Course: Sustainable Energy Technology 1
12150310

Title: Wind Energy –L2

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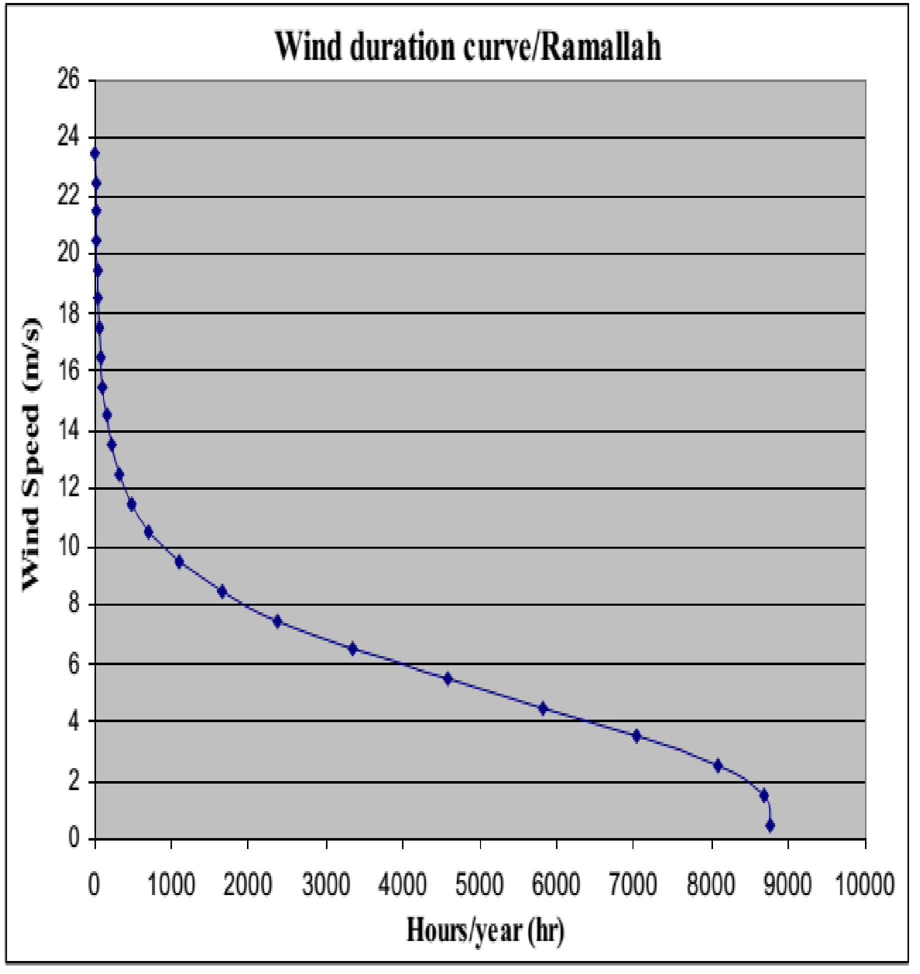
Wind Energy

Wind Speed Measurement (Ramallah):

Speed range (m/s)	Mid range (m/s)	Duration (hours)	Occurrence percentage (%)
0-1	0.5	82	0.936
1-2	1.5	589	6.724
2-3	2.5	1058	12.078
3-4	3.5	1209	13.801
4-5	4.5	1242	14.178
5-6	5.5	1240	14.155
6-7	6.5	961	10.970
7-8	7.5	728	8.311
8-9	8.5	563	6.427
9-10	9.5	390	4.452
10-11	10.5	218	2.489
11-12	11.5	159	1.815
12-13	12.5	103	1.176
13-14	13.5	60	0.685
14-15	14.5	56	0.639
15-16	15.5	28	0.320
16-17	16.5	15	0.171
17-18	17.5	14	0.160
18-19	18.5	10	0.114
19-20	19.5	9	0.103
20-21	20.5	4	0.046
21-22	21.5	7	0.080
22-23	22.5	7	0.080
23-24	23.5	8	0.091
Sum		8760	100%

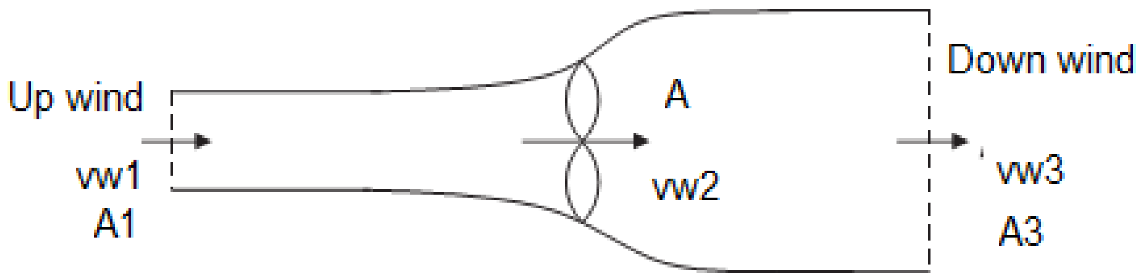
Speed range (m/s)	Mid range (m/s)	Duration (hours)	Commultive Duration (Hours)
23-24	23.5	8	8
22-23	22.5	7	15
21-22	21.5	7	22
20-21	20.5	4	26
19-20	19.5	9	35
18-19	18.5	10	45
17-18	17.5	14	59
16-17	16.5	15	74
15-16	15.5	28	102
14-15	14.5	56	158
13-14	13.5	60	218
12-13	12.5	103	321
11-12	11.5	159	480
10-11	10.5	218	698
9-10	9.5	390	1088
8-9	8.5	563	1651
7-8	7.5	728	2379
6-7	6.5	961	3340
5-6	5.5	1240	4580
4-5	4.5	1242	5822
3-4	3.5	1209	7031
2-3	2.5	1058	8089
1-2	1.5	589	8678
0-1	0.5	82	8760
Sum		8760	



Wind Energy

Wind Power:

It is the power extracted from wind by delaying mass of wind.



$$E_{kin} = 0.5\, m_{air}\, v_w^2$$

$$E_{kin} = 0.5\, \rho\, V\, v_w^2$$

ρ Air density

V Volume

v_w Wind speed

m_{air} Air mass

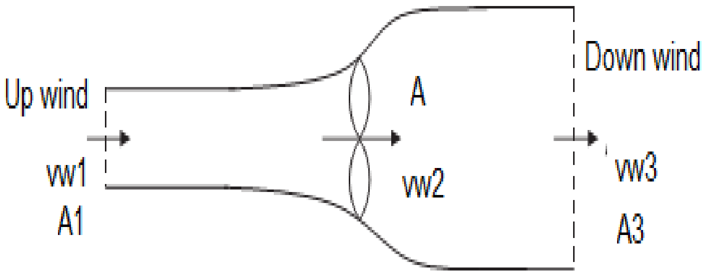
$$P = \frac{d(\Delta E_{kin})}{dt} = 0.5\, \rho\, (v_{w_1}^2 - v_{w_3}^2)\, \frac{dV}{dt} = 0.5\, \rho\, (v_{w_1}^2 - v_{w_3}^2)\, A\, v_{w_2}$$

Wind Energy

According to aerodynamic theorem:

Pmax of wind power extraction from wind turbine occurs when

$v_{w2} = (2/3)\, v_{w1}$ and $v_{w3} = (1/3)\, v_{w1}$



$$P_{max} = \frac{16}{27}\, 0.5\, \rho\, A\, v_{w1}^{3}$$

$\frac{16}{27}$ is the Pitz number = 59.3%

$$P_{in} = 0.5\, \rho\, A\, v_{w1}^{3}$$

P_{in} is the input power in wind (available power in wind)

Cp is the coeffecient performance or can be defined as

$$\eta_{tur} = \frac{P_{out}}{P_{in}}$$

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Tip Speed Ratio:

It is given by dividing the speed of the tips of the turbine blades by the speed of the wind.

For a given wind speed, rotor efficiency is a function of the rate at which the rotor turns.

If the rotor turns too slowly, the efficiency drops off since the blades are letting too much wind pass by unaffected.

If the rotor turns too fast, efficiency is reduced as the turbulence caused by one blade increasingly affects the blade that follows.

The usual way to illustrate rotor efficiency is to present it as a function of its tip-speed ratio (TSR).

$$\text{Tip-Speed-Ratio (TSR)} = \frac{\text{Rotor tip speed}}{\text{Wind speed}} = \frac{\text{rpm} \times \pi D}{60\, v_w}$$

where rpm is the rotor speed, revolutions per minute; D is the rotor diameter (m); and v is the wind speed (m/s) upwind of the turbine.

η_{tur} is function of TSR

Solidity of the machine = Area of the baldes / Captured area and it is function of TSR

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Optimum Tip Speed Ratio

- The optimum tip speed ratio depends on the number of blades in the wind turbine rotor. The fewer the number of blades, the faster the wind turbine rotor needs to turn to extract maximum power from the wind.
- A two-bladed rotor has an optimum tip speed ratio of around 6, a three-bladed rotor around 5, and a four-bladed rotor around 3**.**

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Example 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. Estimate the windspeed and the specific power in the wind at a height of 50 m. The friction coefficient α for ground with hedges is estimated to be 0.20 The air density $\rho = 1.225\ \text{kg/m}^3$.

$$\left(\frac{v}{v_0}\right) = \left(\frac{H}{H_0}\right)^{\alpha}$$

$$v_{50} = 5 \cdot \left(\frac{50}{10}\right)^{0.20} = 6.9\ \text{m/s}$$

Specific power will be

$$P_{50} = \tfrac{1}{2}\rho v^3 = 0.5 \times 1.225 \times 6.9^3 = 201\ \text{W/m}^2$$

That turns out to be more than two and one-half times as much power as the 76.5 W/m^2 available at 10 m.

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

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Example 2:

A 40-m, three bladed wind turbine produces 600 kW at a windspeed of 14 m/s. Air density is the standard 1.225 kg/m^3. Under these conditions,

a. At what rpm does the rotor turn when it operates with a TSR of 4.0?
b. What is the tip speed of the rotor?
c. If the generator needs to turn at 1800 rpm, what gear ratio is needed to match the rotor speed to the generator speed?
d. What is the efficiency of the complete wind turbine (blades, gear box, generator) under these conditions?

Solution

a.
$$\text{rpm} = \frac{\text{TSR} \times 60\ v}{\pi D} = \frac{4 \times 60\ \text{s/min} \times 14\ \text{m/s}}{40\pi\ \text{m/rev}} = 26.7\ \text{rev/min}$$

That's about 2.2 seconds per revolution . . . pretty slow!

b. The tip of each blade is moving at

$$\text{Tip speed} = \frac{26.7\ \text{rev/min} \times \pi 40\ \text{m/rev}}{60\ \text{s/ min}} = 55.9\ \text{m/s}$$

Notice that even though 2.2 s/rev sounds slow; the tip of the blade is moving at a rapid 55.9 m/s, or 125 mph.

Wind Energy

Example 2:

c. If the generator needs to spin at 1800 rpm, then the gear box in the nacelle must increase the rotor shaft speed by a factor of

$$\text{Gear ratio} = \frac{\text{Generator rpm}}{\text{Rotor rpm}} = \frac{1800}{26.7} = 67.4$$

d. The power in the wind is

$$P_w = \frac{1}{2}\rho A v_w{}^3 = \frac{1}{2} \times 1.225 \times \frac{\pi}{4} \times 40^2 \times 14^3 = 2112 \text{ kW}$$

so the overall efficiency of the wind turbine, from wind to electricity, is

$$\text{Overall efficiency} = \frac{600 \text{ kW}}{2112 \text{ kW}} = 0.284 = 28.4\%$$

Notice that if the rotor itself is about 43% efficient, then the efficiency of the gear box times the efficiency of the generator would be about 66% (43% × 66% = 28.4%).