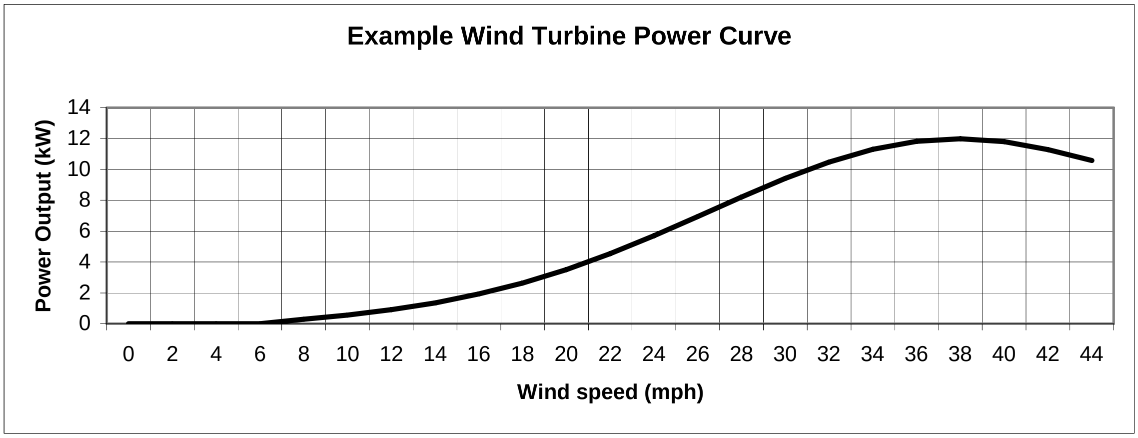

Figure 1. Example wind turbine power curve.

The cut-in speed for the example turbine is about 8 mph. At wind speeds lower then this, no power will be generated. At 40 mph the power output begins to drop. This is due to furling, or the wind turbine turning out of the wind to avoid over speed damage. Performance could be extended to higher speeds, but performance and lower speeds would suffer. The example turbine design is the best overall solution since the majority of time is spent at lower wind speeds.

Putting the wind speeds and example power curve together gives us an estimated power output, shown in Table 2. Column 2 is calculated from Equation 2 based on the values of Column 1. Column 3 is Column 2 multiplied by 8760 hours, to obtain the number of hours per year the turbine will be operating at each speed. The values in Column 4 are taken from the power curve in Figure 1.

Table 2. Estimated power generation for example turbine power curve.

Wind speed (mph)	Ratio of time at speed (Rayleigh)	Time per year at speed (hrs)	Power at speed (kW)	Annual Energy Output (kWh/yr)
1	0.012898	112.985	0	0
2	0.025298	221.612	0	0
3	0.036735	321.802	0	0
4	0.046805	410.011	0	0
5	0.055186	483.431	0	0
6	0.061660	540.141	0	0
7	0.066116	579.172	0	0
8	0.068551	600.503	0.284	170.510
9	0.069062	604.986	0.420	254.334
10	0.067833	594.214	0.570	338.600
11	0.065108	570.344	0.735	419.033
12	0.061177	535.907	0.918	492.172
13	0.056347	493.603	1.125	555.207
14	0.050927	446.119	1.358	605.854
15	0.045202	395.972	1.622	642.315
16	0.039428	345.386	1.921	663.354
17	0.033815	296.216	2.256	668.410
18	0.028528	249.901	2.632	657.717
19	0.023683	207.466	3.048	632.355
20	0.019354	169.545	3.505	594.211
21	0.015574	136.426	4.001	545.832
22	0.012342	108.115	4.534	490.202
23	0.009635	84.399	5.100	430.464
24	0.007410	64.913	5.695	369.650
25	0.005616	49.196	6.310	310.445
26	0.004195	36.745	6.940	255.014
27	0.003088	27.051	7.575	204.917
28	0.002241	19.631	8.206	161.090
29	0.001603	14.044	8.822	123.902
30	0.001131	9.906	9.413	93.247
31	0.000786	6.889	9.968	68.671
32	0.000539	4.725	10.474	49.489
33	0.000365	3.195	10.923	34.902
34	0.000243	2.131	11.303	24.088
35	0.000160	1.402	11.607	16.270
36	0.000104	0.909	11.826	10.754
37	0.000066	0.582	11.955	6.957
38	0.000042	0.367	11.991	4.405
39	0.000026	0.229	11.936	2.730
40	0.000016	0.140	11.792	1.656
41	0.000010	0.085	11.569	0.985
42	0.000006	0.051	11.278	0.574
43	0.000003	0.030	10.939	0.328
44	0.000002	0.017	10.576	0.185
Total	1.000000	8760		9901

Notes:
(a) The values above 44 mph are not included as the amount of time at these higher speeds is very small.
(b) There are 8760 hours in a year
(c) Based on average wind speed of 11 mph

From Table 2 it is estimated that the example wind turbine would produce 9901 kWh of electricity in an average year in a class 2 power area. This estimated power is for a height of 33 feet. Reviewing Table 1 shows average wind speeds at 33 feet and 164 feet for each power class. Notice that the power density doubles between the two heights. Wind speeds at heights different from the original measured value can be found by using Equation 3.

Equation 3. Height and wind velocity equation for undisturbed air.[2]

$$\frac{P_r}{P_a} = \left(\frac{Z_r}{Z_a}\right)^{\left(3*\frac{1}{7}\right)}$$

Where

Pr,Pa are wind power densities at heights Zr, Za

At a height of 164 feet in a power class of 2, the example turbine will generate an estimated 18,267 kWh of electricity, or almost twice the amount as at 33 feet. Both power estimates assume no wind obstructions from trees or buildings etc. The rule of thumb to avoid obstructions states that wind turbines should be installed at least 30 feet above any obstruction within 200 feet of the tower.[1]

The estimated power is somewhat lower then would be expected if derived from the power densities in Table 1 for both heights. This happens in reality because of physical limitations of the rotor. A discussion of this phenomenon and the related formulas for calculating the power can be found here. There is also a loss in the generator part of the turbine. Typical peak efficiencies for the complete unit are less then 30%, and decrease when not at the optimum wind speed.

Measuring the Proposed Site

It cannot be stressed enough how important it is to measure the wind speed at the proposed site. Measurement for one day is not enough. Measurement for one month is not enough. One year is probably a good time period if additional data is available. An example measured wind speed graph is shown in Figure 2 for the airport at Champaign, Illinois. This data contains the average and maximum wind speed for each day of 2005.

Figure 2. shows us that the maximum and average wind speeds change from season to season. It also gives lower values for wind speed then would be expected from Table 1. The main reason for this is probably the location of the anemometer (wind speed measuring device). Trees, buildings, or other obstacles may be obstructing the wind.

Data from other local sources is very beneficial because it can be compared to the measured data at the proposed site to establish a difference factor between the two. Once the difference factor is found, all of the historical data from the local source can be converted to approximate what would be seen at the proposed site.

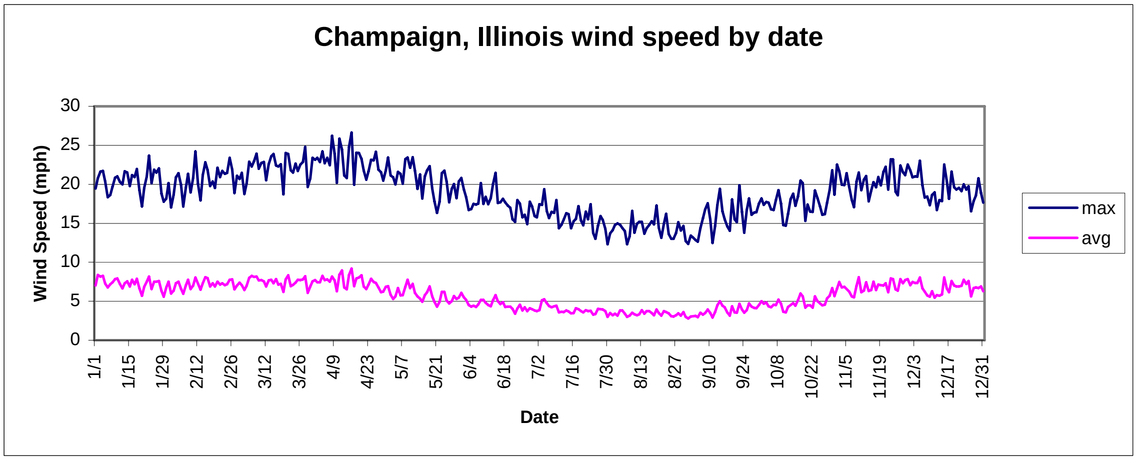

Figure 2. Maximum and average wind speed for Champaign, Illinois 1989-2005 at 33 feet.

Another important item to take into consideration is the tower. This is what the wind turbine itself will be mounted on. For wind speeds, the higher the better but there are other factors to include when selecting height. The fall zone is the area impacted if the tower was to fall. It is the height of the tower is all directions from the base. Local regulations usually require that no buildings can be located in this zone. For a 100 foot tower, the fall zone will cover approximately 1 acre.

Noise can also be a factor in tower location. Some smaller turbines are designed to be quite, but this depends on the brand. Larger turbines need higher speeds to be efficient and this can lead to noisier operation. The manufacturer should be consulted for each specific turbine.

Components of a wind power system

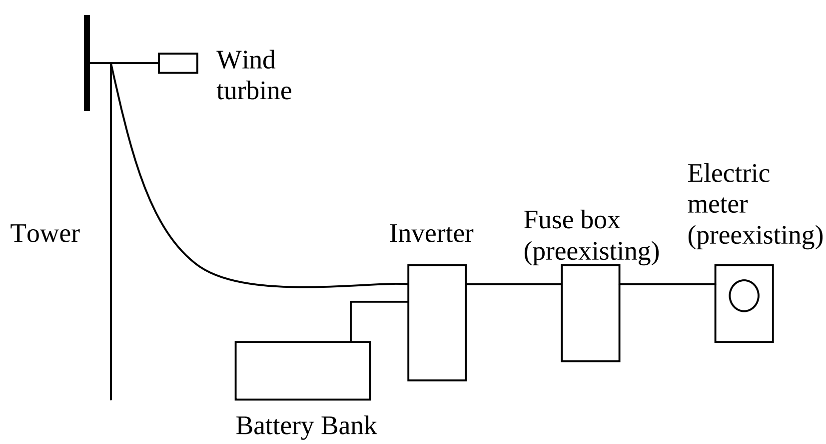

Figure 3. An example of a wind power system.

Tower: The tower is the supporting structure for the wind turbine.

Wind Turbine: Generates power and the most noticeable part of the wind power system.

Battery Bank: Multiple batteries used for energy storage, Optional.

Inverter: Converts voltage from the wind turbine to set value (for example, 120 volts) and maintains voltage.

The power produced by the wind turbine is not user friendly. Varying wind speeds produce different line currents and voltages. These variations would cause light bulbs to flicker, and damage to electronic devices. This type of current is termed “Wild Power”. In order to tame this power, there are several options. The two that are most practical are using a Battery Bank or connecting the wind turbine to the power grid through a special type of inverter.

Battery bank:

- Requires routine maintenance
- Batteries last a finite amount of time
- Require a specialized enclosure because explosive hydrogen gas is created
- Addition dummy load is needed to load wind turbine when batteries are full
- Provides power when electric grid is down

Power grid connection

- Grid serves as battery
- Inverter must shut off power when grid power not available (not turning off power could result in live wires without utility knowledge)
- Subtracts usage directly from utility bill
- Excess power purchased at wholesale rate by utility
- Monthly connection fee must be paid by excess power generation before wind energy customer is due money

Battery bank and Power grid connection

- High initial cost
- All other points apply, except power is available when there is no grid power

Incentives

Federal:
EPact 2005 offers a tax credit of 10% up to up to $200/kW for micro wind turbines. This credit is only applicable to businesses, and the wind turbine must be 26% efficient and be rated less then 2000kW.

State of Illinois:
Currently, Illinois has grants available for renewable energy. These are described on the DSIRE web site. Illinois does not have a net metering law. Some utilities, such as Commonwealth Edison do offer net metering. Contact your local utility for more information.

References:

1. Schaeffer, John, *Solar Living Source Book*, (White River Junction, VT.: Chelsea Green, 2001).
2. National Renewable Energy Laboratory (NREL): rredc.nrel.gov/wind/
3. Water and Atmospheric Resources Monitoring Program. Illinois Climate Network. (2006). Illinois State Water Survey, 2204 Griffith Drive, Champaign, IL 61820
4. Gipe, Paul, *Wind Power*, (White River Junction, VT.: Chelsea Green, 2004).