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Wind Energy

Wind Energy – The Facts

- **Wind energy comes from a series of energy transformations from solar energy (radiation) to wind energy (kinetic).**
- **About 2% of the solar energy absorbed by the earth goes into wind.**
- **Solar radiation is absorbed by the surface of the earth and heats it unevenly.**

Wind Energy – The Facts

- **Land heats up faster than water does, but also loses heat faster (inland vs. coast).**
- **These differences in air temperature across the globe can create wind!**

Wind Energy – The Facts

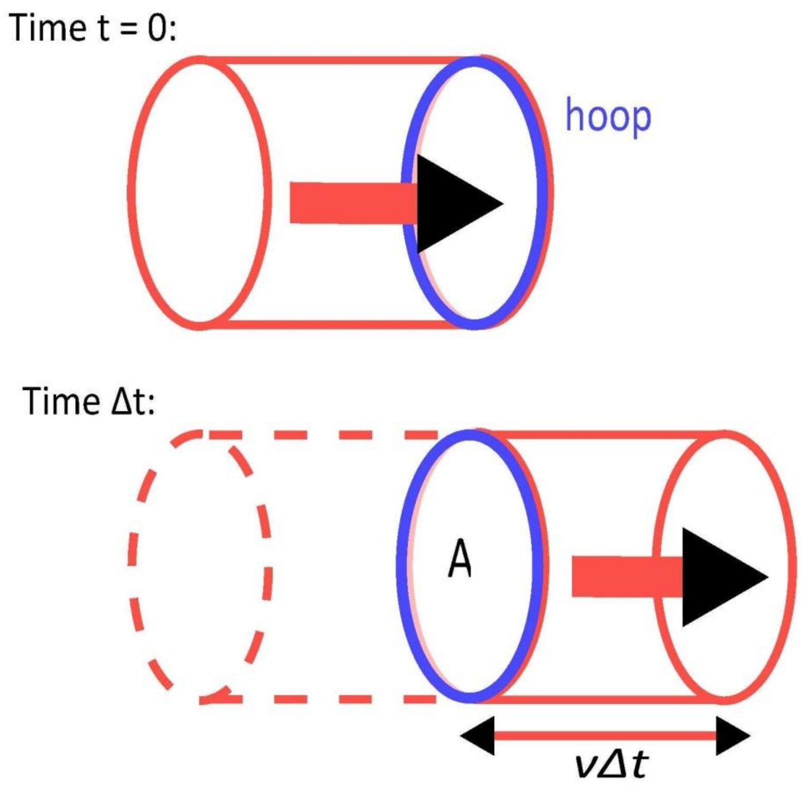
- **To calculate the power extracted from wind, calculate kinetic energy, KE where:**

  KE = ½*mv*^{2} of air passing through the rotor of the wind turbine.

- **To do that we need to measure the mass of air travelling through the area of circle swept out by rotor blades in time *Δt*.**

Wind Energy – The Facts

At time $t = 0$, the mass of air is just about to pass through the hoop, but Δt later, the mass of air has passed through the hoop. The mass of this piece of air is the product of its density ρ, area A, and length $v \cdot \Delta t$.



Wind Energy – The Facts

From this you can find the mass...

$$Mass = density \cdot volume$$

$$= \rho A v \Delta t$$

ρ is the density of the air (1.2 kg/m^3 for standard temperature and pressure)

v is the average velocity of the air passing through the wind turbine, i.e.

Wind Energy – The Facts

$v = (v1 + v2)/2$

Where:

v1 is the speed of the wind just before entering the wind turbine

v2 is the speed of the wind just after leaving the wind turbine

Δt is the length of time for a unit of air to pass through the loop.

A is the area swept by the blades, not the blade area.

Wind Energy – The Facts

Therefore the kinetic energy, *K*, is found to be:

$$K = \frac{1}{2}mv^2 = \frac{1}{2}\rho A \Delta t v^3$$

while the power of the wind passing through our hoop, P, is:

$$P = \frac{1}{2}\frac{\rho A \Delta t v^3}{\Delta t} = \frac{1}{2}\rho A v^3$$

Wind Energy – Betz Law

Considering the ideal model of a wind turbine, shown in the following slide, the cross sectional area swept by the turbine blades is designated as S, with the air cross-section upwind from the rotor designated as S1 and downwind as S2. The wind speed passing through the turbine rotor is considered uniform as *v*, with its value as *v*1 upwind, and as *v*2 downwind at a distance from the rotor. Extraction of mechanical energy by the rotor occurs by reducing the kinetic energy of the air stream from upwind to downwind, or simply applying a braking action on the wind. This implies that:

$$v2 < v1$$

Consequently the air stream cross sectional area increases from upstream of the turbine to the downstream location, and:

$$S1 > S2$$

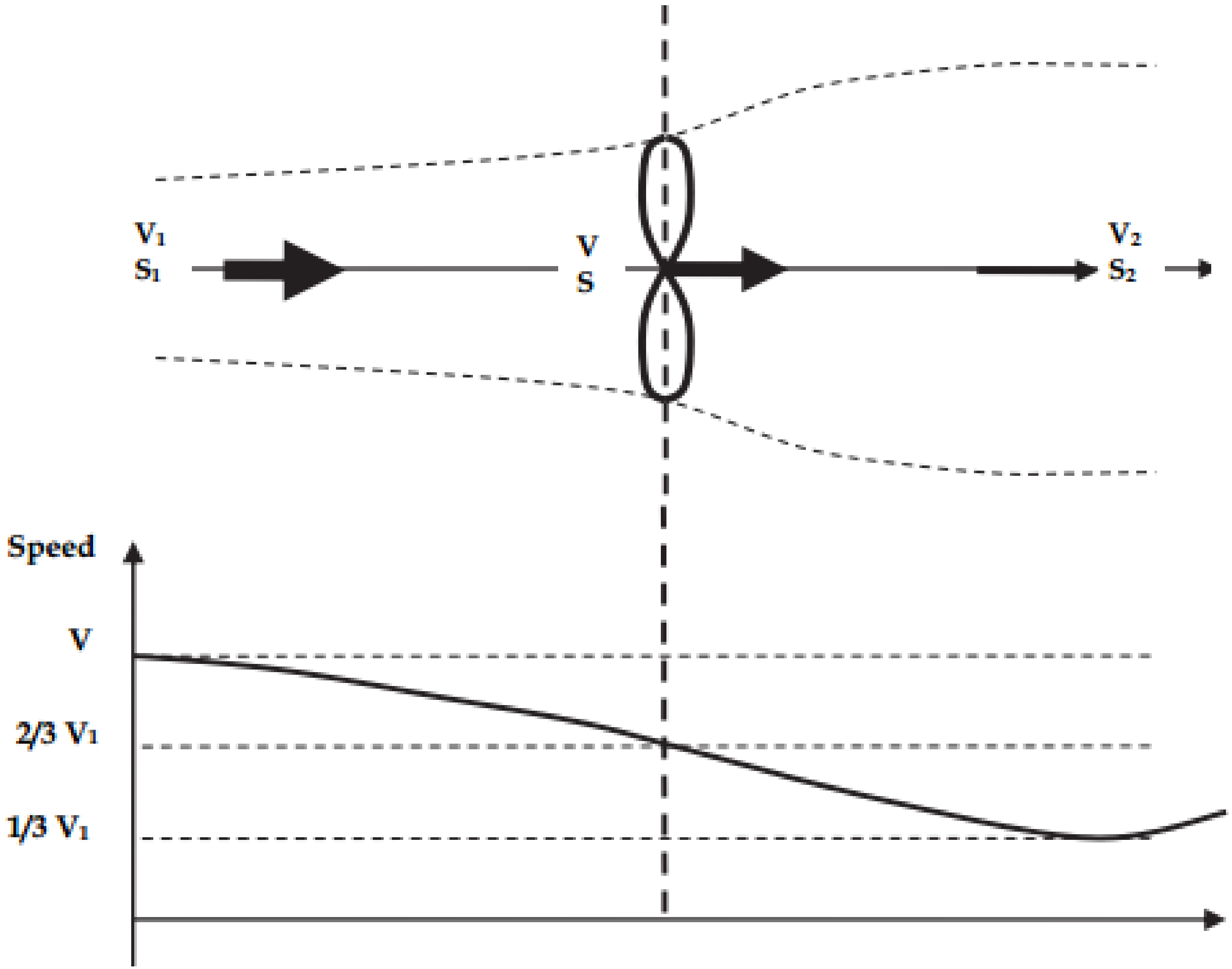


Fig. 1. Wind speed variation in an ideal model of a wind turbine.

Wind Energy – Betz Law

- This implies that wind turbines cannot extract all of the kinetic energy of the passing wind.

Why not?

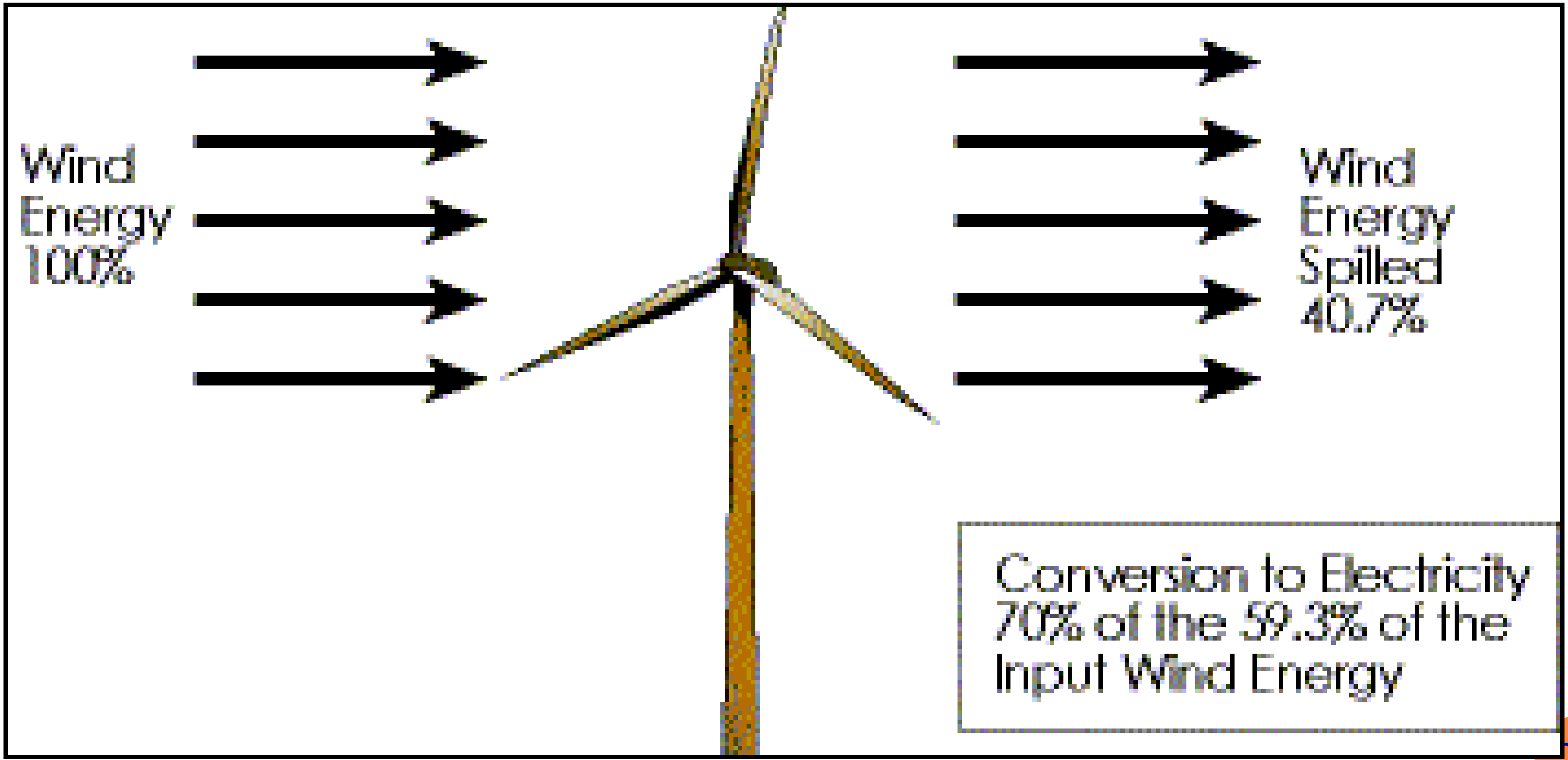
- If this was the possible the air would stop as soon as it passes through the blades and no other air would be able to pass through!!

Wind Energy – Betz Law

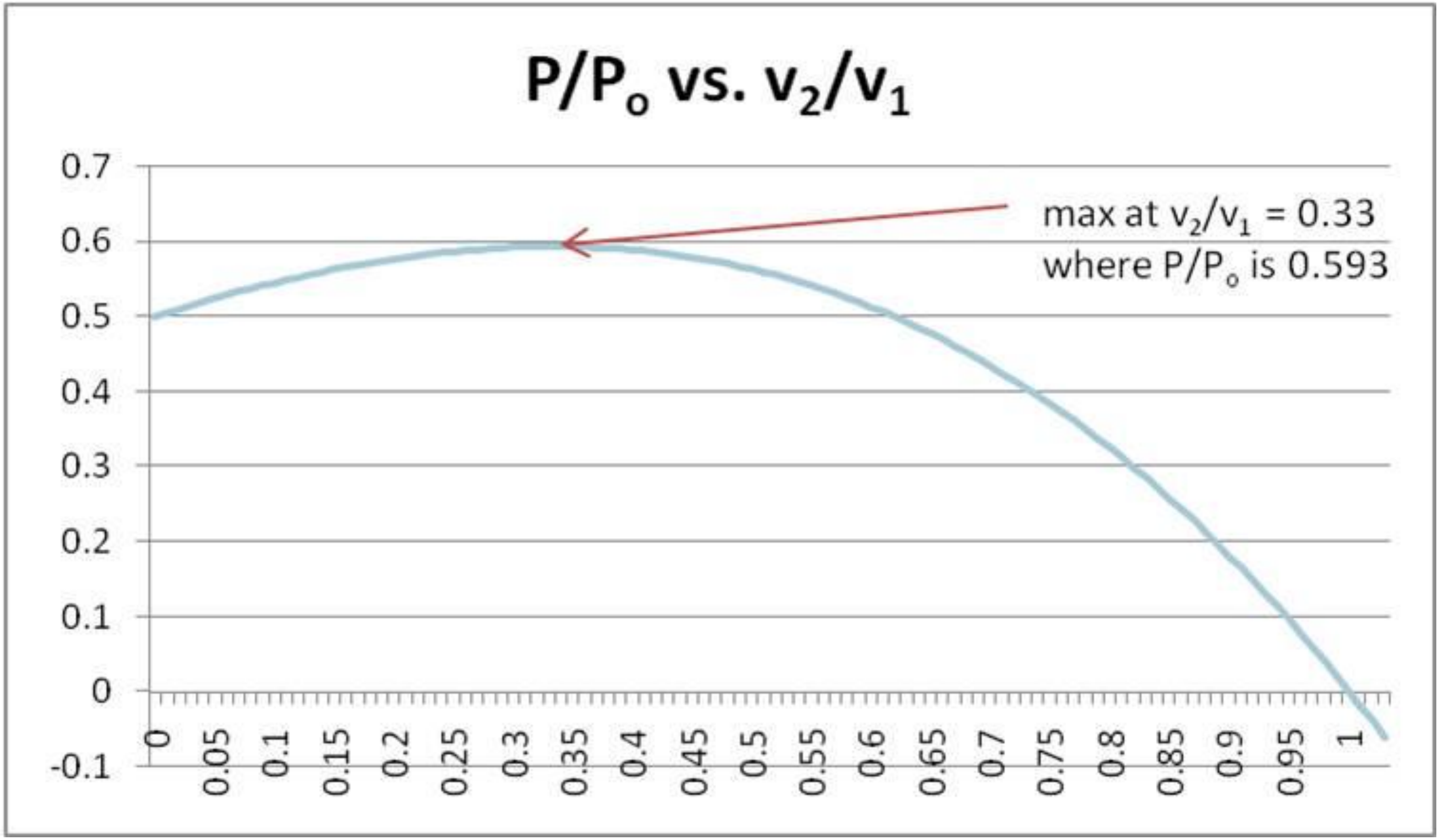
- **Betz (German Scientist) showed in 1919 that you cannot capture more than 59.3% (2/3) of the wind's energy (Betz, 1919).**
- **maximum ratio of P/P_0 = 2/3 is found at $v_2/v_1 \approx 1/3$.**
- **Ideally you want the turbine to slow the wind down by 2/3 of its original speed.**

Wind Energy – Betz Law

Interpretation of Betz Law for energy transfer in wind turbines



Wind Energy – Betz Law



This plot agrees with Betz's conclusions that the maximum power output of the turbine, Po, is 59.3% of the power input and this power occurs when v_2 (wind speed after leaving the turbine) is 1/3 of v_1 (wind speed at the turbine inlet)

Wind Energy – Output Power

Wind turbines are not 100% efficient:

Power = Efficiency x Max Power Extracted

$$P = \eta \frac{1}{2} \rho A v^3$$

$$= \eta \frac{1}{2} \rho v^3 \pi \left(\frac{d}{2} \right)^2$$

$$= \frac{1}{8} \eta \rho v^3 \pi d^2$$

where *d* is the diameter of the circle covered by the rotor.

Wind Energy – Output Power

- Therefore, power output of a wind turbine is proportional to:

$$\text{power} \ \alpha \ (\text{wind speed})^3$$

$$\text{power} \ \alpha \ (\text{blade diameter})^2$$

- The speed of the wind passing through the wind turbine should be, on average, at least 7 m/s at 25 m above the earth's surface in order to make harnessing wind from it worthwhile.

Rotor Blade Count

Wind turbines developed over the last 50 years have almost universally used either two or three blades. However, there are patents that present designs with additional blades. Aerodynamic efficiency increases with number of blades but with diminishing return. Increasing the number of blades from one to two yields a six percent increase in aerodynamic efficiency, whereas increasing the blade count from two to three yields only an additional three percent in efficiency. Further increasing the blade count yields minimal improvements in aerodynamic efficiency and sacrifices too much in blade stiffness as the blades become thinner

Wind Turbine Tower Height

Wind velocities increase at higher altitudes due to surface aerodynamic drag (by land or water surfaces) and the viscosity of the air. The variation in velocity with altitude, called wind shear, is most dramatic near the surface.

Typically, in daytime the variation follows the wind profile power law, which predicts that wind speed rises proportionally to the seventh root of altitude. Doubling the altitude of a turbine, then, increases the expected wind speeds by 10% and the expected power by 34%. To avoid buckling, doubling the tower height generally requires doubling the diameter of the tower as well, increasing the amount of material by a factor of at least four.

Rotor Blade Types

Three-Blade Rotors

• Popular design - about 95% of the current wind turbine are 3-rotor blade design

• Favorable mass distribution & less vibrations

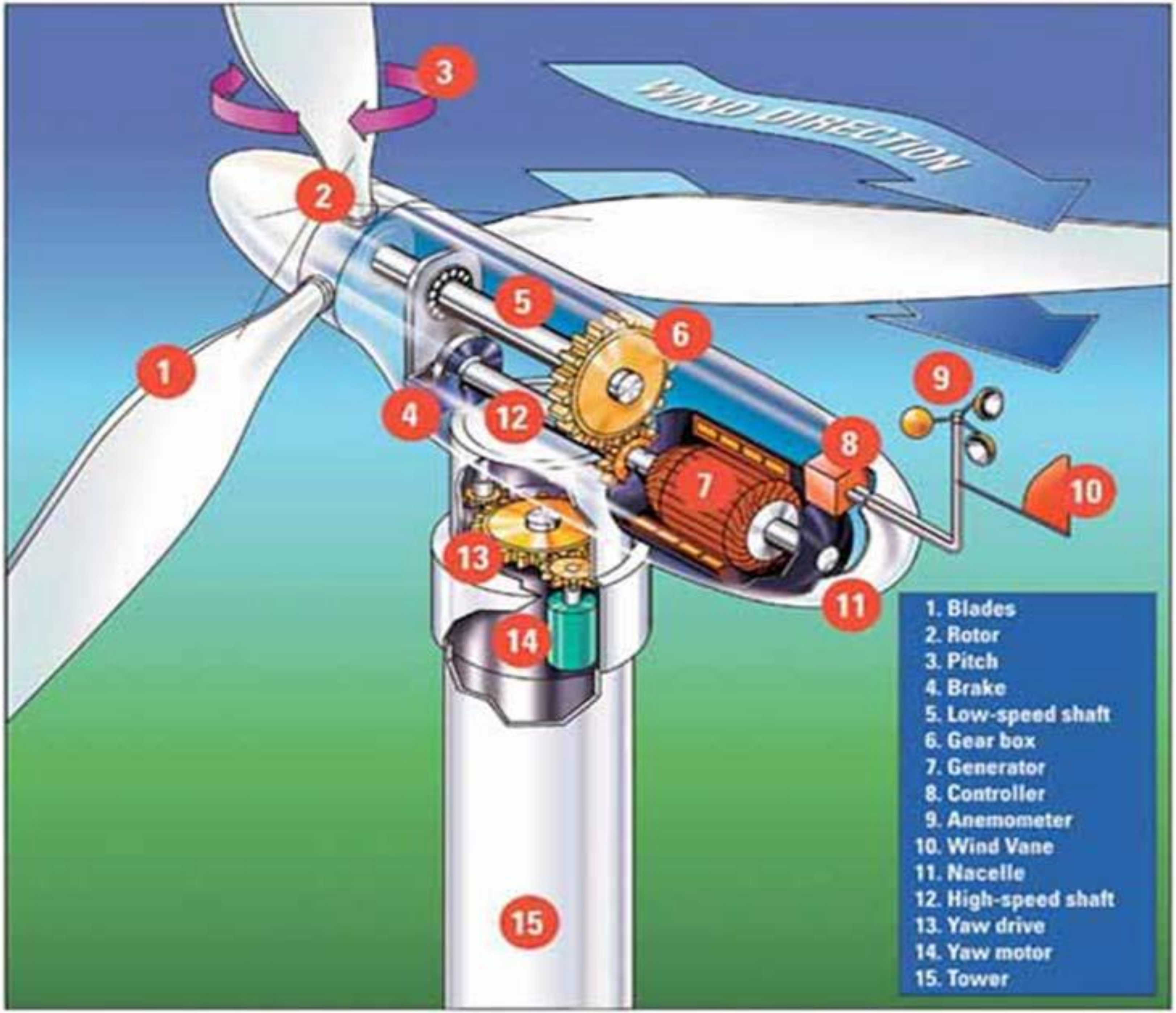
• No exaggerated noise

Two-Blade Rotors:

• Less material used

• More dynamic stresses on the hub & high vibrations

• More noise but still acceptable


WIND DIRECTION
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15
1. Blades
2. Rotor
3. Pitch
4. Brake
5. Low-speed shaft
6. Gear box
7. Generator
8. Controller
9. Anemometer
10. Wind Vane
11. Nacelle
12. High-speed shaft
13. Yaw drive
14. Yaw motor
15. Tower