Lecture#03

2.1 Introduction

2.2 Wind Turbine Components

2.2.1 Turbine Blade

2.2.2 Pitch Mechanism

2.2.3 Gearbox

2.2.4 Rotor Mechanical Brake

2.2.5 Generator

2.2.6 Yaw Drive

2.2.7 Tower and Foundation

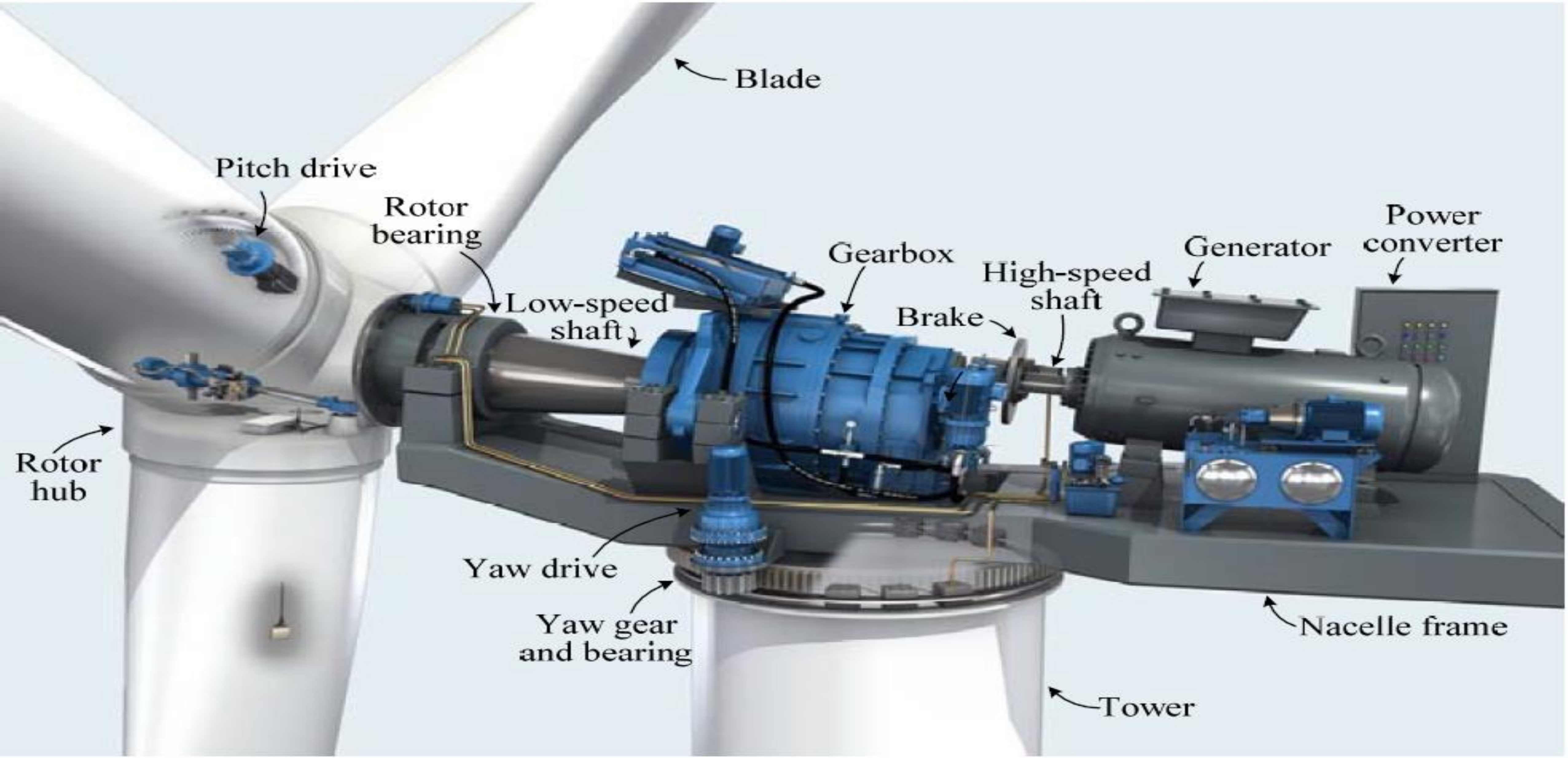
2.2.8 Wind Sensors (Anemometers)

2.1 Introduction

Q.What is the input power of generator?

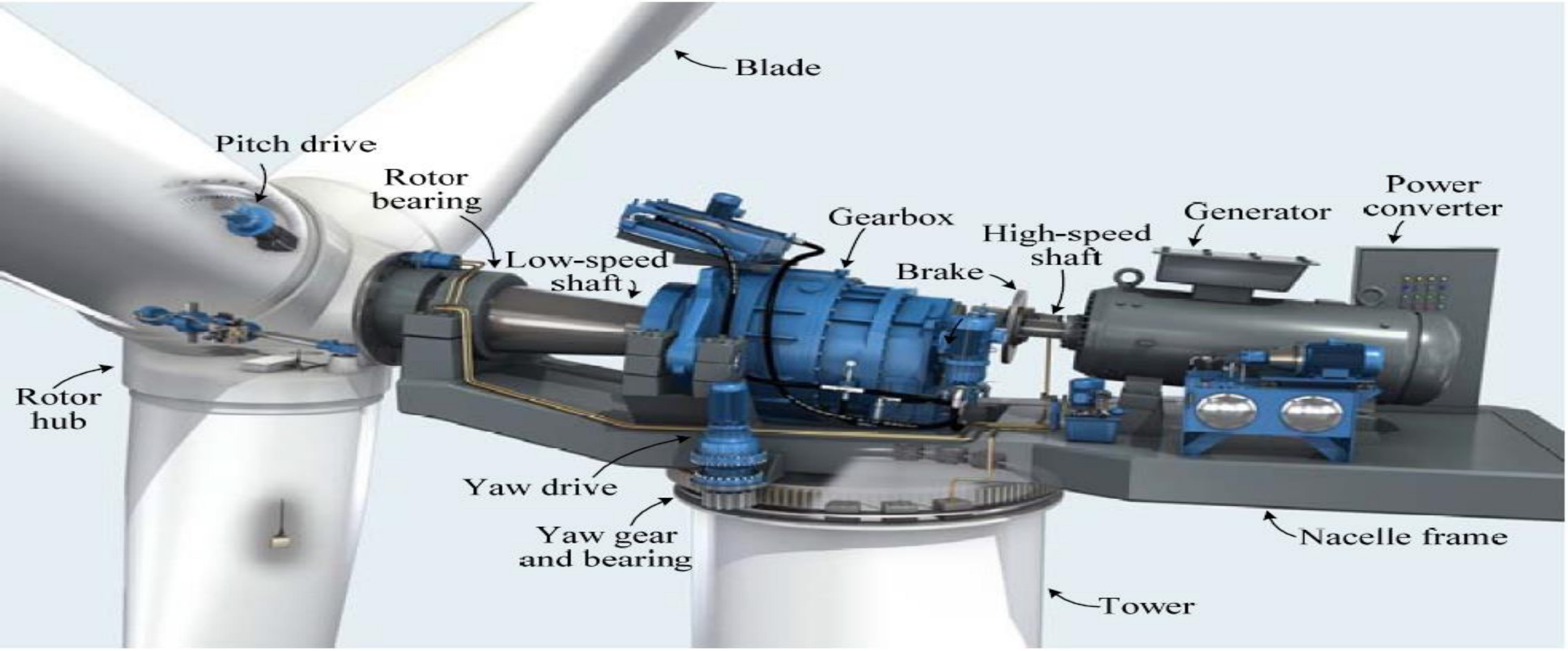
What is the function of Wind Energy Conversion System (WECS)?

Function of Wind Energy Conversion System (WECS)

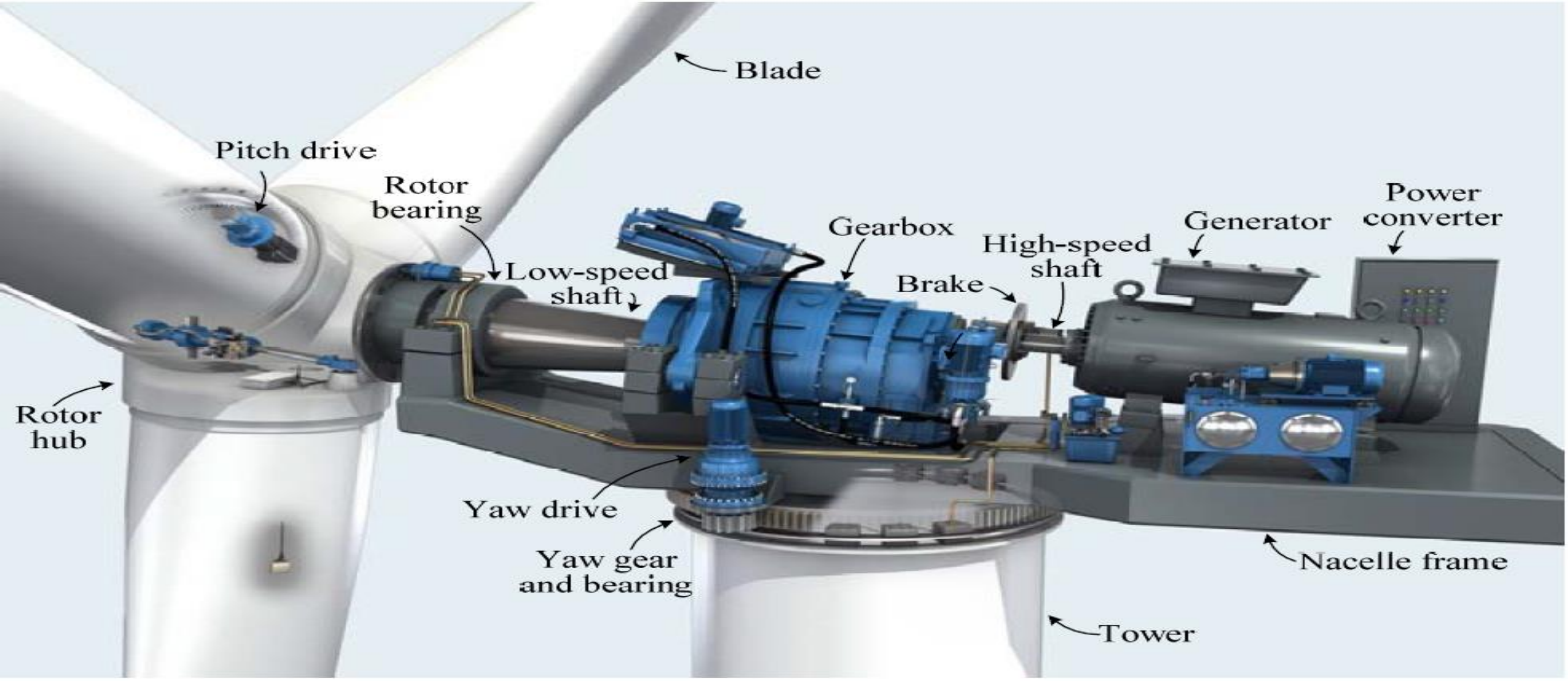


1st ----transforms wind kinetic energy to mechanical energy with the help of rotor blades,

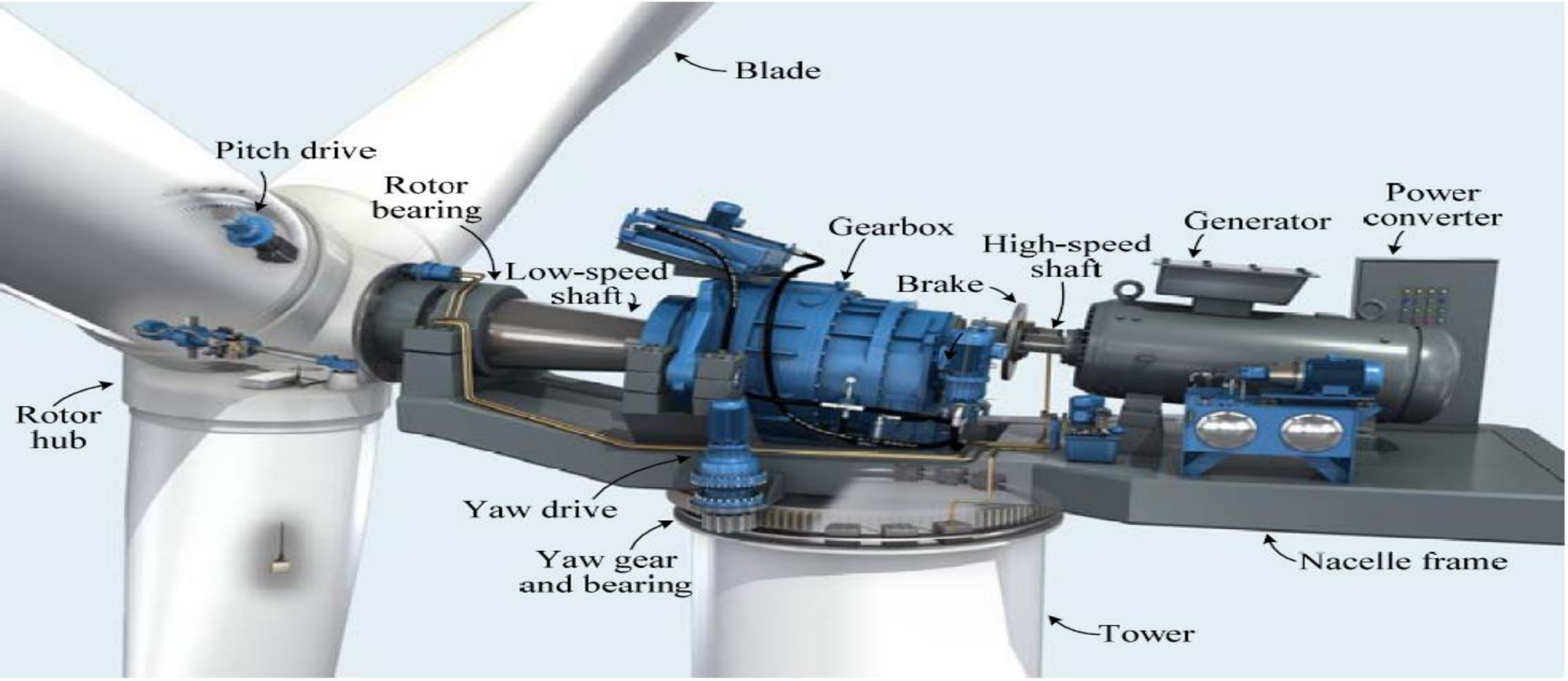
2nd---Mechanical energy is transformed to electric energy by a generator. (K.E…M.E…E.E)



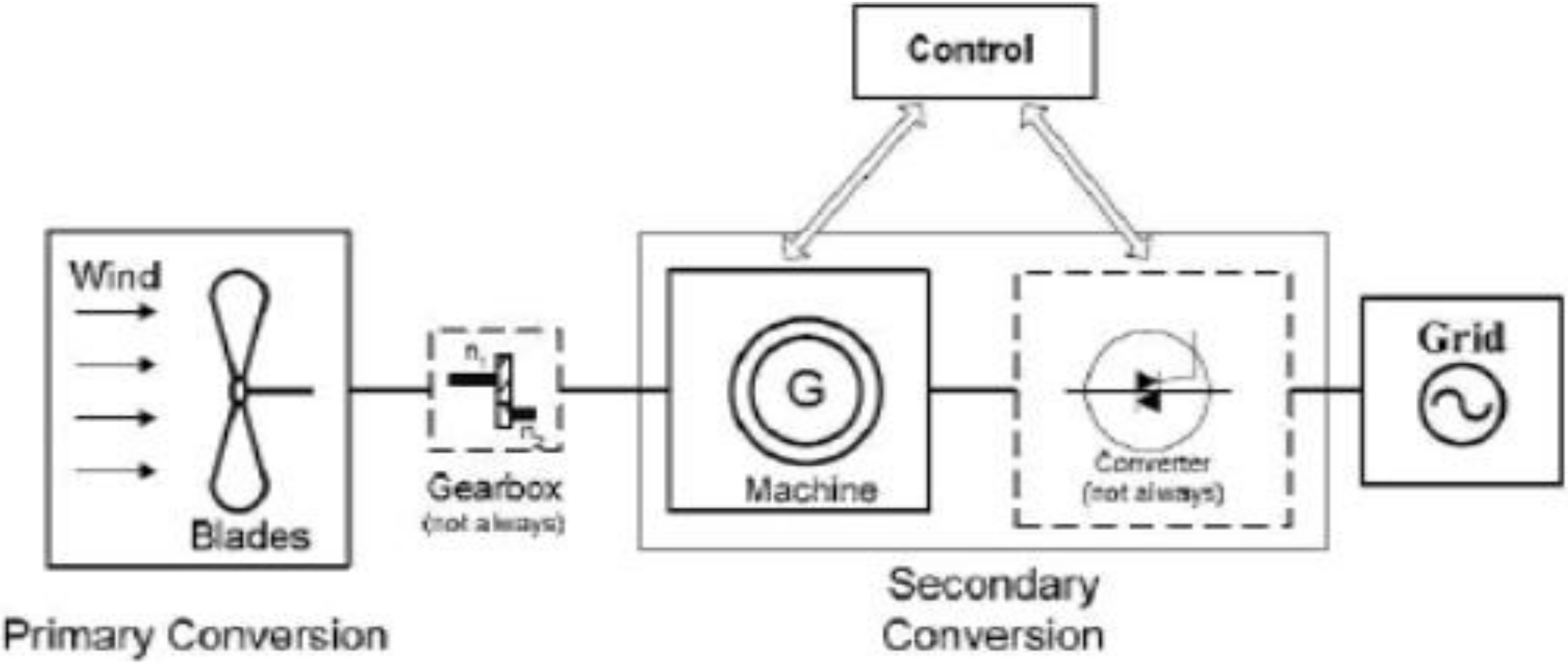
In the process of wind energy conversion several components, participate directly & indirectly



Other components also assist for controlled, reliable & efficient (CORE) operation.

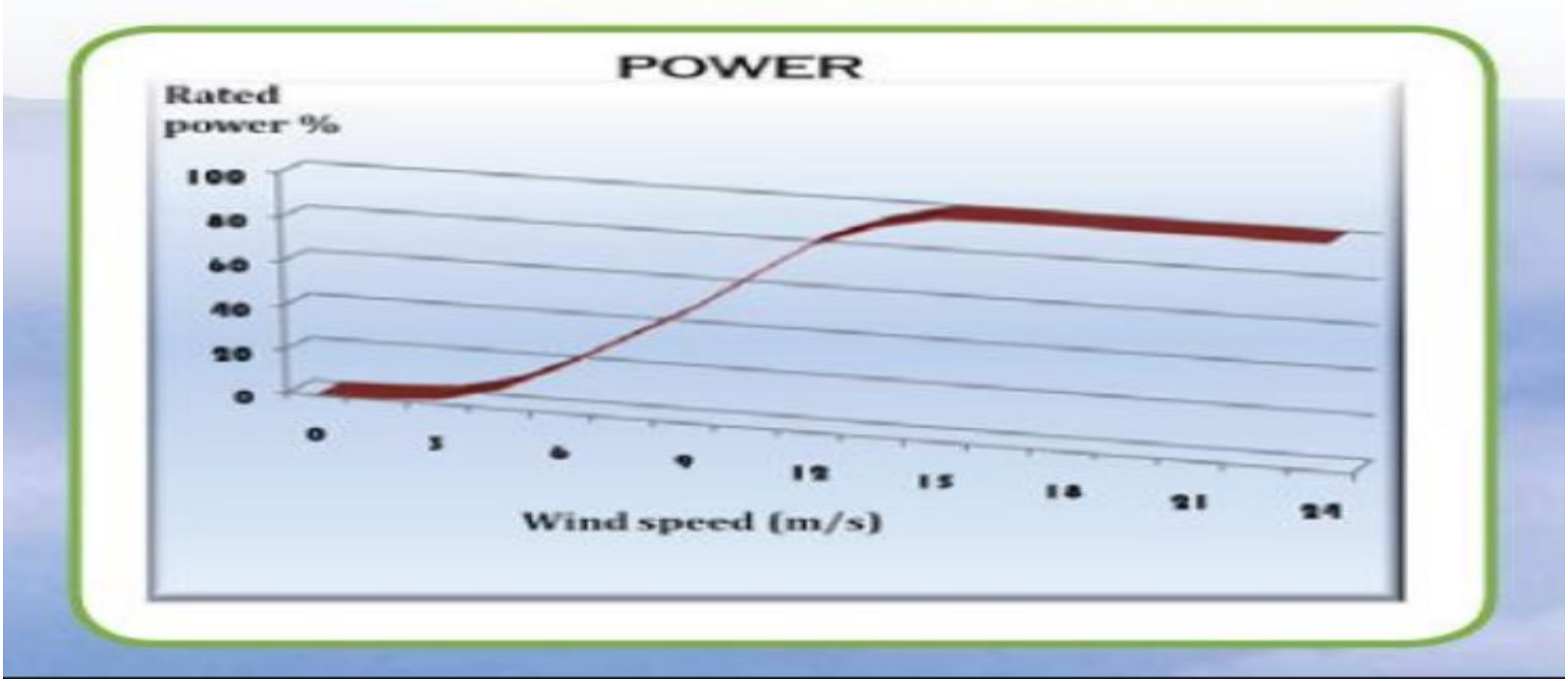


Energy source for a WECS is?



Wind kinetic energy

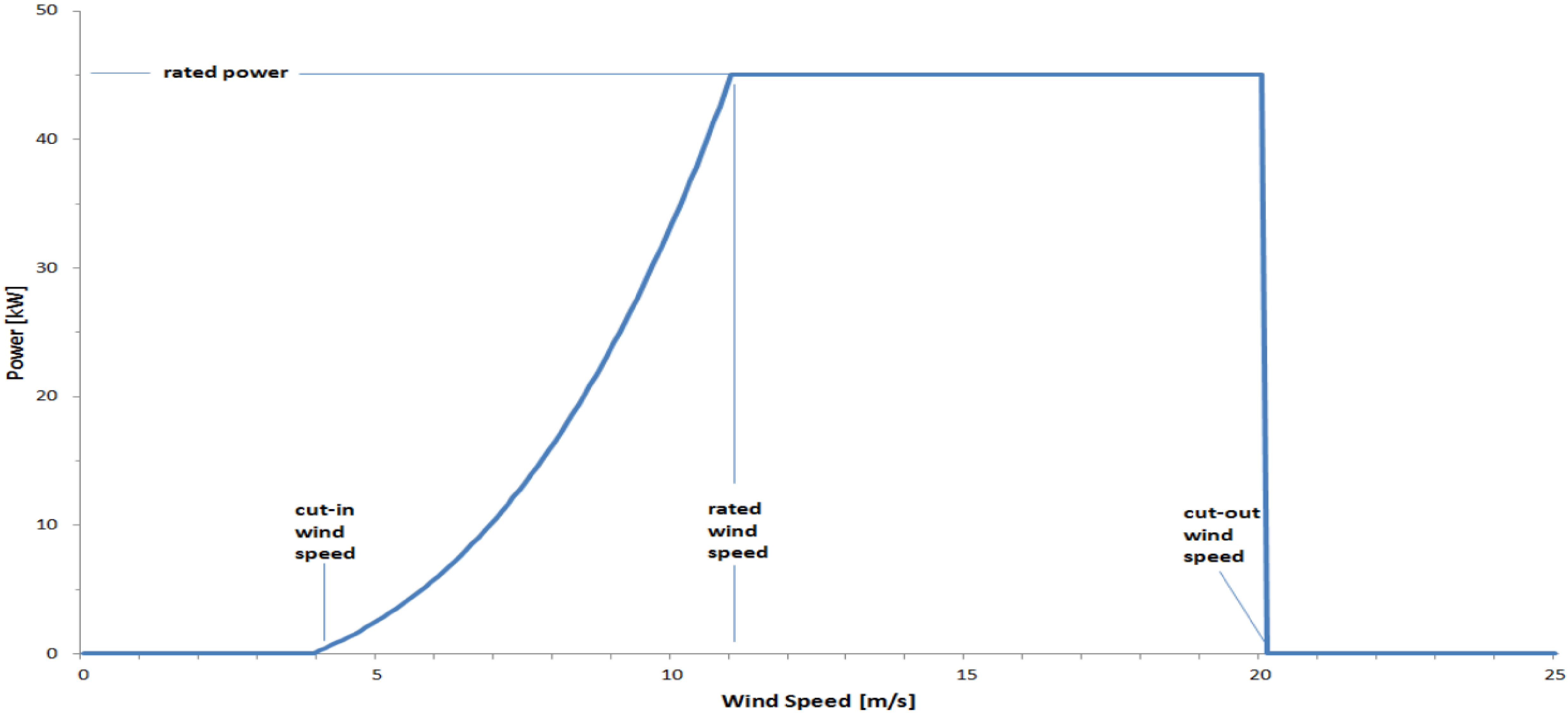
Wind speed plays a key role for maximum power output



Wind power is captured by blades. So there must be some relations between wind speed & power captured.

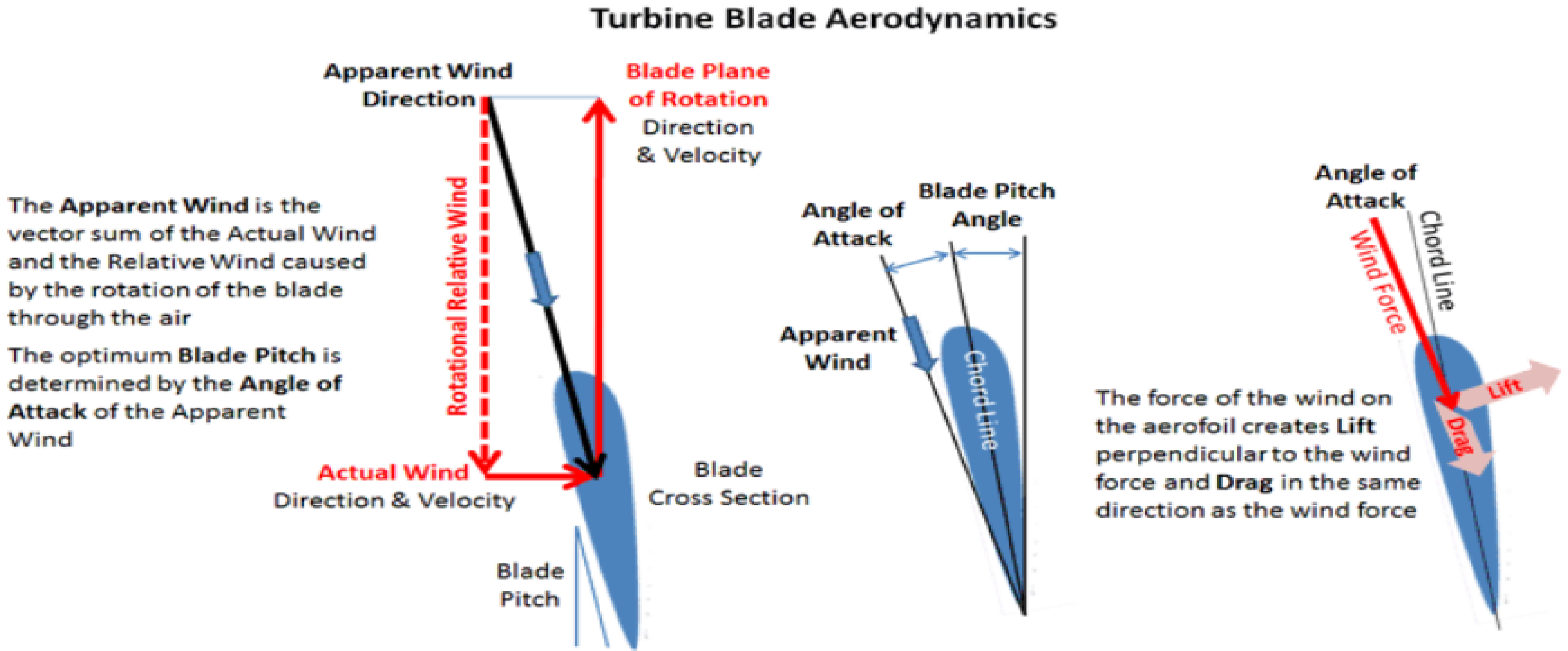
- Try to draw waveform(x-axis=wind speed in m/s) while on y-axis=Power in KW

Relations between wind speed & power captured.

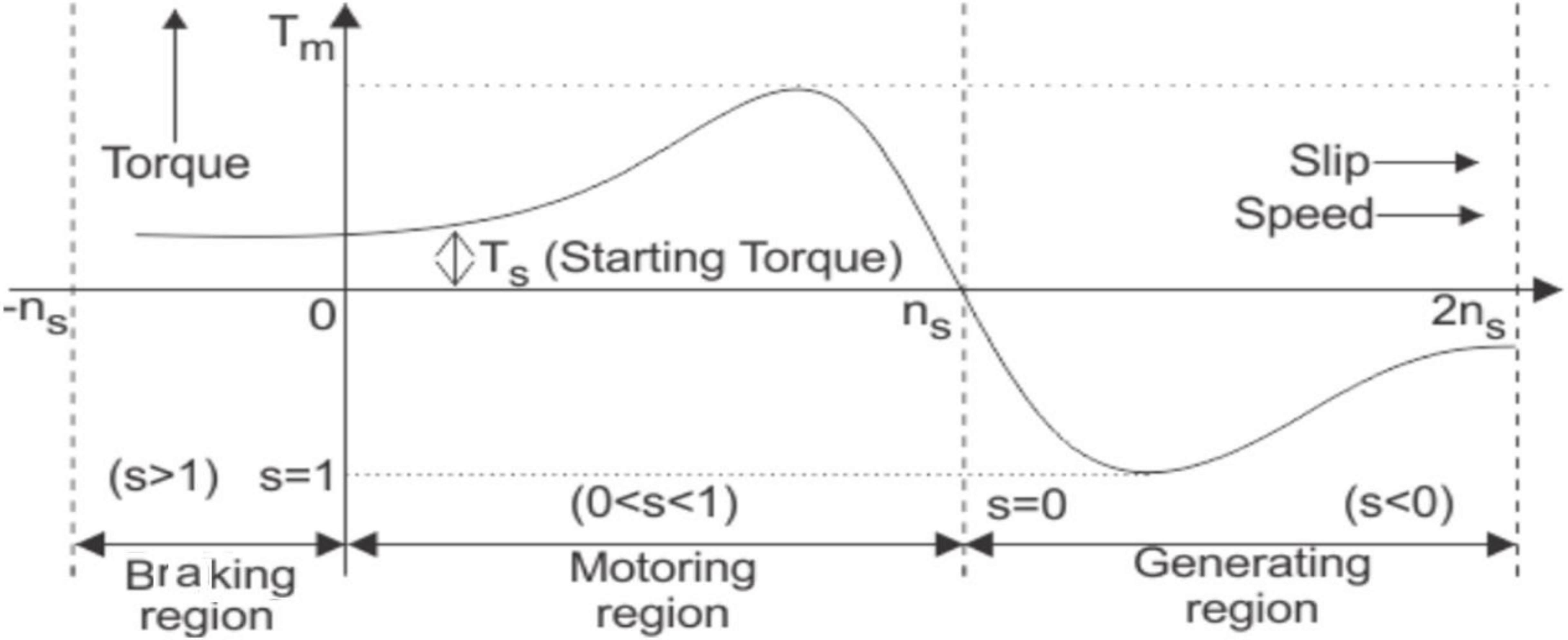


How to regulate power output of a wind turbine?

1. Adjusting blade pitch angle



2. Controlling generator's torque or speed.



Significance of power control methods

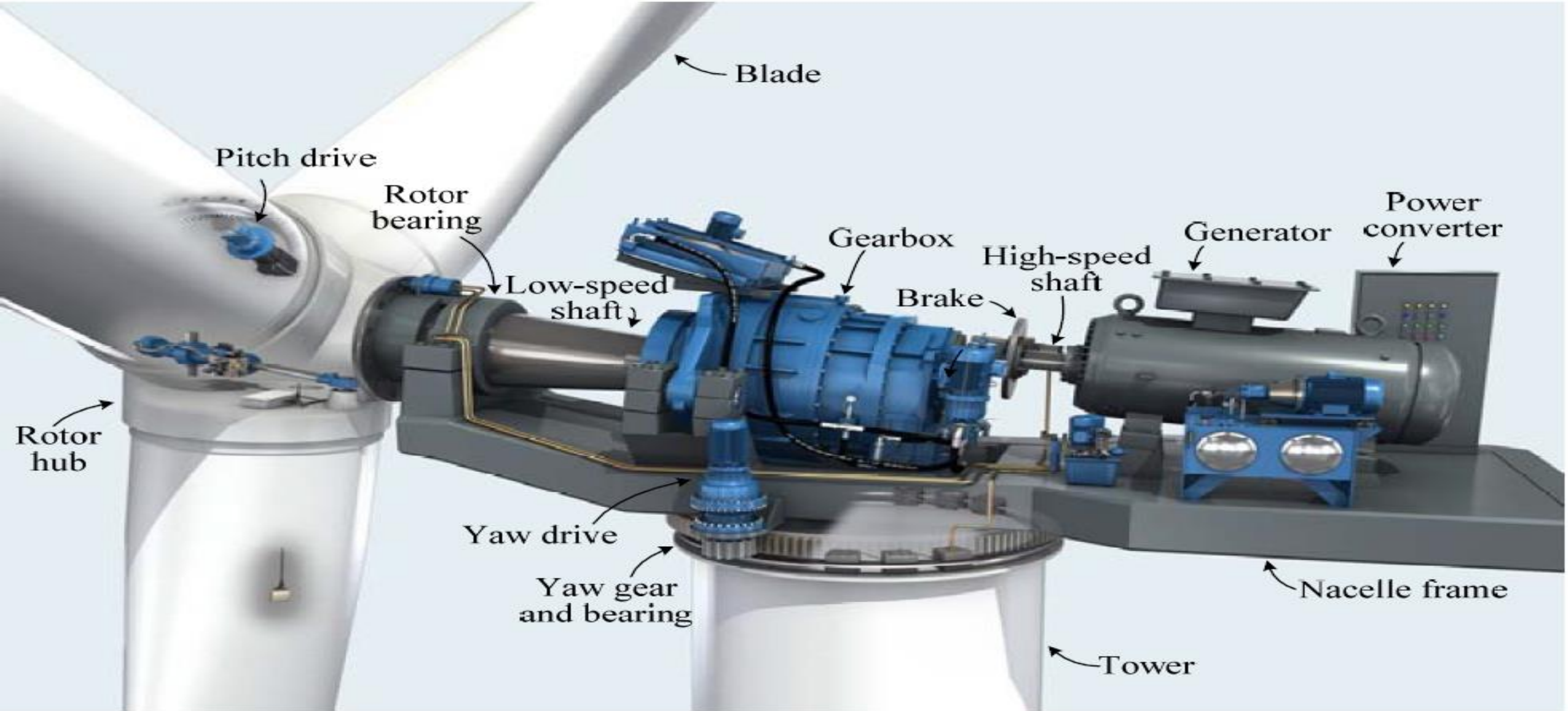
1. They ensure maximum power output over a wide range of wind speeds.
2. They also enable reliable & safe operation.
3. They protect mechanical & structural parts of wind turbine from damage during strong wind gusts.

This chapter shall provide a brief overview of

1. Wind turbine major components,
2. Blade aerodynamic power control, and
3. Maximum power tracking schemes.

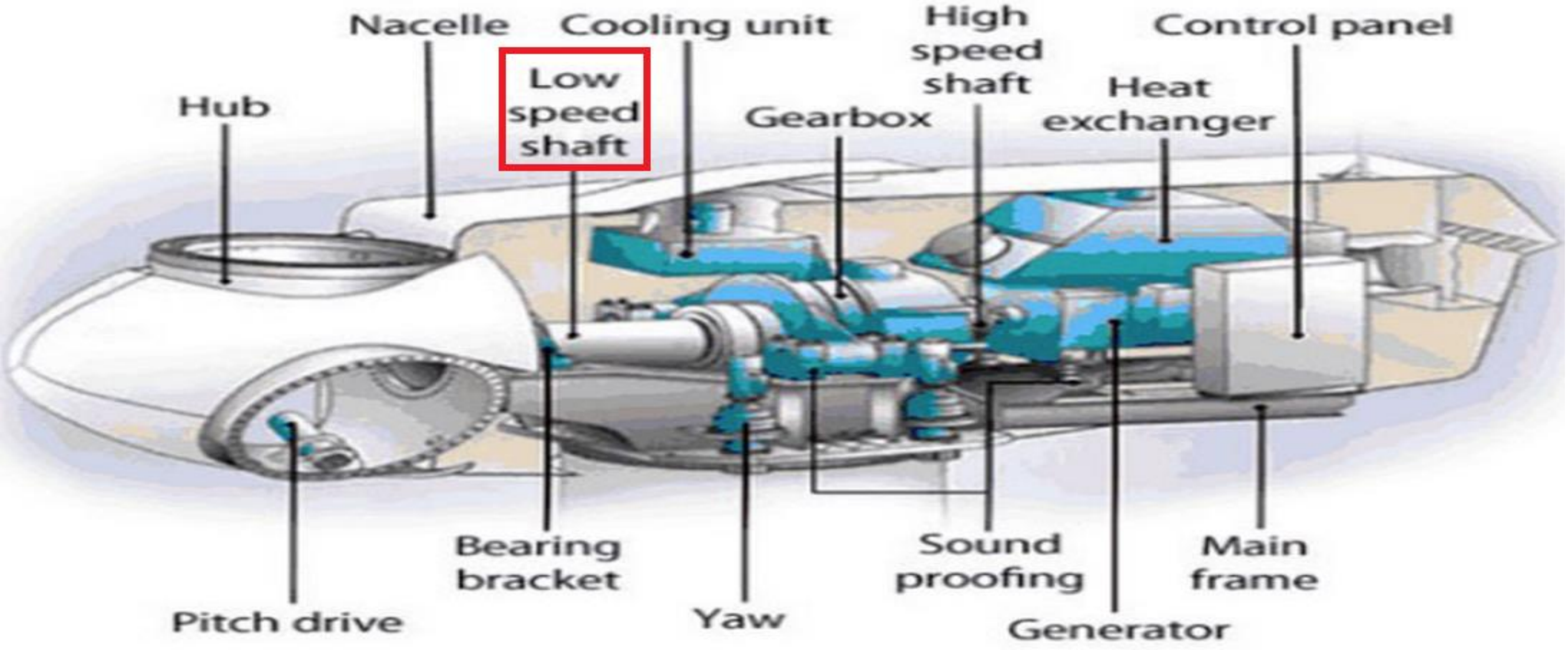
2.2 Wind Turbine Components

A wind turbine is composed of several parts to achieve kinetic to electric energy conversion.

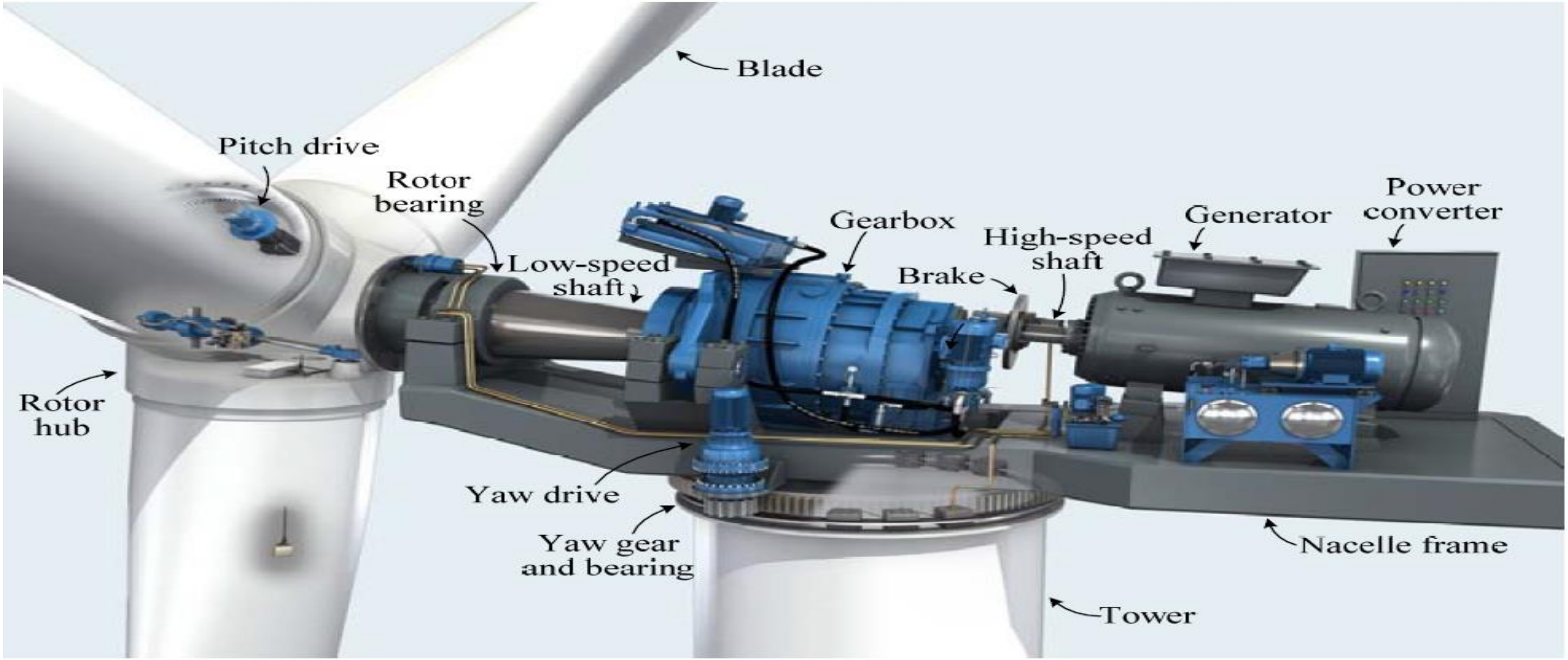


Wind kinetic energy is converted to mechanical energy by **blades** mounted on rotor hub.

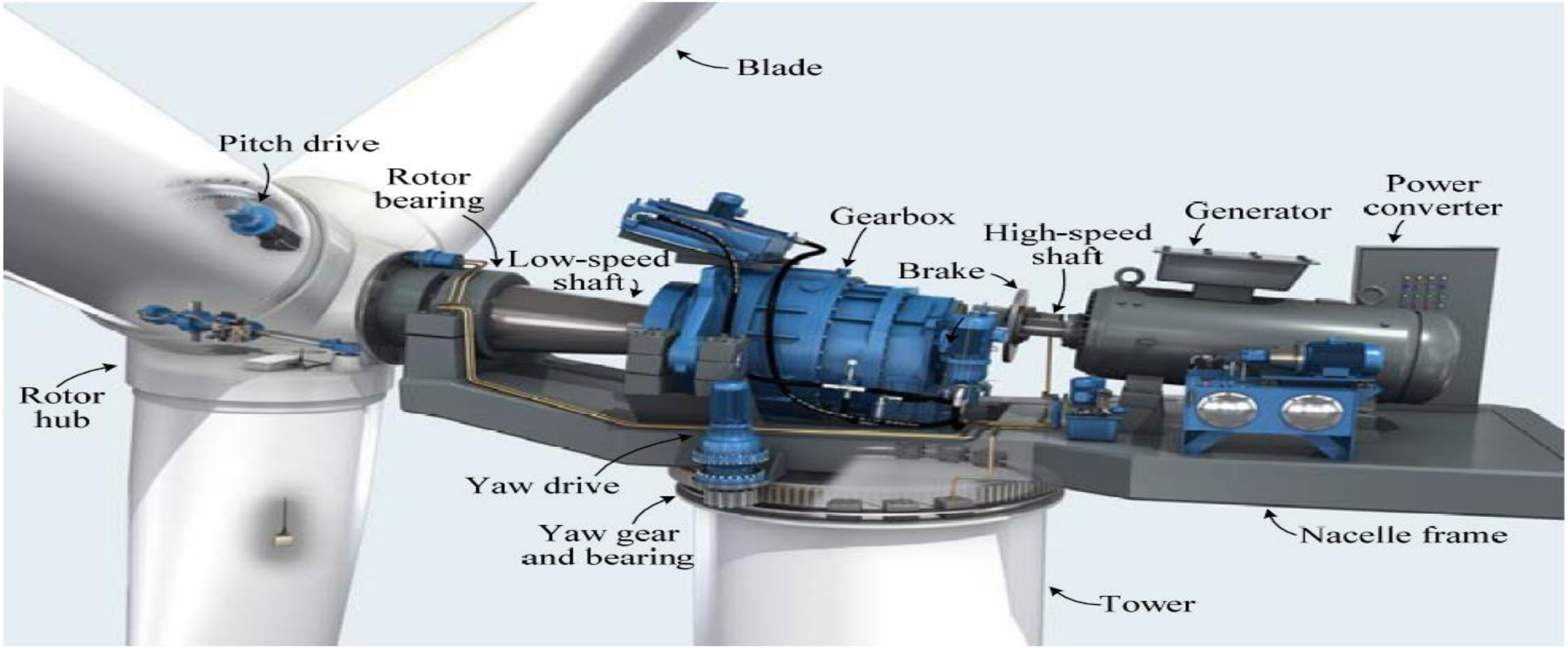
Rotor hub is installed on main shaft, also known as low-speed shaft.



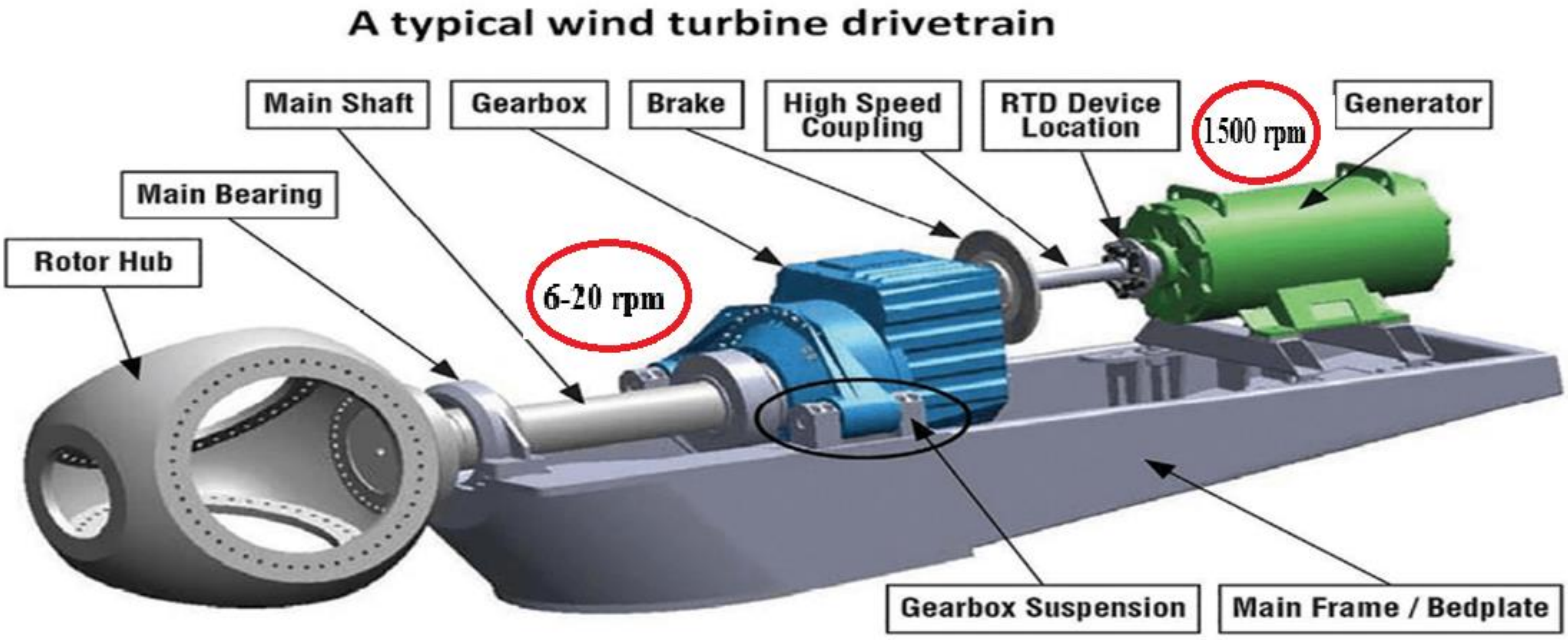
Can we transmit Mechanical energy to generator directly?



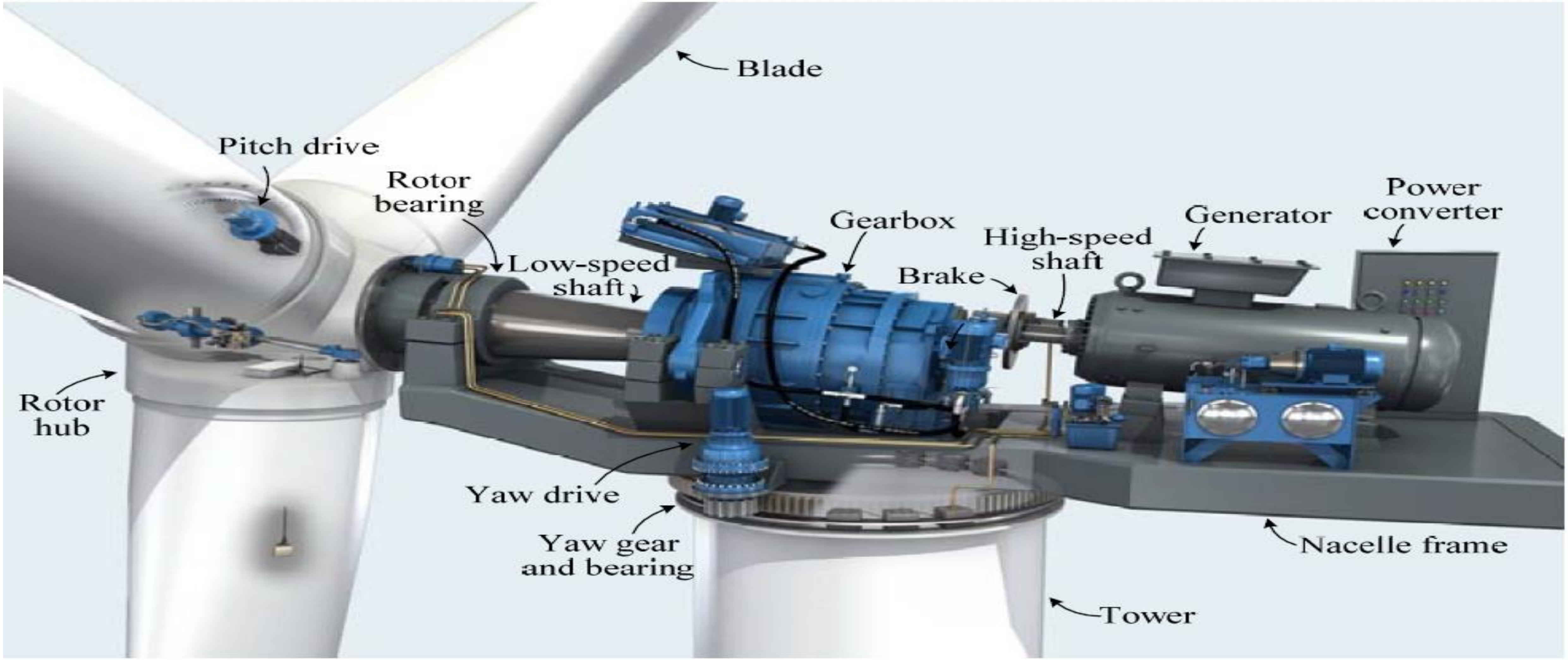
Why the mechanical energy cannot be provided to generator directly?



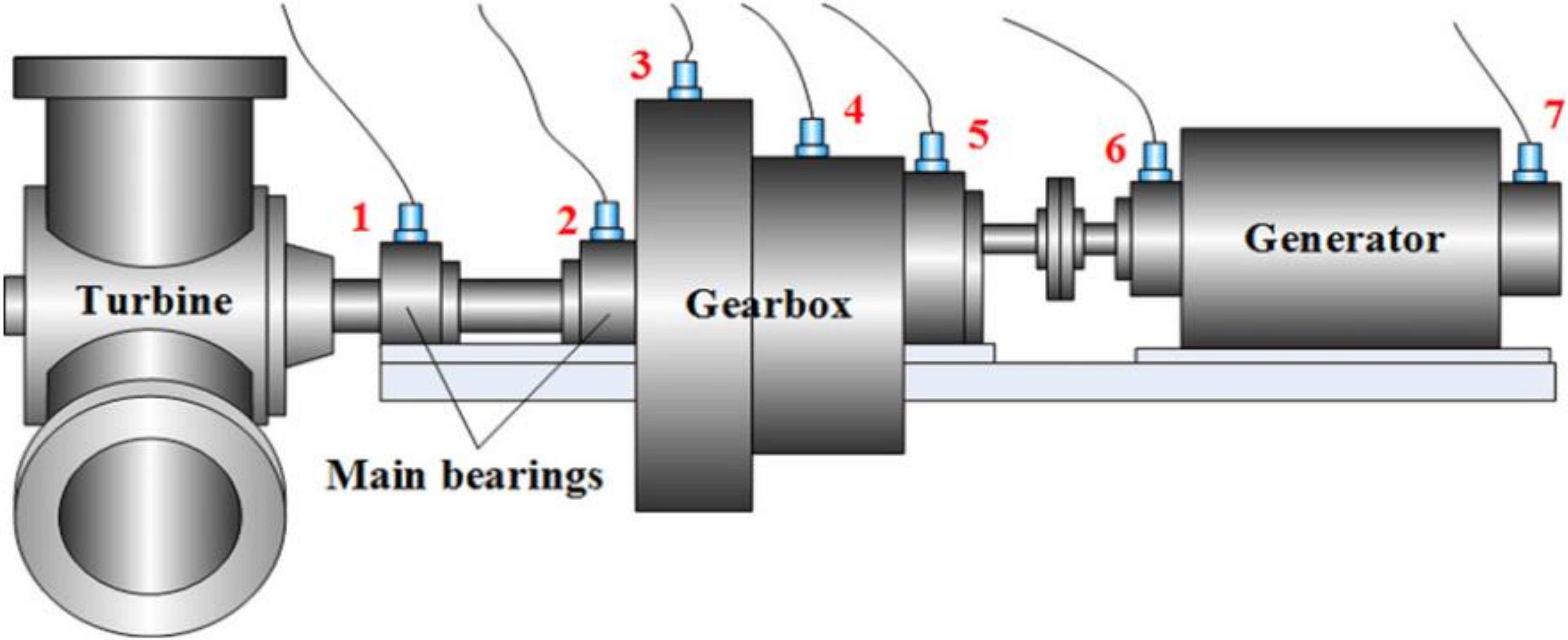
A. In order to synchronize Rotor RPMs with generator.



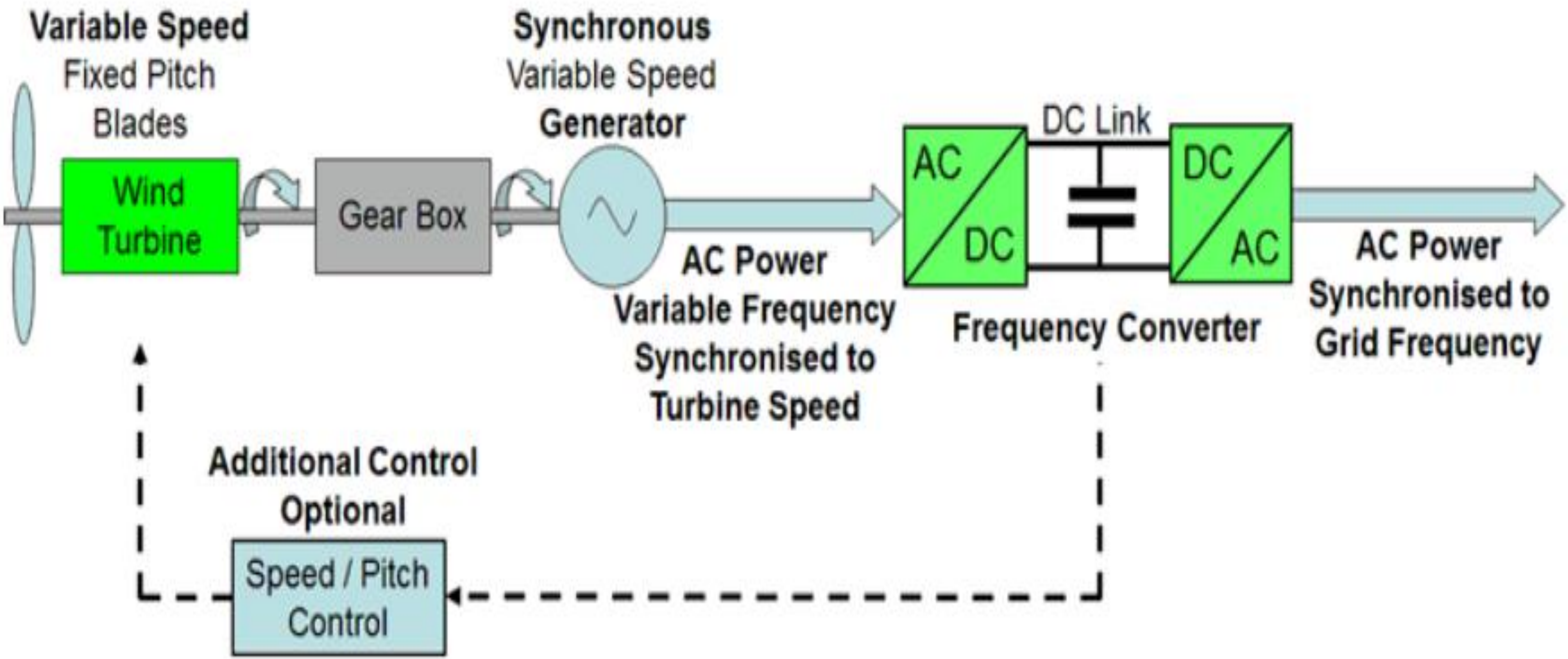
Mechanical energy is transmitted through drive train (shafts+ bearings+gearbox) to generator.



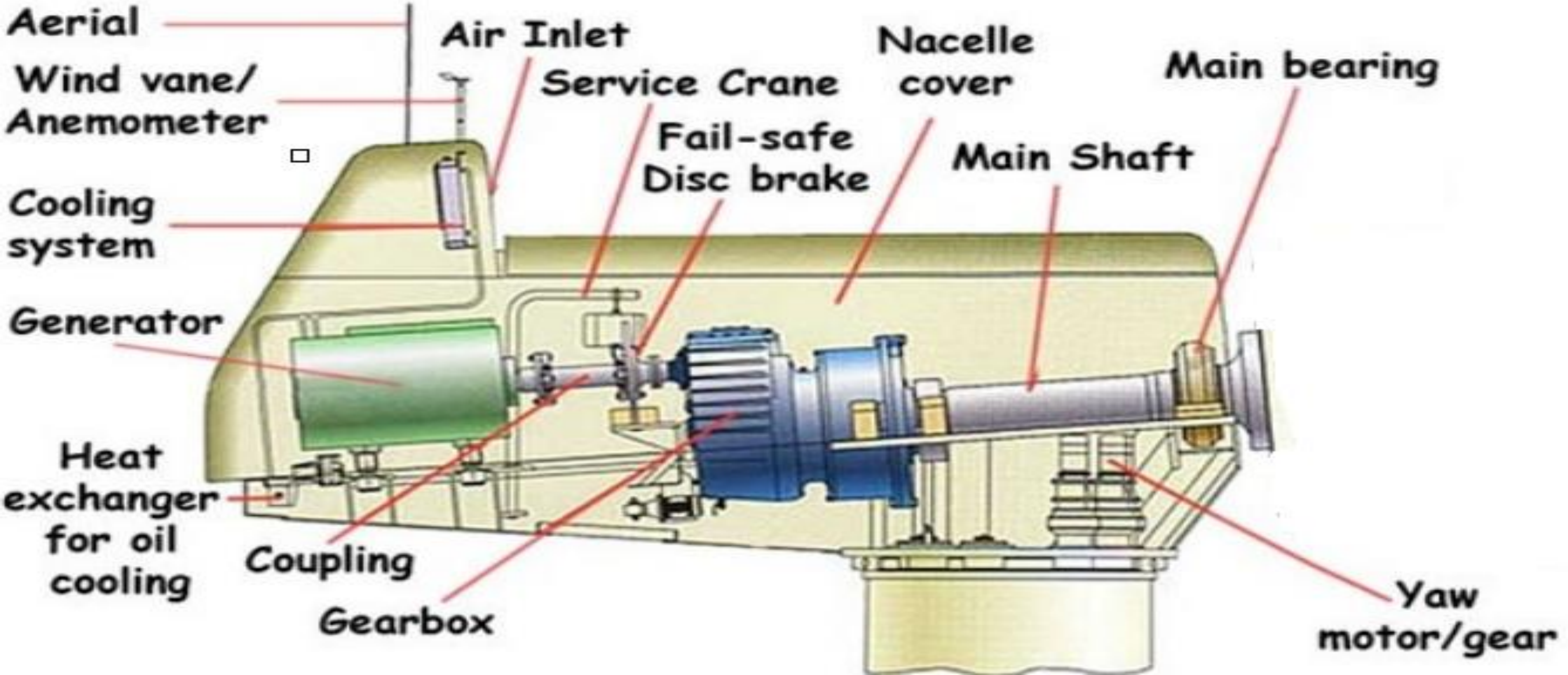
Drive train (shafts+ bearings+ gearbox)



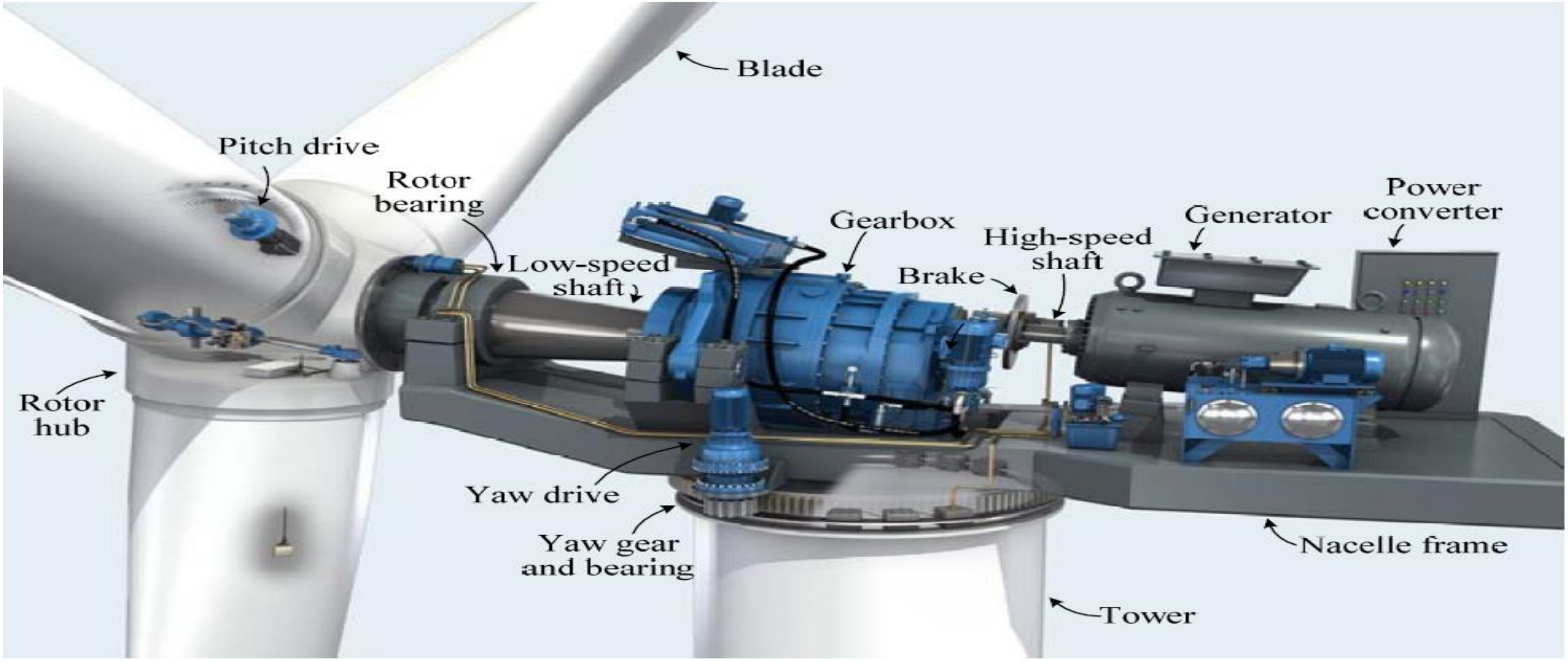
Power converter delivers power from generator to grid.



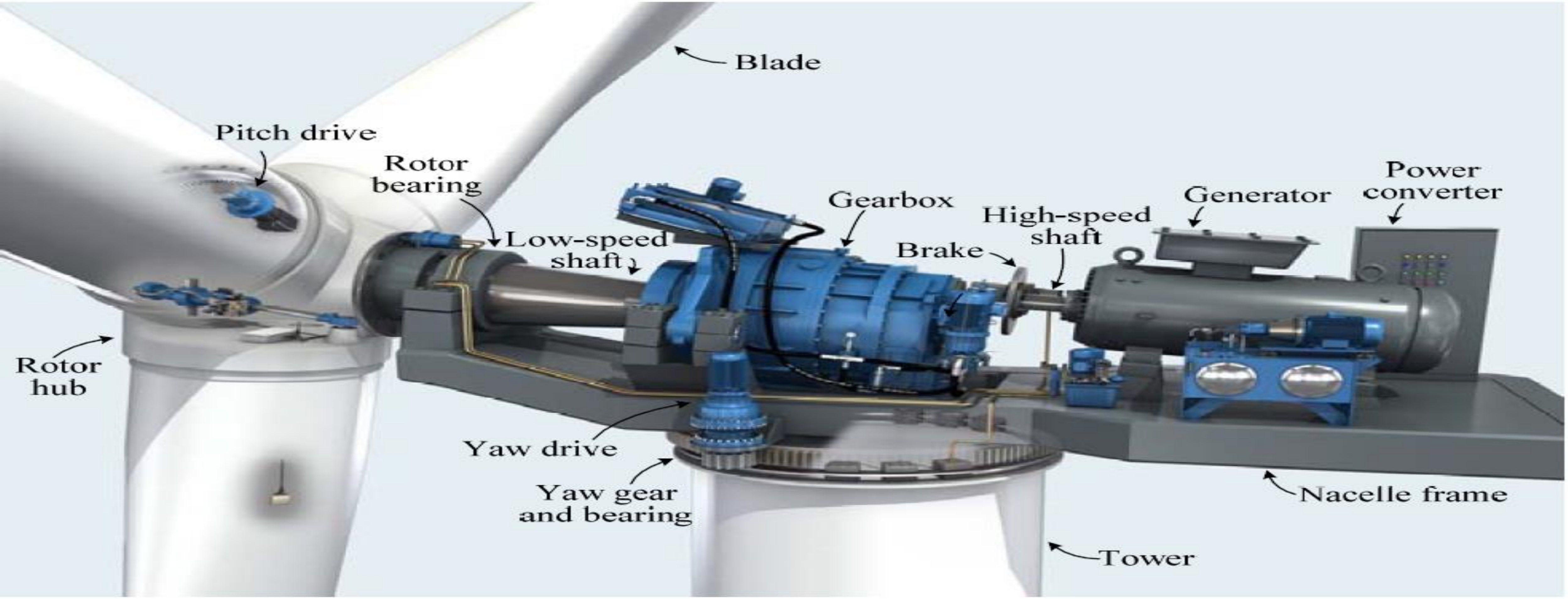
Most of wind turbine components are enclosed in a nacelle on top of tower.



Parts that are in-directly involved in power conversion, e.g



1.Pitch system 2.Yaw system 3.Mechanical brake 4. Wind speed & direction sensors 5.Power distribution cables 6.Heat dissipation/exchange system 7. Lightning protection system & Structural components e.g



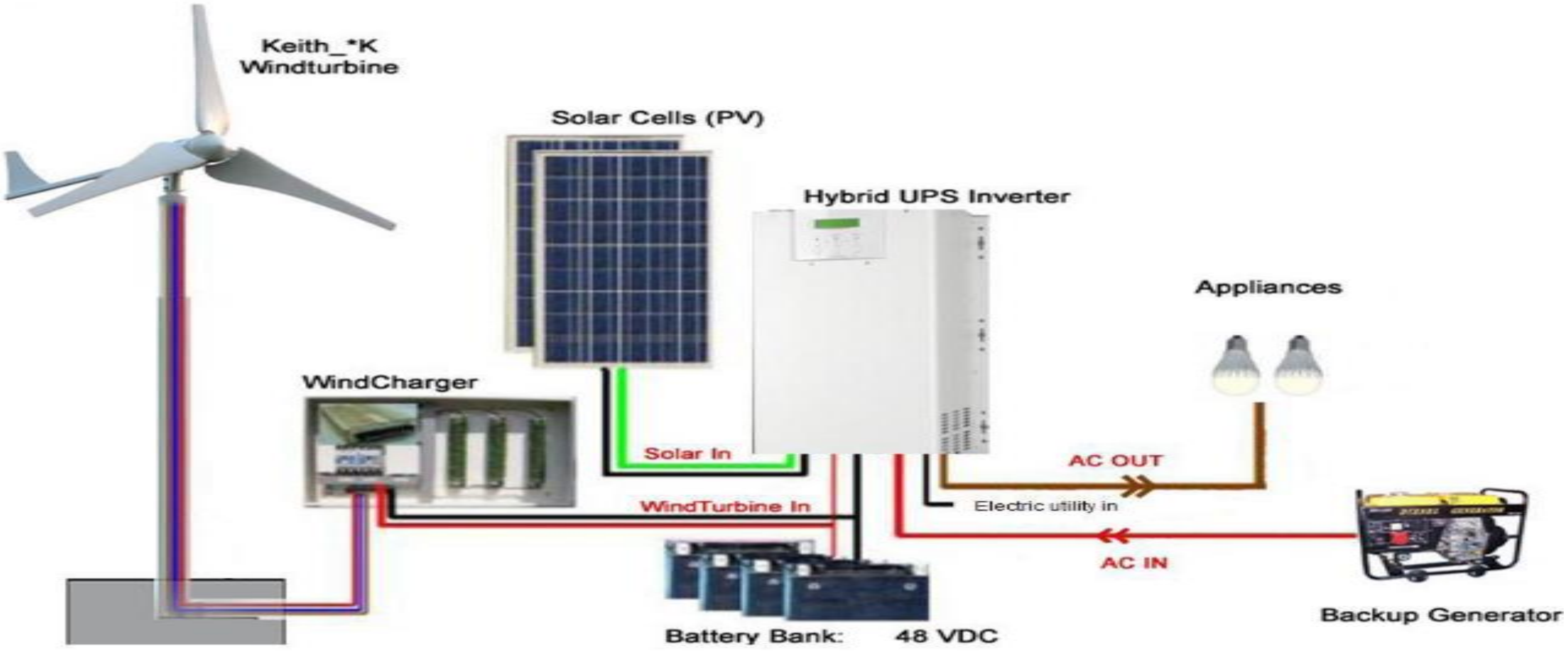
Structural components e.g

i. Tower

ii. Foundation &

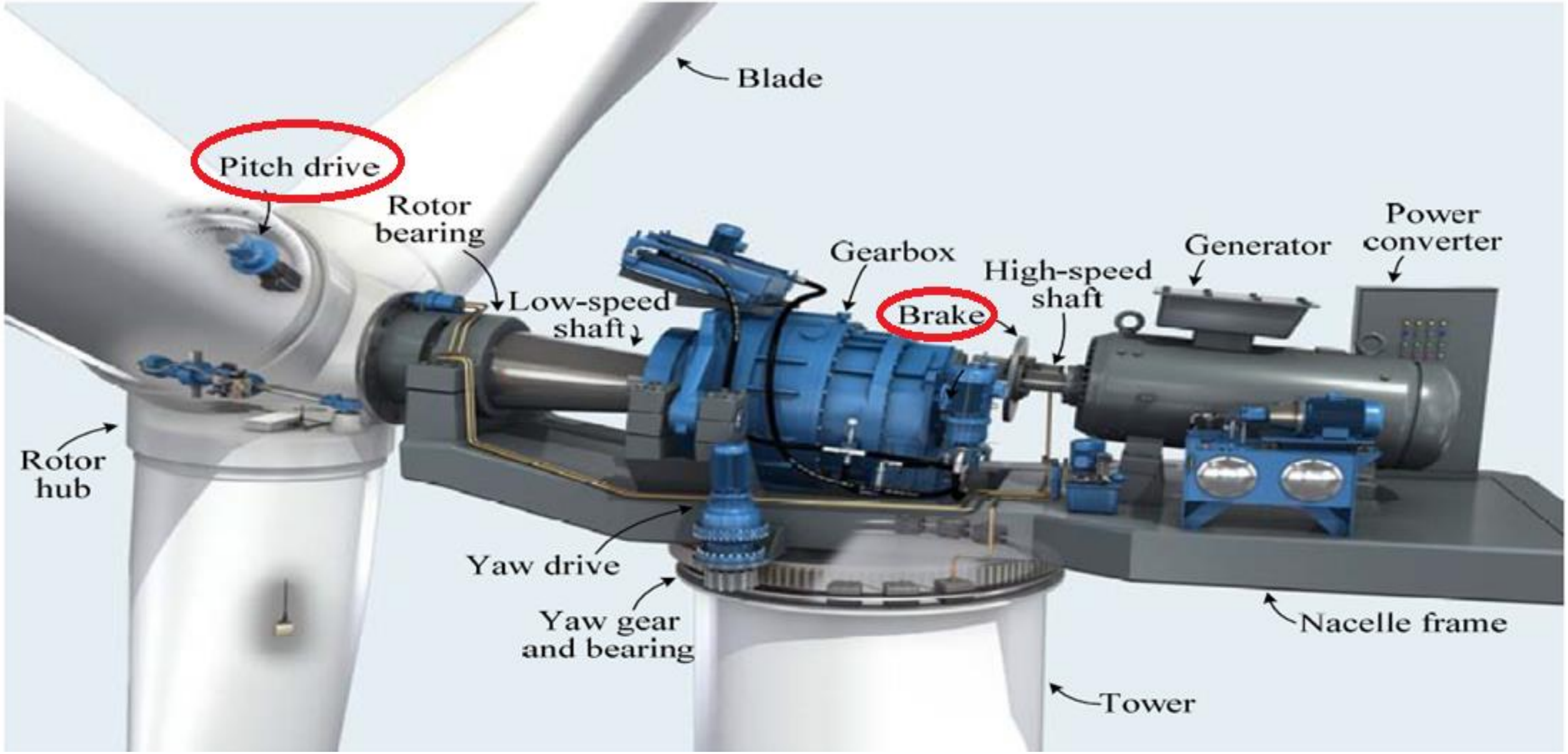
iii. Nacelle enclosure.

Large wind turbines are also equipped with an uninterruptable power supply or backup energy system



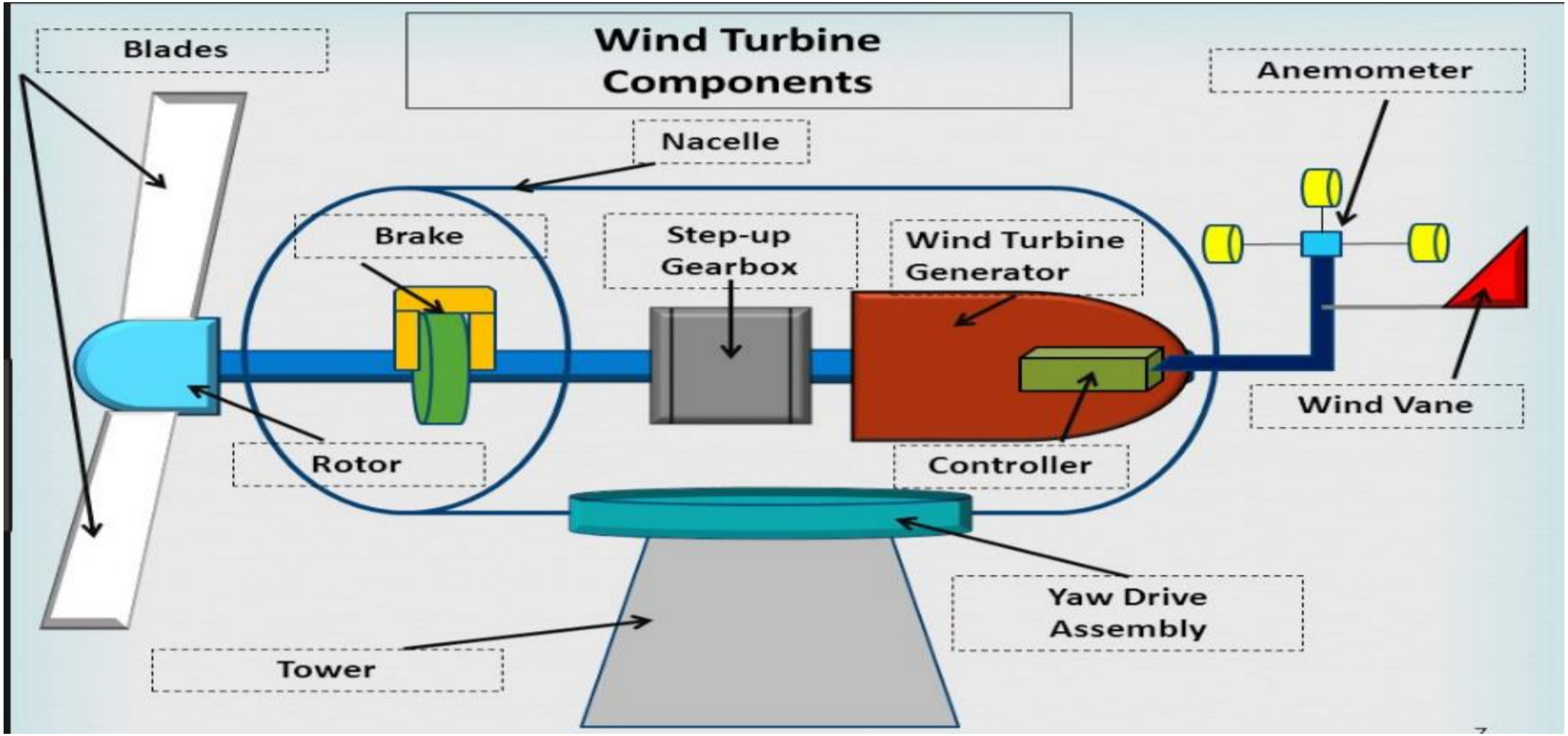
Why we use UPS in Large wind turbines?

UPS ensure uninterrupted operation for:
1.Control system



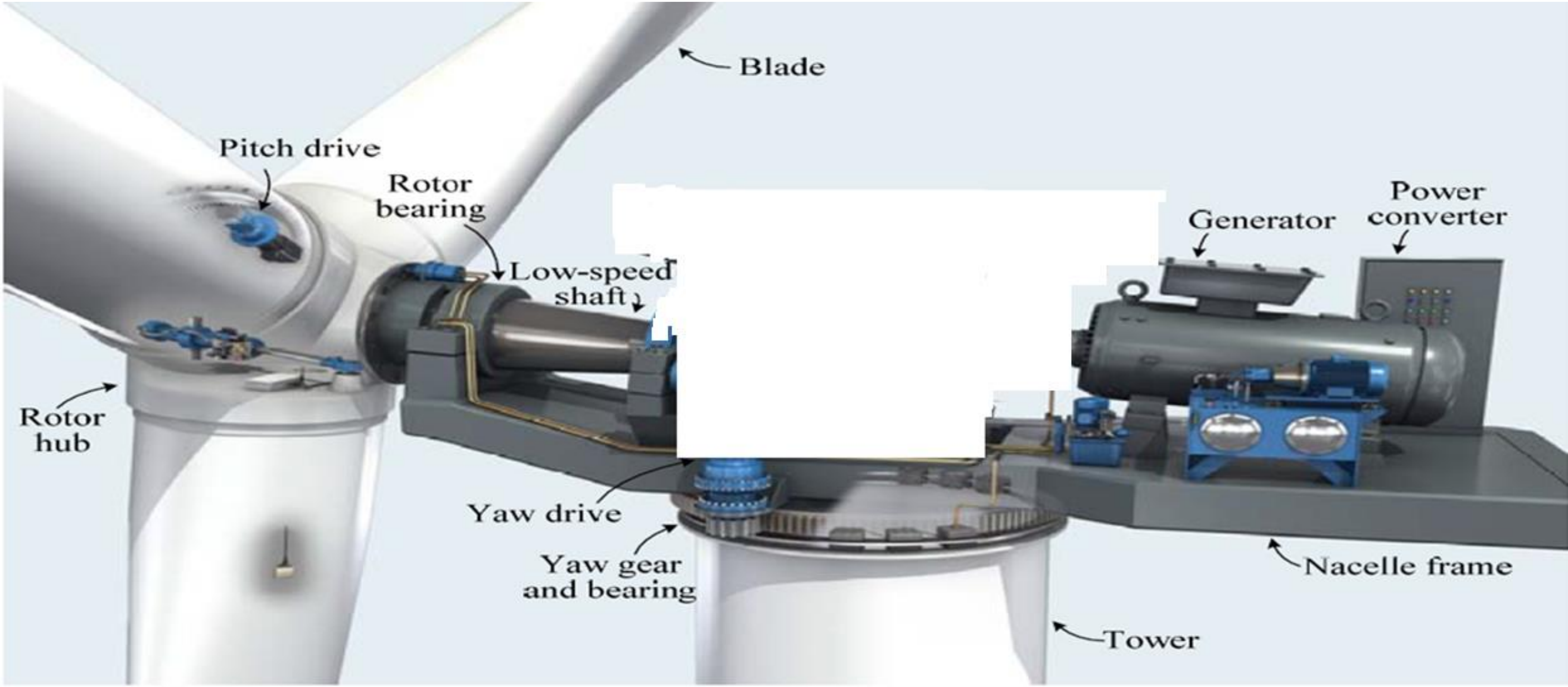
2.Pitch drive

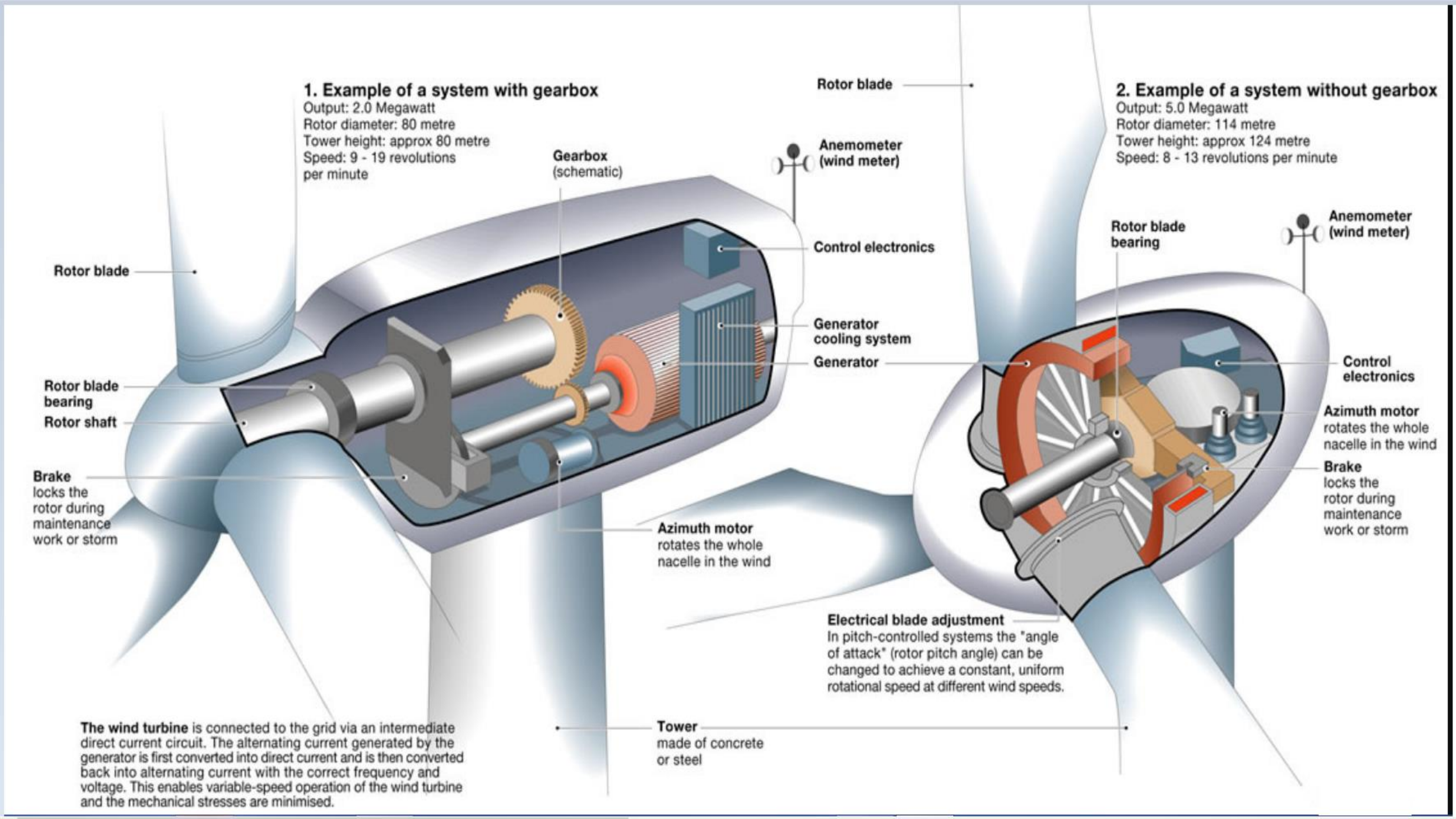
3.Brakes



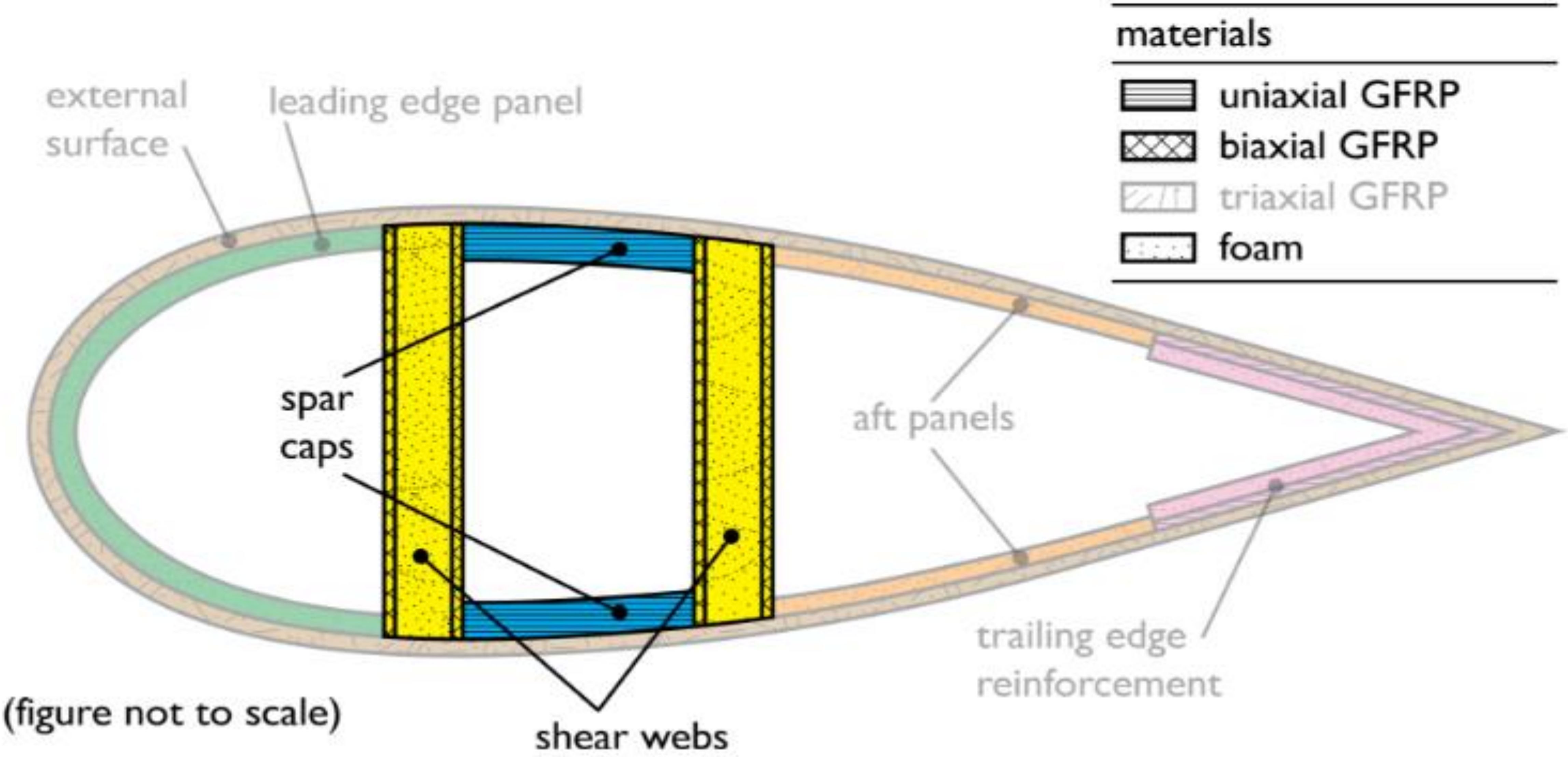
Wind Turbine Components
Blades
Anemometer
Nacelle
Brake
Step-up Gearbox
Wind Turbine Generator
Wind Vane
Rotor
Controller
Yaw Drive Assembly
Tower

In Direct drive (gearless) turbines nacelle is shorter due to absence of gearbox & high-speed shaft

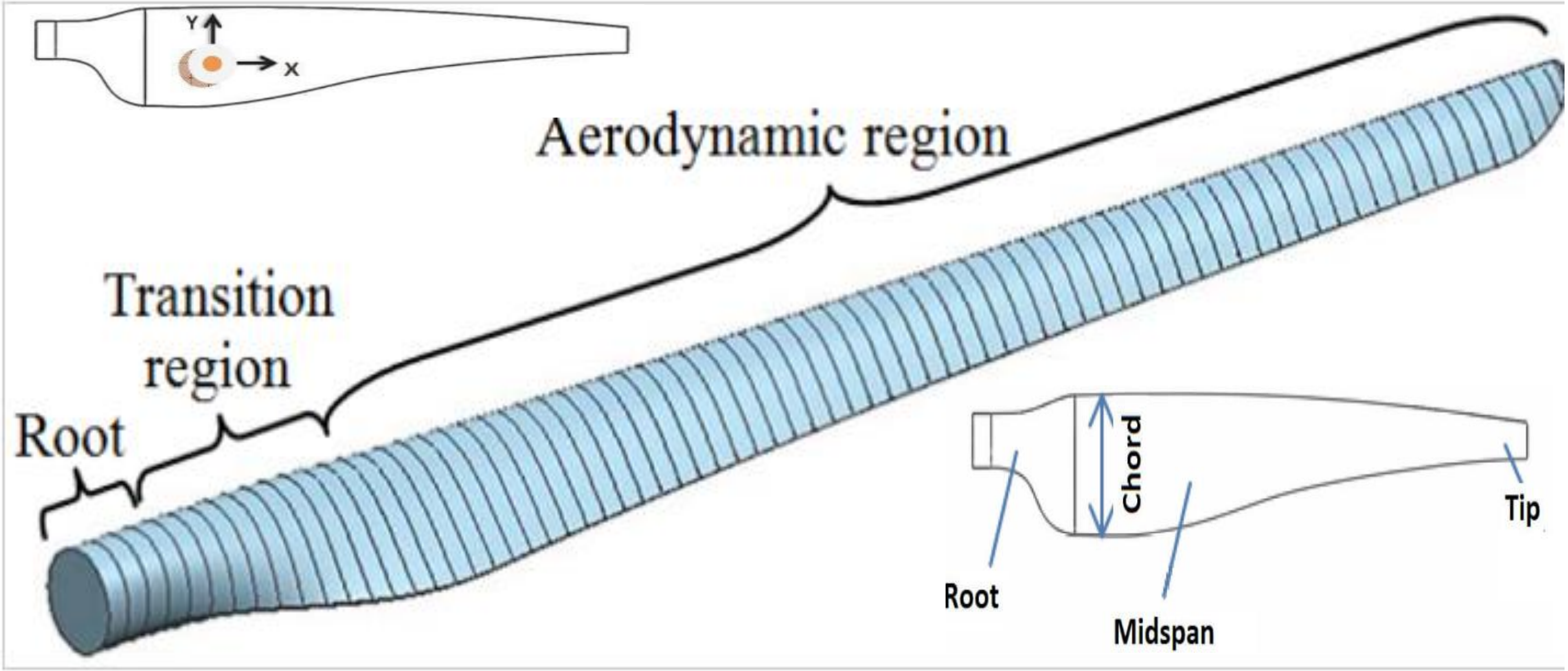



1. Example of a system with gearbox
Output: 2.0 Megawatt
Rotor diameter: 80 metre
Tower height: approx 80 metre
Speed: 9 - 19 revolutions per minute
Gearbox (schematic)
Anemometer (wind meter)
Rotor blade
Control electronics
Generator cooling system
Generator
Rotor blade bearing
Rotor shaft
Brake locks the rotor during maintenance work or storm
Azimuth motor rotates the whole nacelle in the wind
2. Example of a system without gearbox
Output: 5.0 Megawatt
Rotor diameter: 114 metre
Tower height: approx 124 metre
Speed: 8 - 13 revolutions per minute
Rotor blade bearing
Anemometer (wind meter)
Control electronics
Azimuth motor rotates the whole nacelle in the wind
Brake locks the rotor during maintenance work or storm
Electrical blade adjustment
In pitch-controlled systems the "angle of attack" (rotor pitch angle) can be changed to achieve a constant, uniform rotational speed at different wind speeds.
Tower made of concrete or steel
The wind turbine is connected to the grid via an intermediate direct current circuit. The alternating current generated by the generator is first converted into direct current and is then converted back into alternating current with the correct frequency and voltage. This enables variable-speed operation of the wind turbine and the mechanical stresses are minimised.

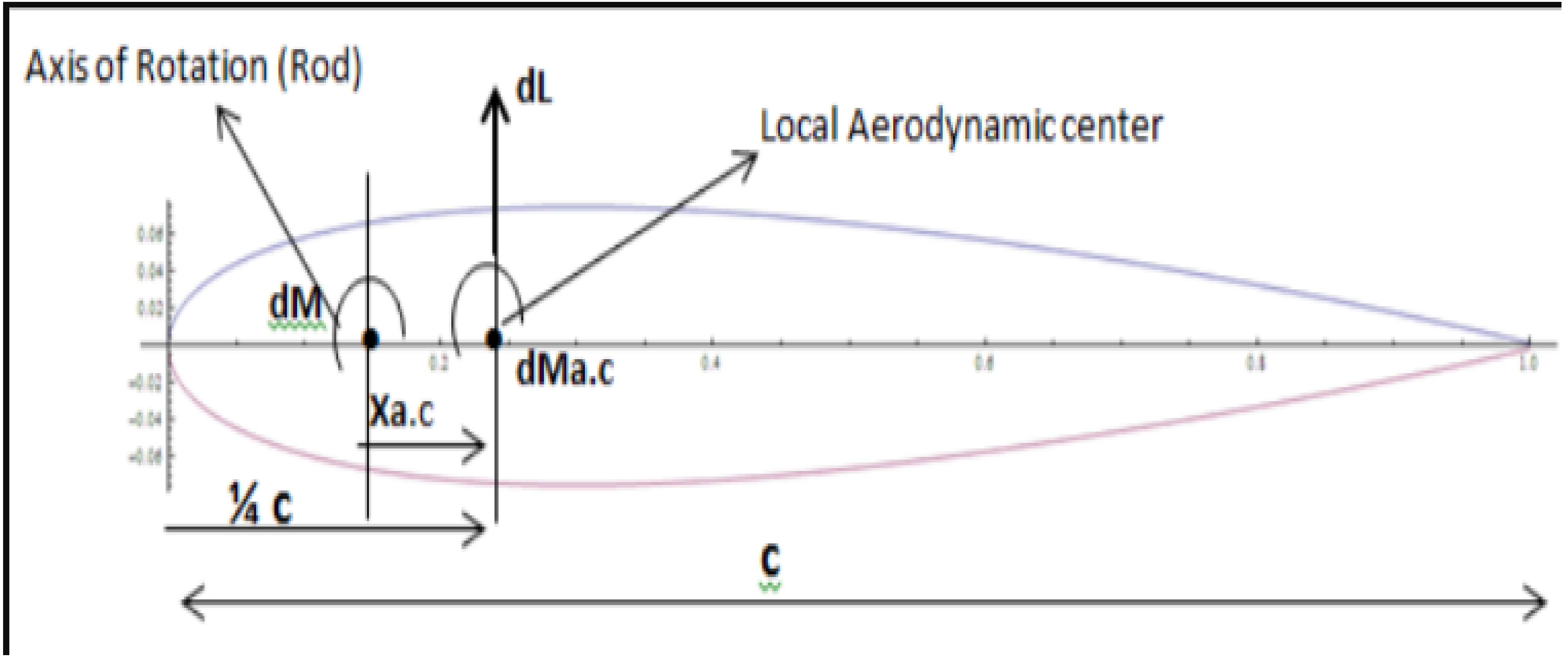
2.2.1 Turbine Blade



Blades transform wind kinetic energy into rotational mechanical energy.



State-of-the-art blades have been developed through **aerodynamic design**



Materials from early wind mill blades made of wood & cloth.

- Modern blades are commonly made of :

i. Aluminium,

ii. glass-fiber or

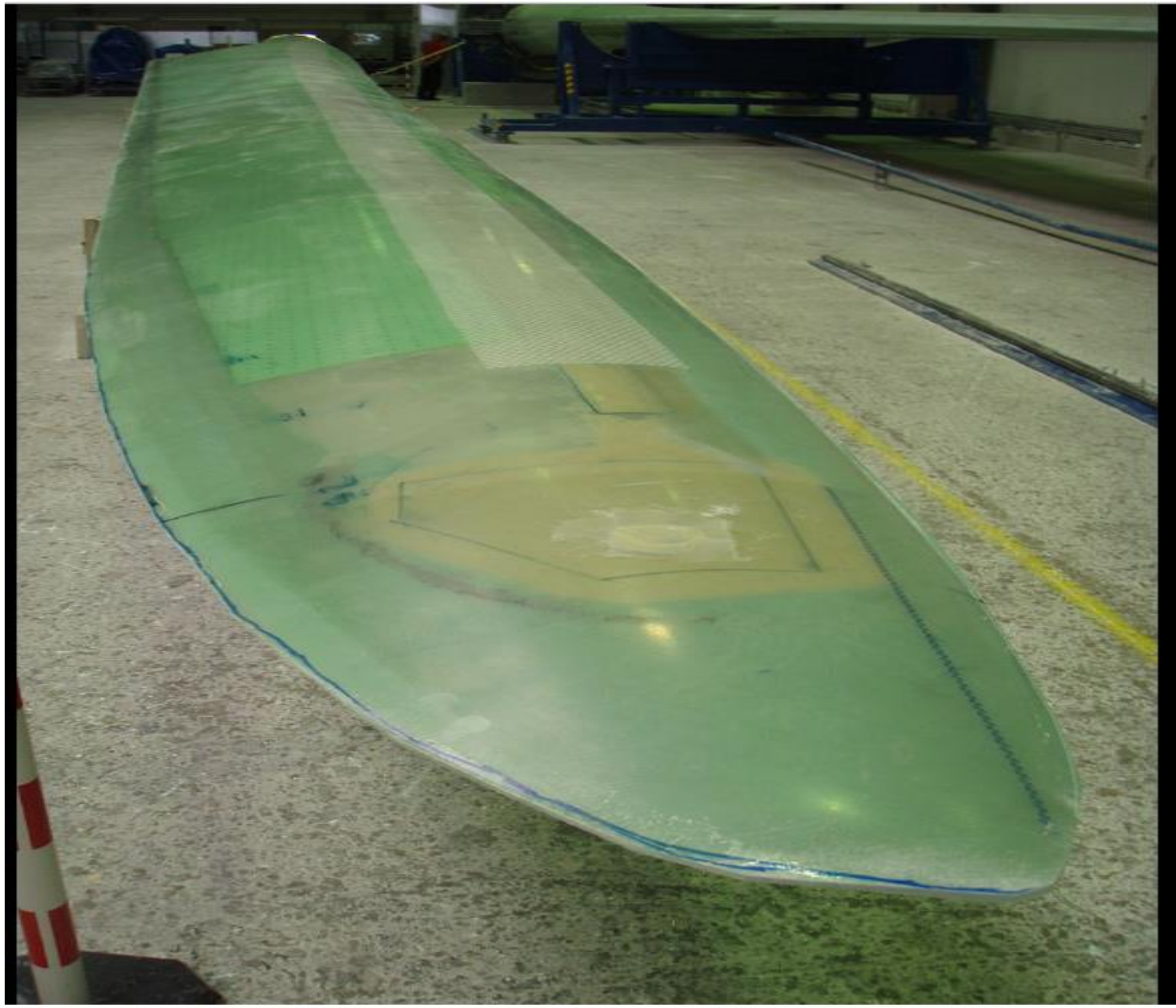
iii. carbon-fiber

- that provide necessary strength to:

a. weight ratio,

b. fatigue life &

c. stiffness while minimizing weight.



Fiberglass-reinforced epoxy blades of Siemens wind turbines with blade size of 49 meters

Single,2 and 3-bladed wind turbines

Which one can be selected on the basis of 1.mechanical stress 2.Acoustic noise 3.Cost 4. Rotational speed?



Single & 2-bladed wind turbines have found practical.

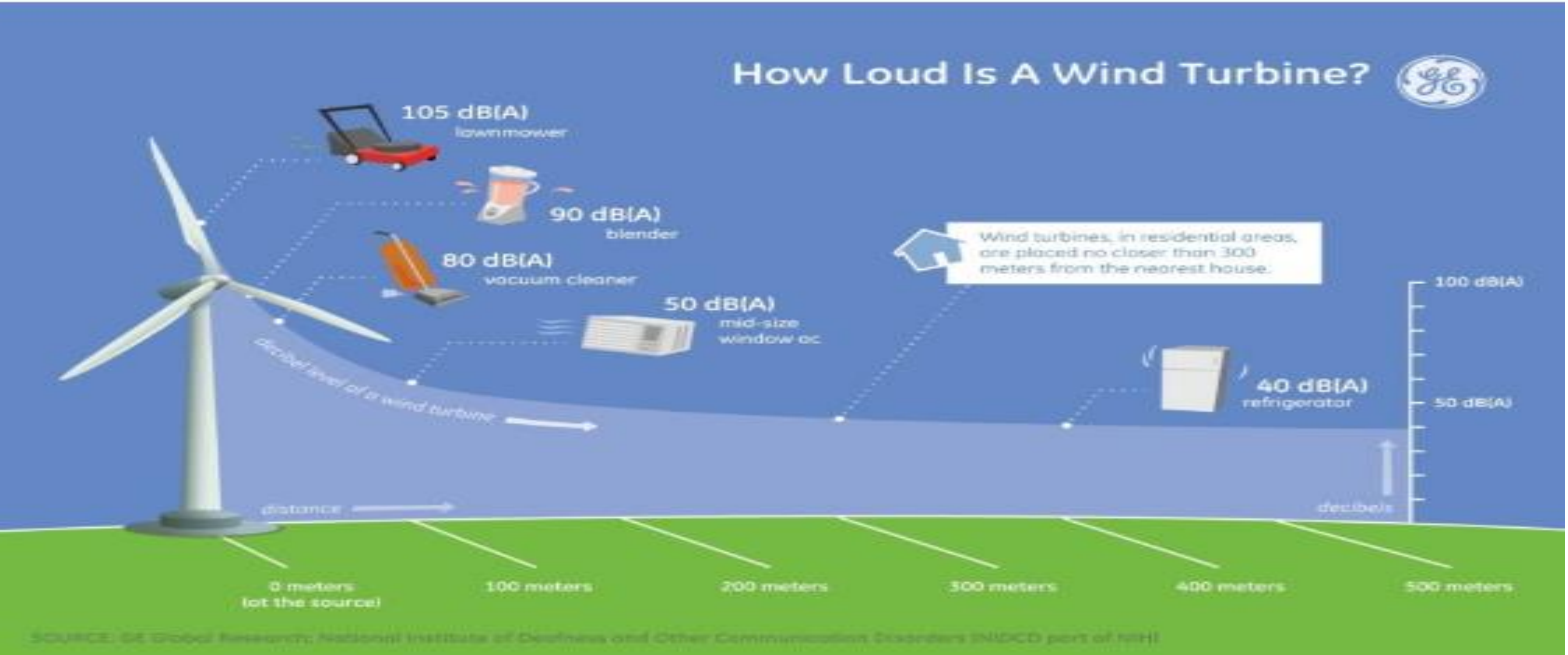
Turbines with fewer blades operate at higher rotational speeds.

Why fewer blades imply lower costs?

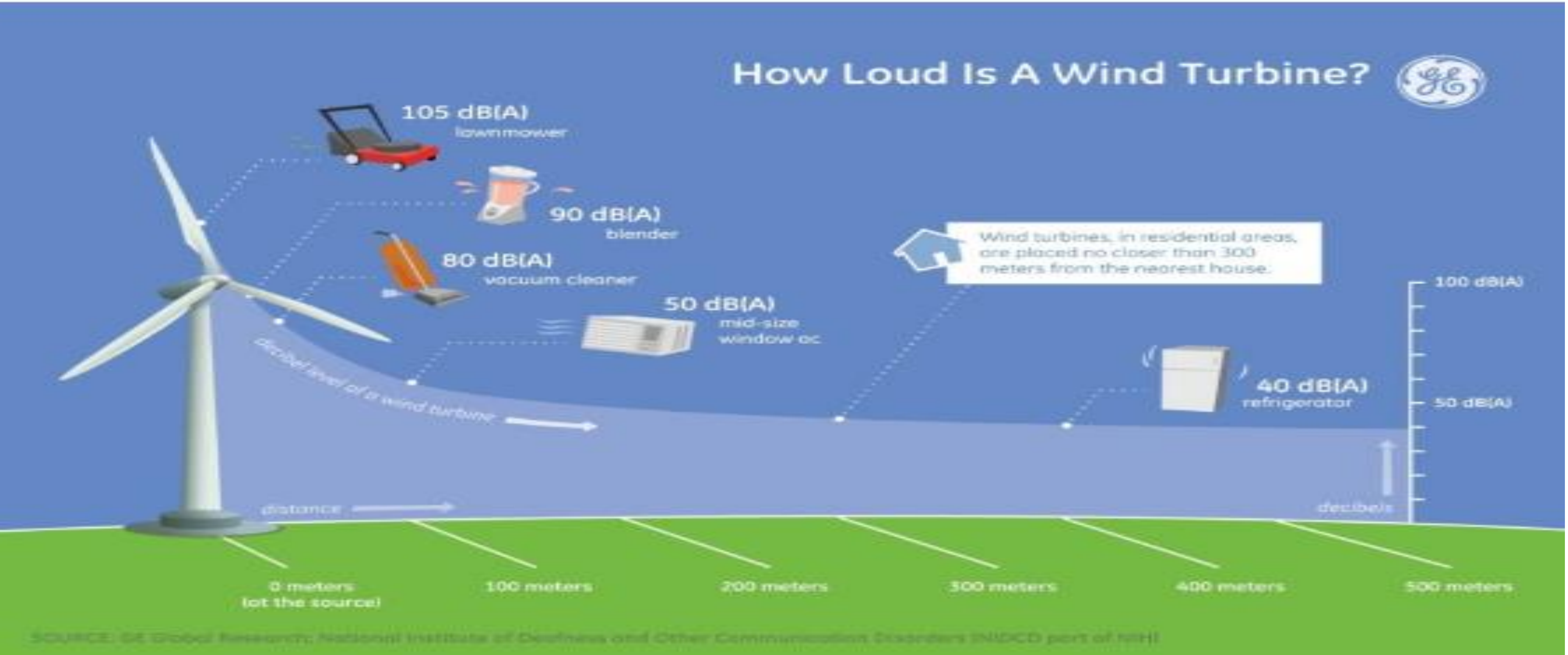
An advantage from drive train point of view since they require a gearbox with lower gear ratio, which translates into lower cost.

For large wind turbines, 3-blade rotor is used because it is INDUSTRY STANDARD

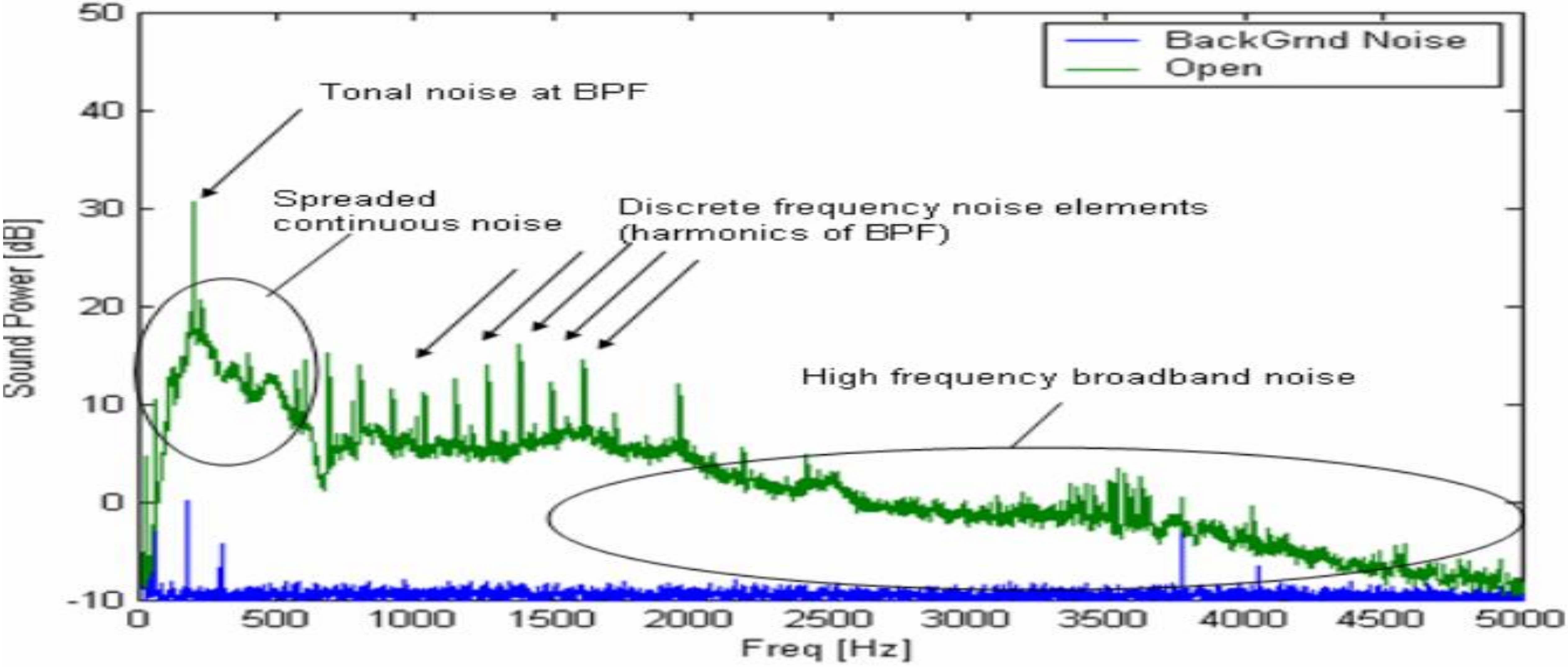
Acoustic noise is an important problem in populated areas



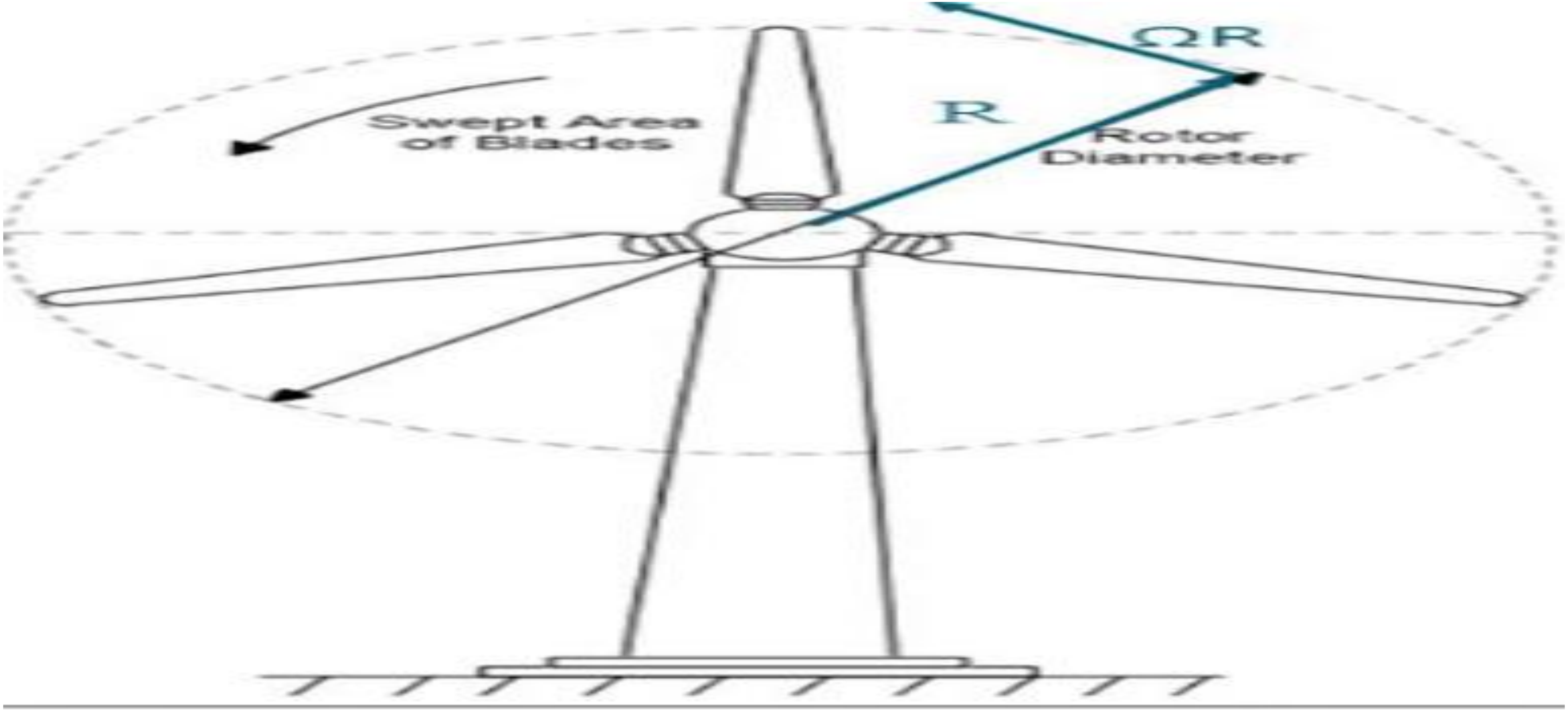
Wind turbine in residential areas are placed no closer than 300meters from the nearest house.



Acoustic noise increases proportionally to blade tip speed.

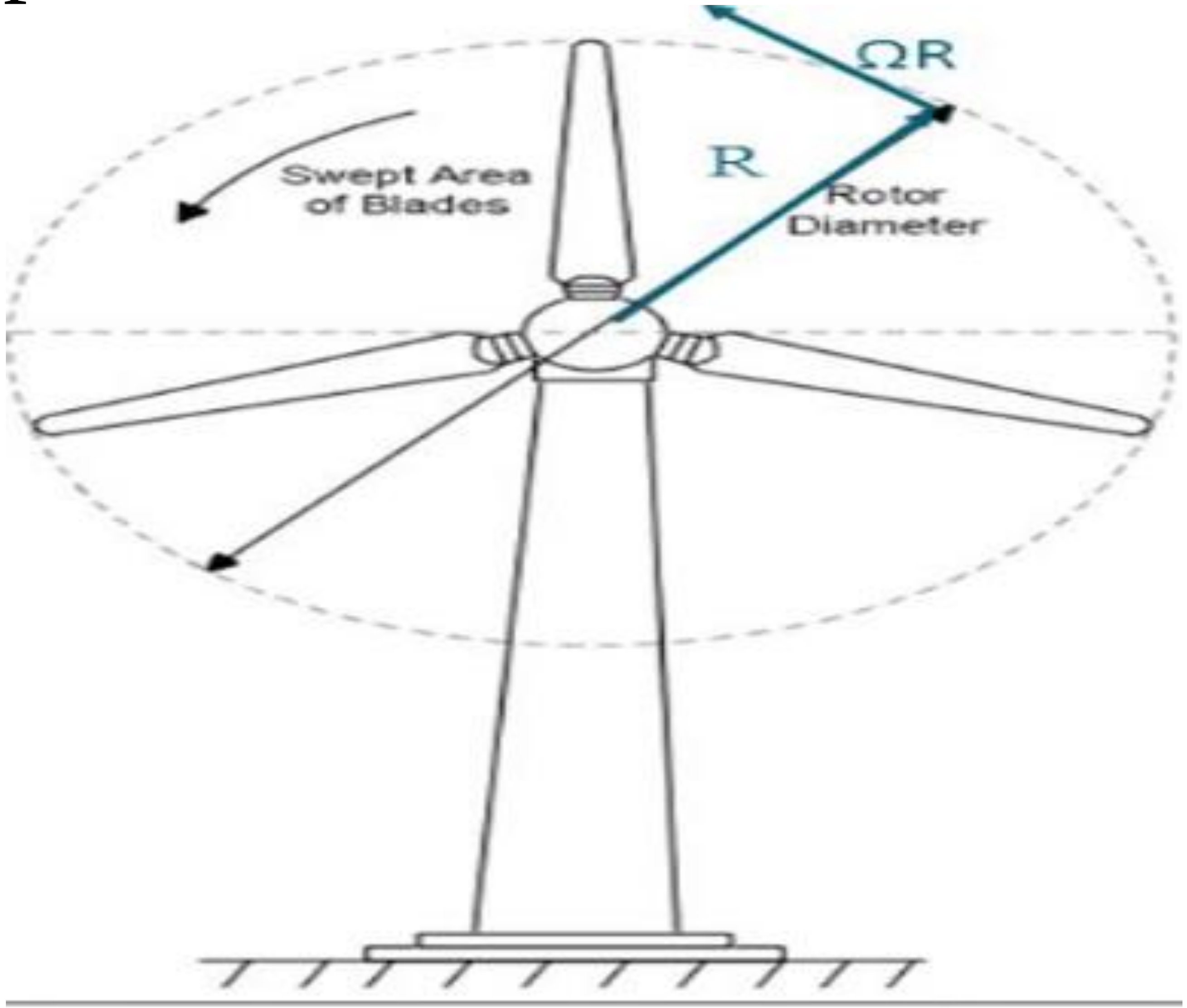


What is Tip Speed Ratio(TSR)?



Tip-speed ratio(TSR) is the ratio of the speed of the rotating blade tip to the speed of the free stream wind.

$$\mathrm{TSR} = \frac{\Omega R}{V}$$



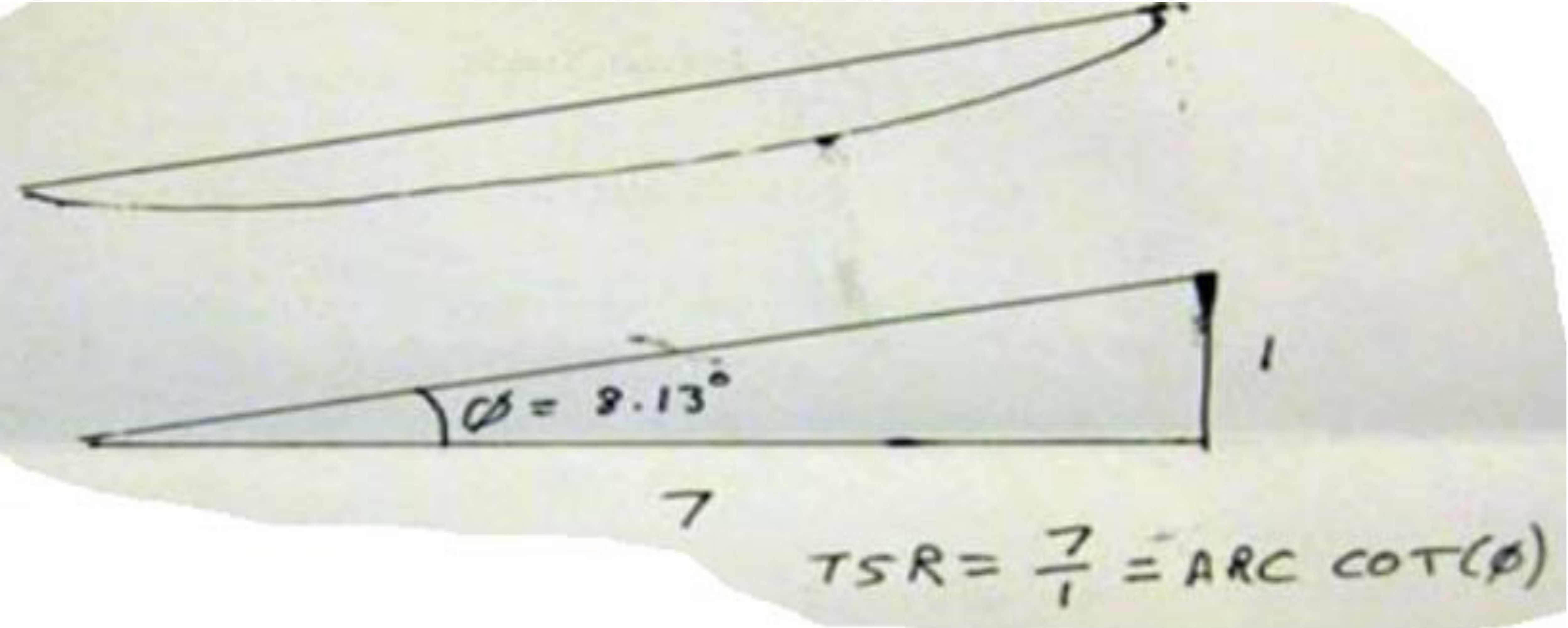
where,

Ω = rotational speed in radians /sec

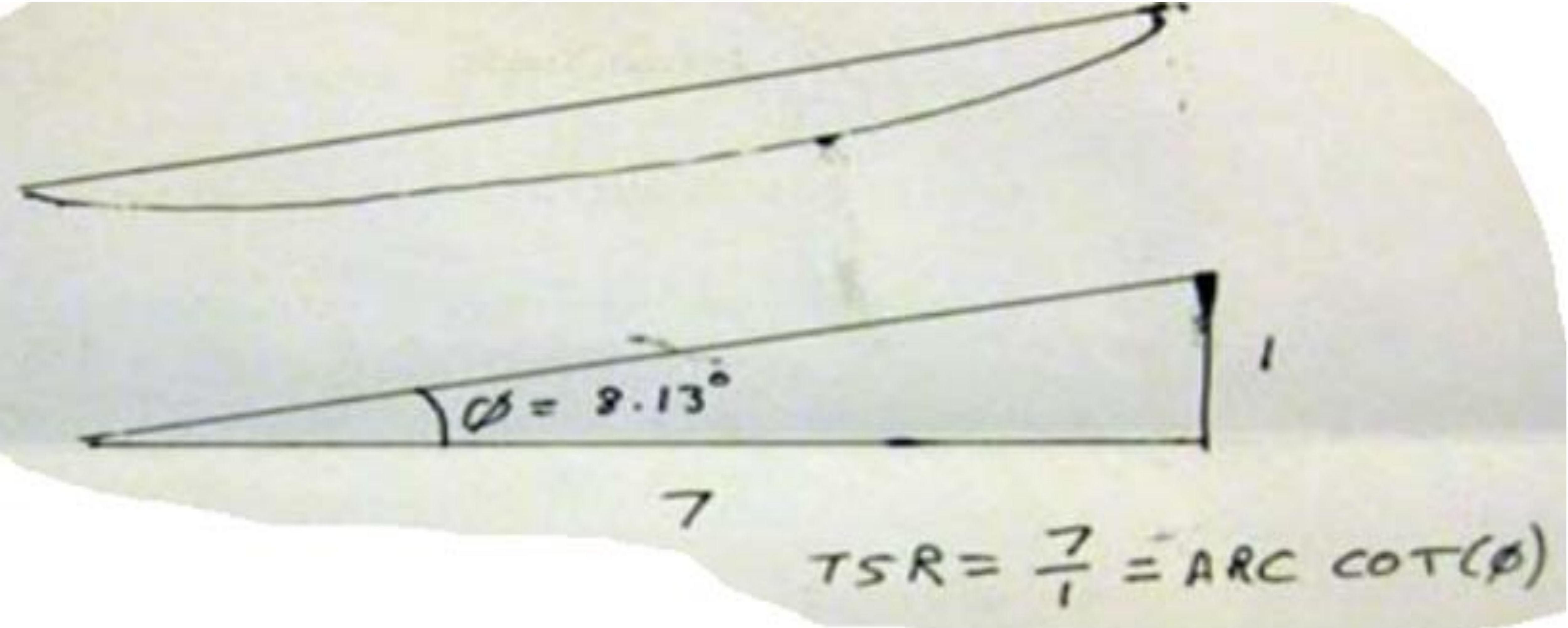
R = Rotor Radius(blade length)

V = Wind “Free Stream” Velocity

Using Trigonometry: TSR=7/1=Arc Cot(Ø)



High efficiency 3-blade-turbines have tip speed/wind speed ratios of 6 to 7



Acoustic noise is higher for single-and 2-bladed turbines

Single-blade turbines have an asymmetrical mechanical load distribution.

- Turbine rotors are aerodynamically unbalanced.
- which can cause mechanical vibrations.

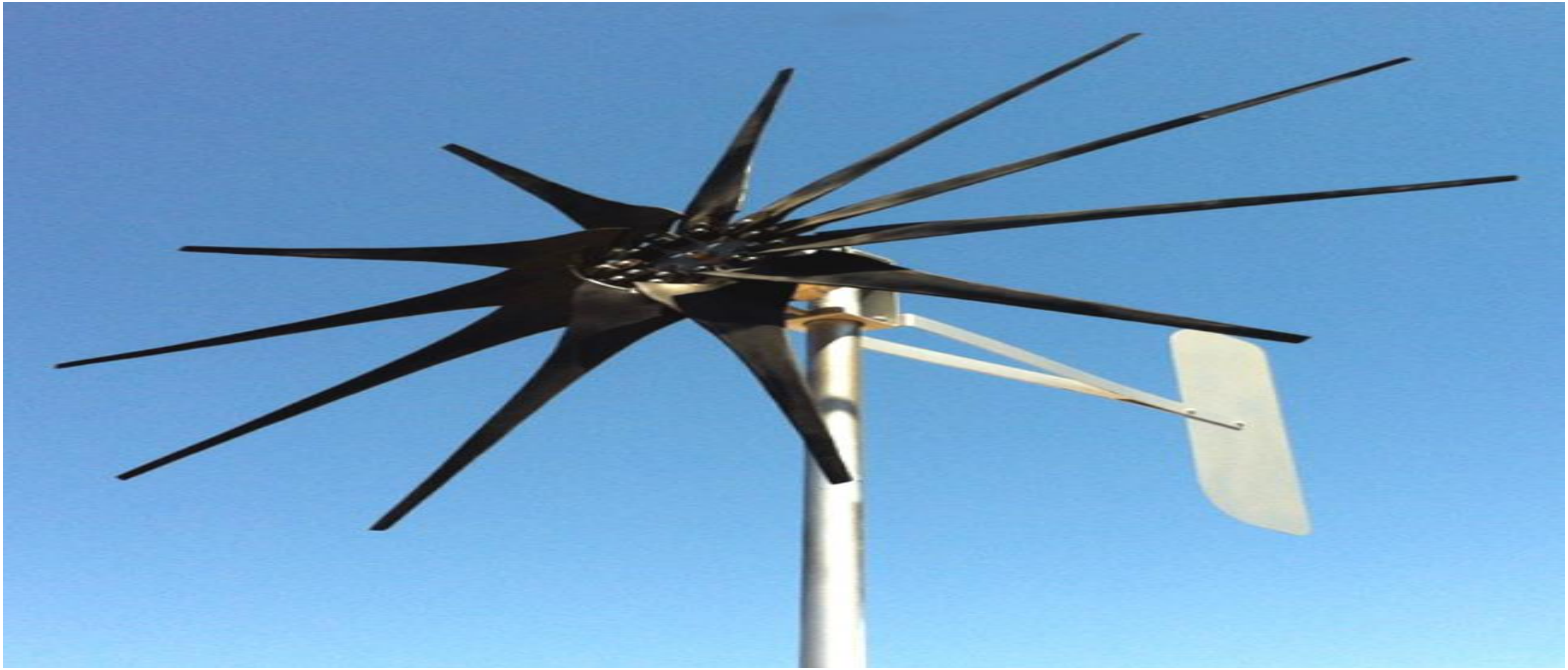
Higher rotational speed imposes more mechanical stress on (i)blade(ii)turbine structure & other components, e.g

- bearings and gearbox,
- leading to more design challenges & lower life span.

Rotors with more than 3 blades are not common since they are more expensive (more blades).

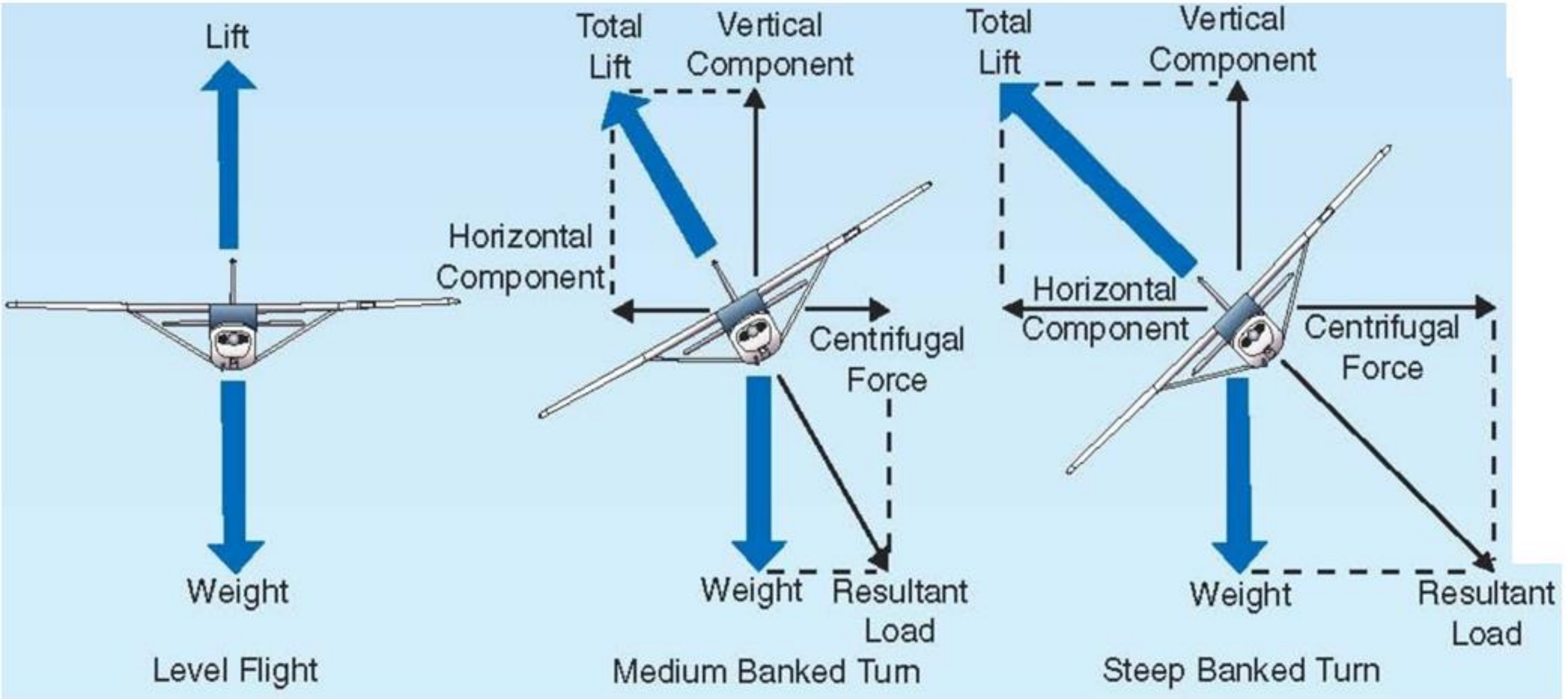
Operating at lower rotational speeds requires higher gear ratio.

Lagging wind turbulence of 1 blade can affect other blades since they are closer to each other.

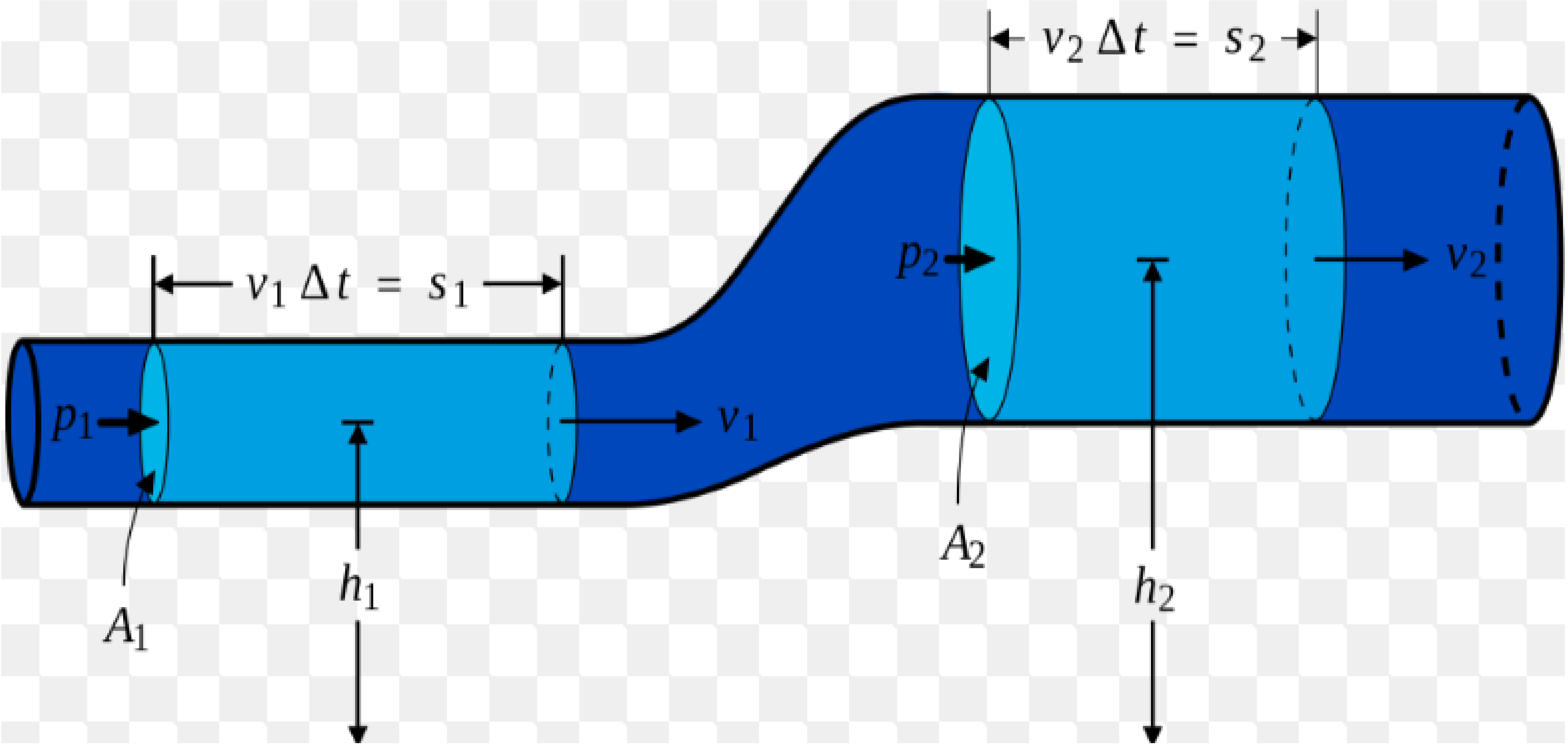


Hence 3 blade rotor presents the best trade-off between mechanical stress, acoustic noise, cost & rotational speed for large wind turbines.

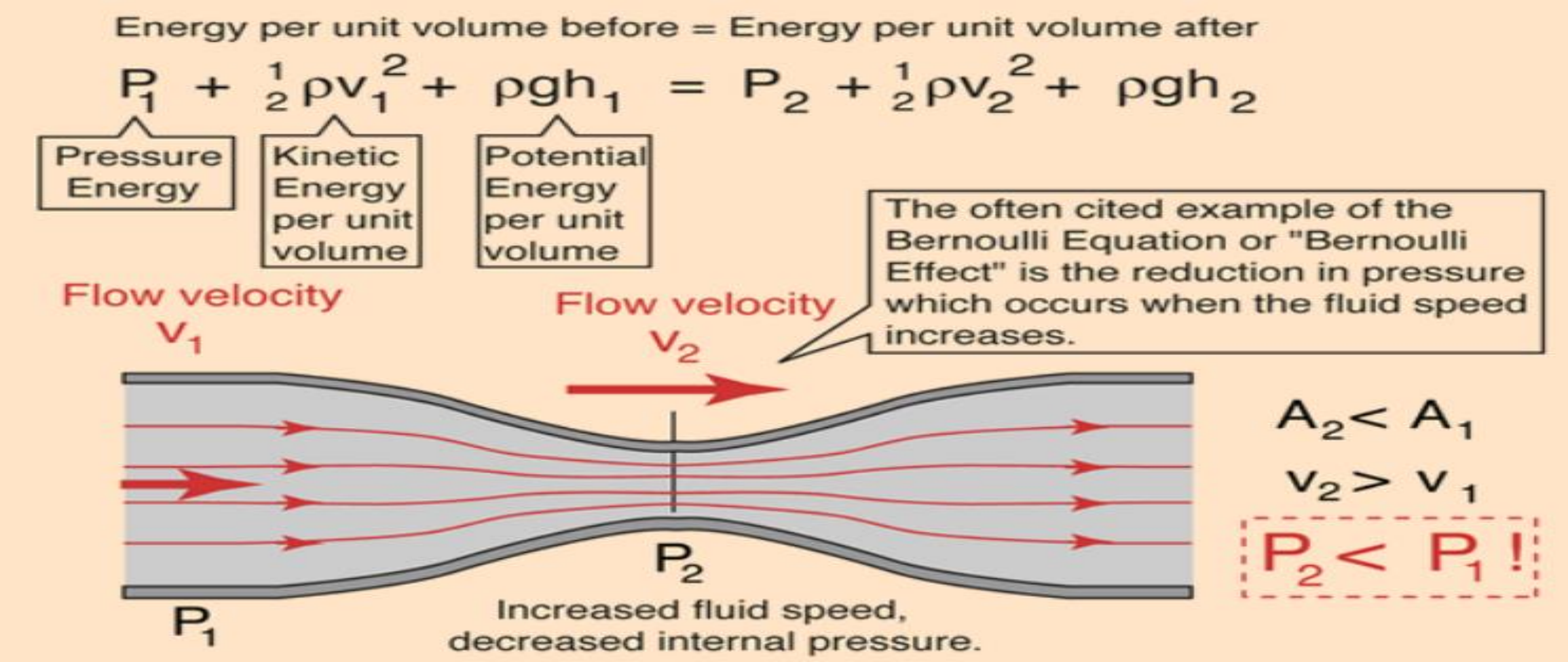
Aerodynamic operating principle of turbine is similar to wings of an aeroplane.



What is Bernoulli's principle?



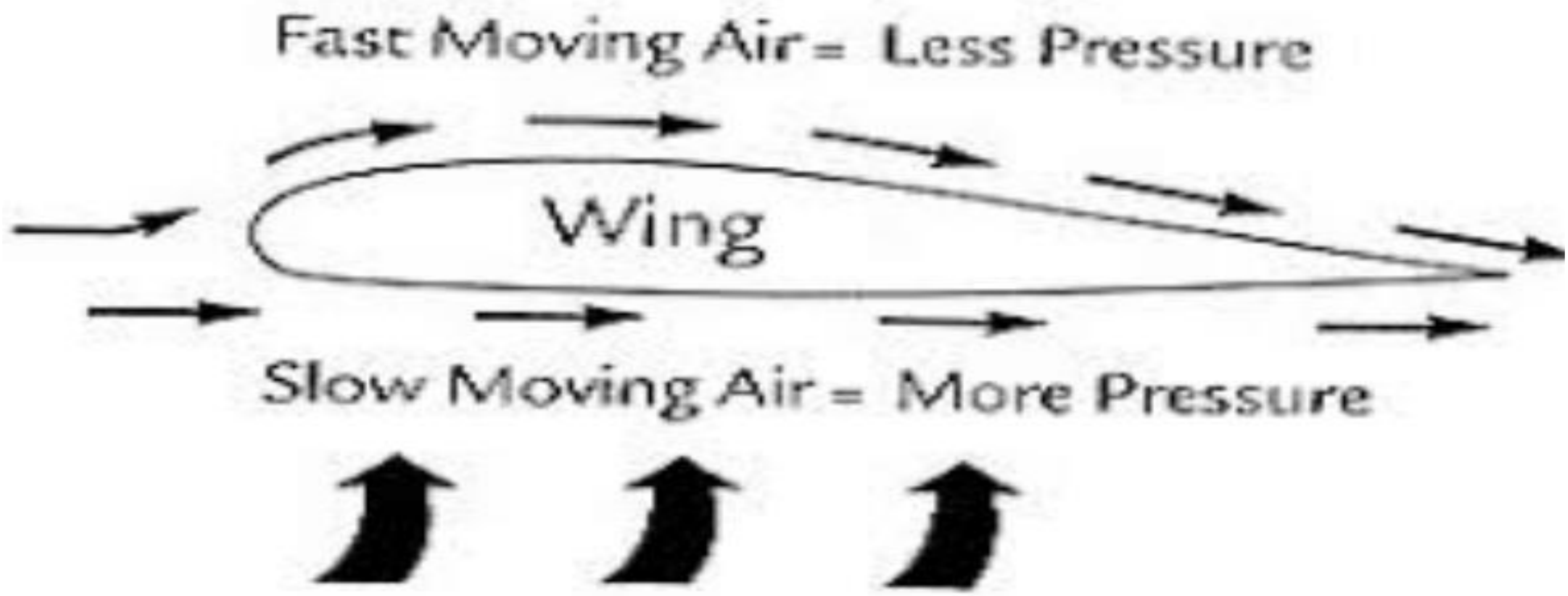
Bernoulli’s principle: **“As speed of a moving fluid (liquid or gas) increases, pressure within fluid decreases”.**



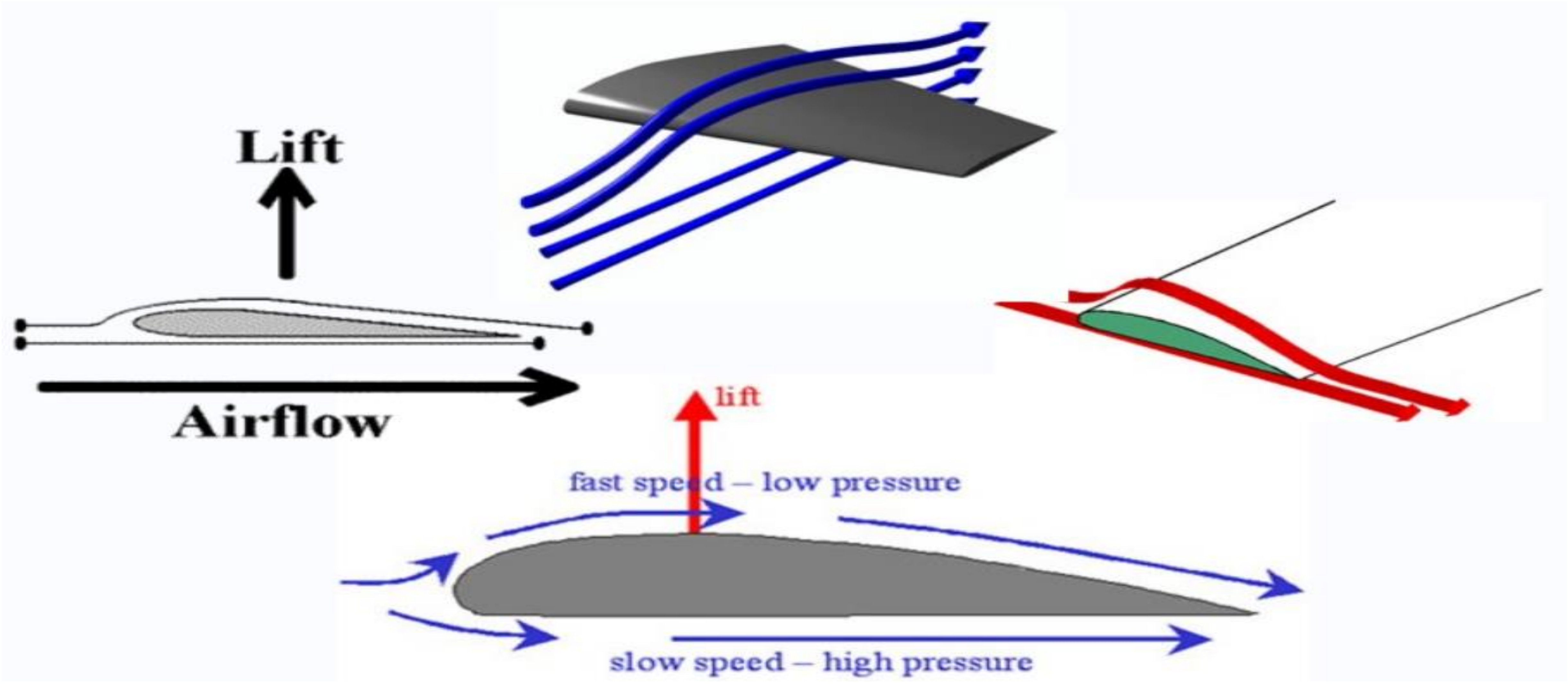
The top of the wing is?

The top of the wing is curved

The top of the wing is curved



Air moves quickly over the curved blade with low Pressure. On lower part of blade, wind speed is slow with high pressure. Hence wing is pushed(lift) up-ward.

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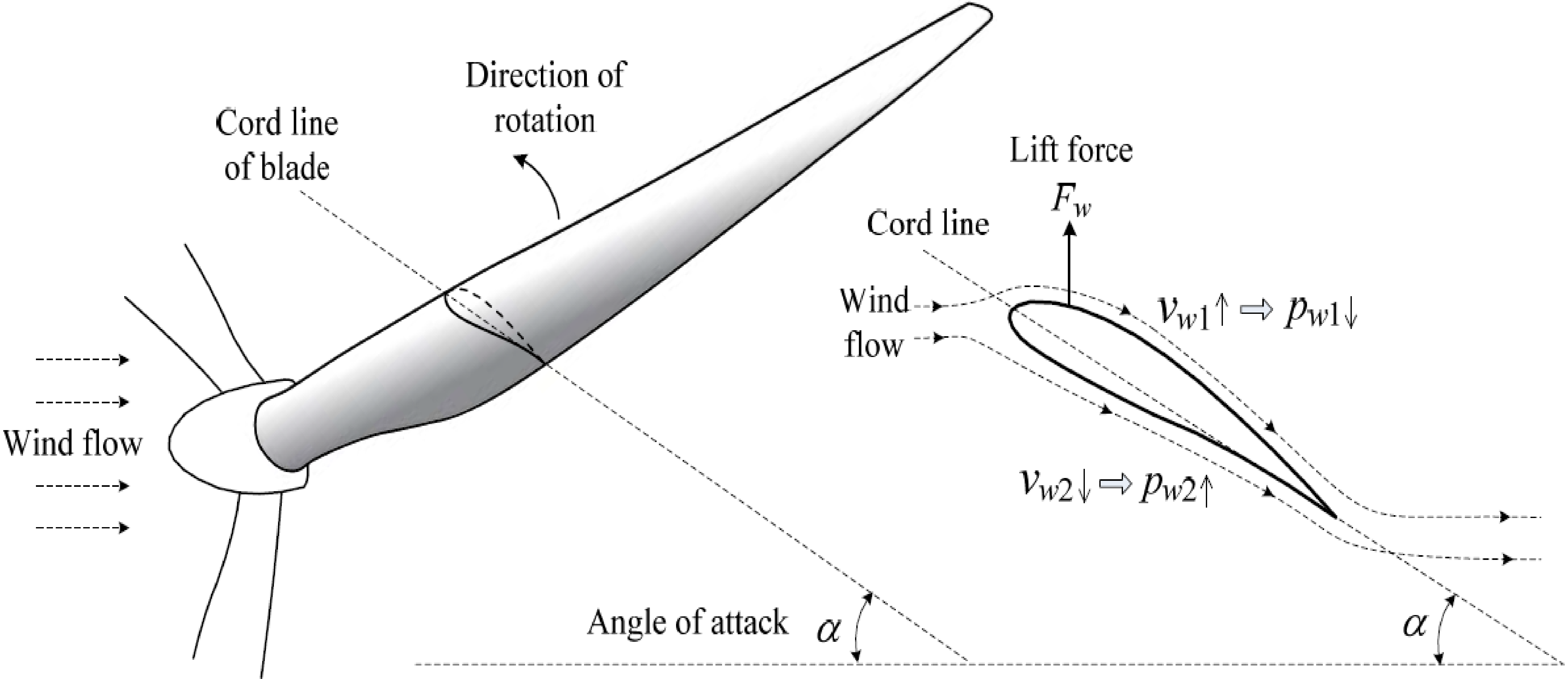
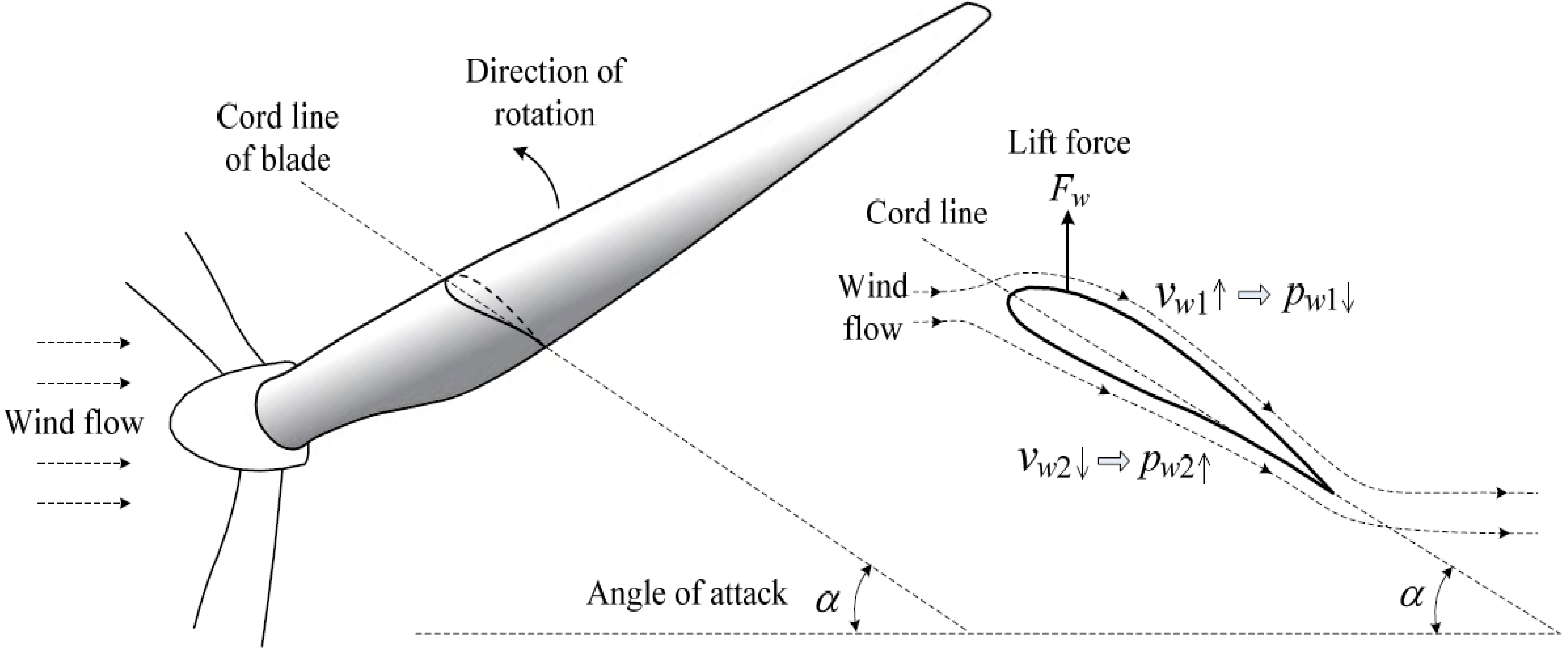
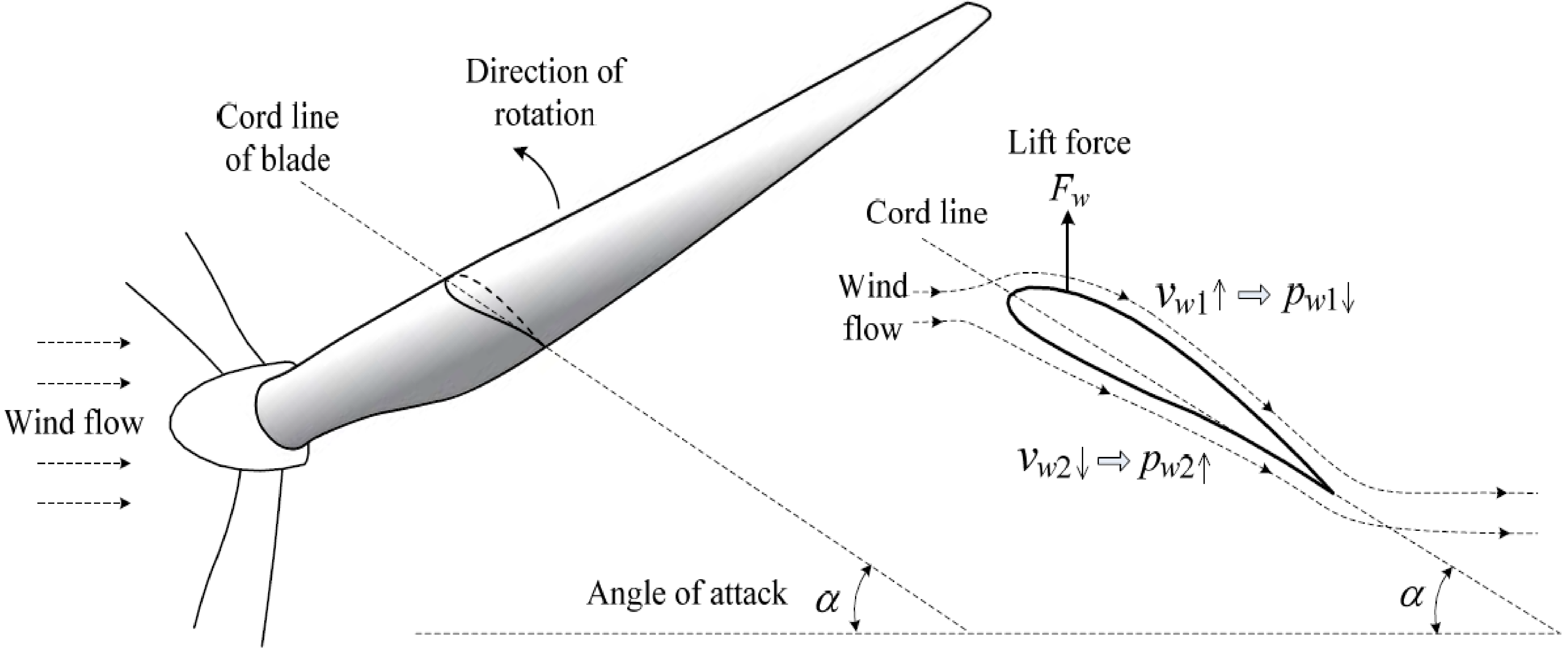
Curved shape of blade creates a difference between wind speed above V_{w1} & below V_{w2} blade



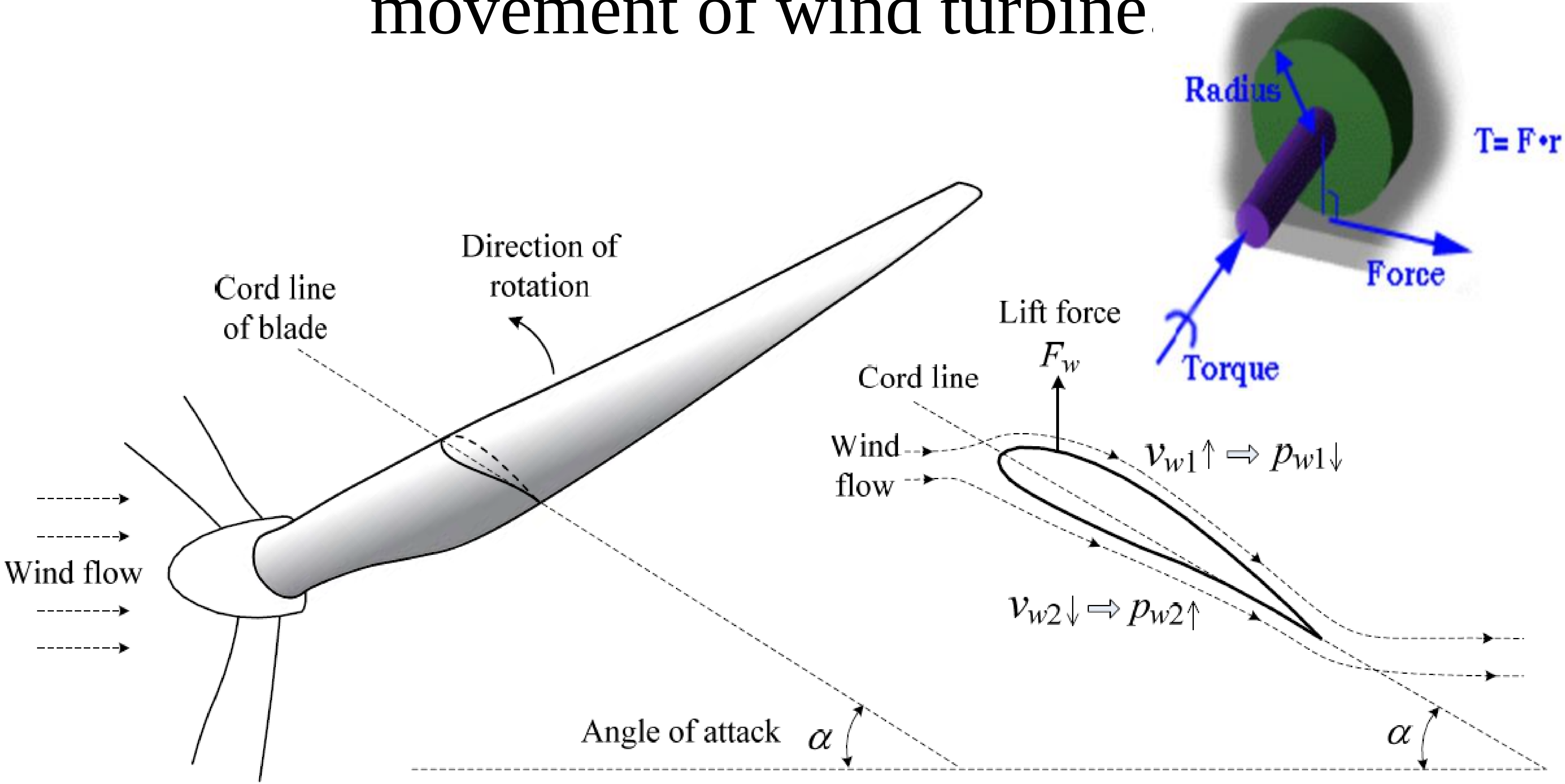
Airflow above blade is faster than the one below , $(V_{w1} \succ V_{w2})$ which according to Bernoulli's principle has inverse effect on pressure $(p_{w2} \succ p_{w1})$



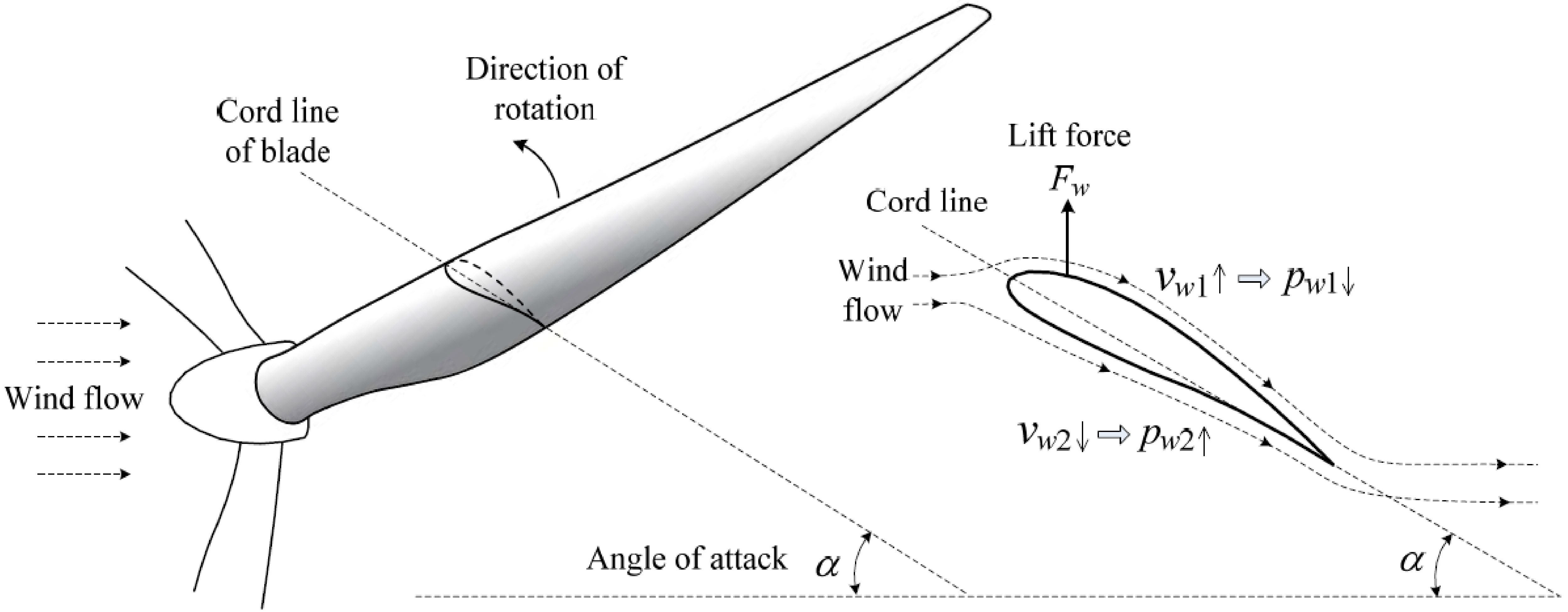
Pressure difference between top & bottom of blade results in a net lift force *Fw* on blade.



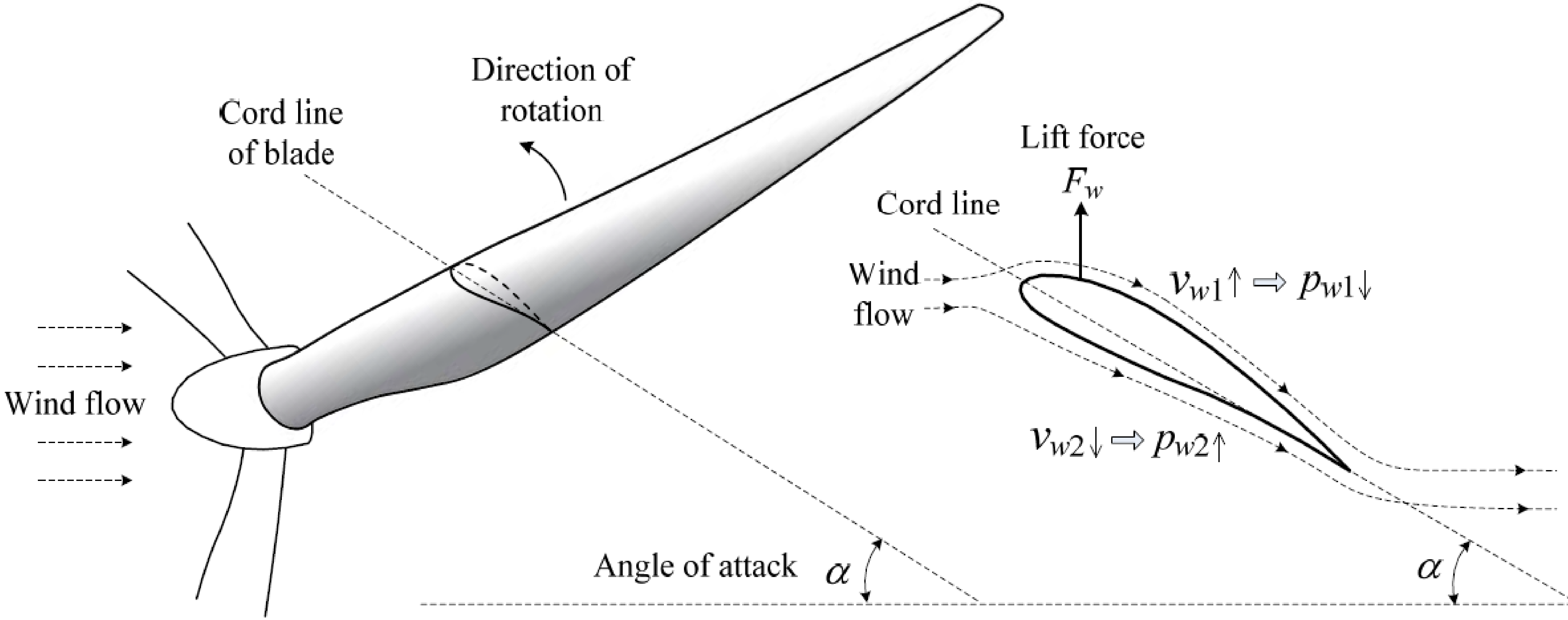
Applied force produces torque creates rotational movement of wind turbine.



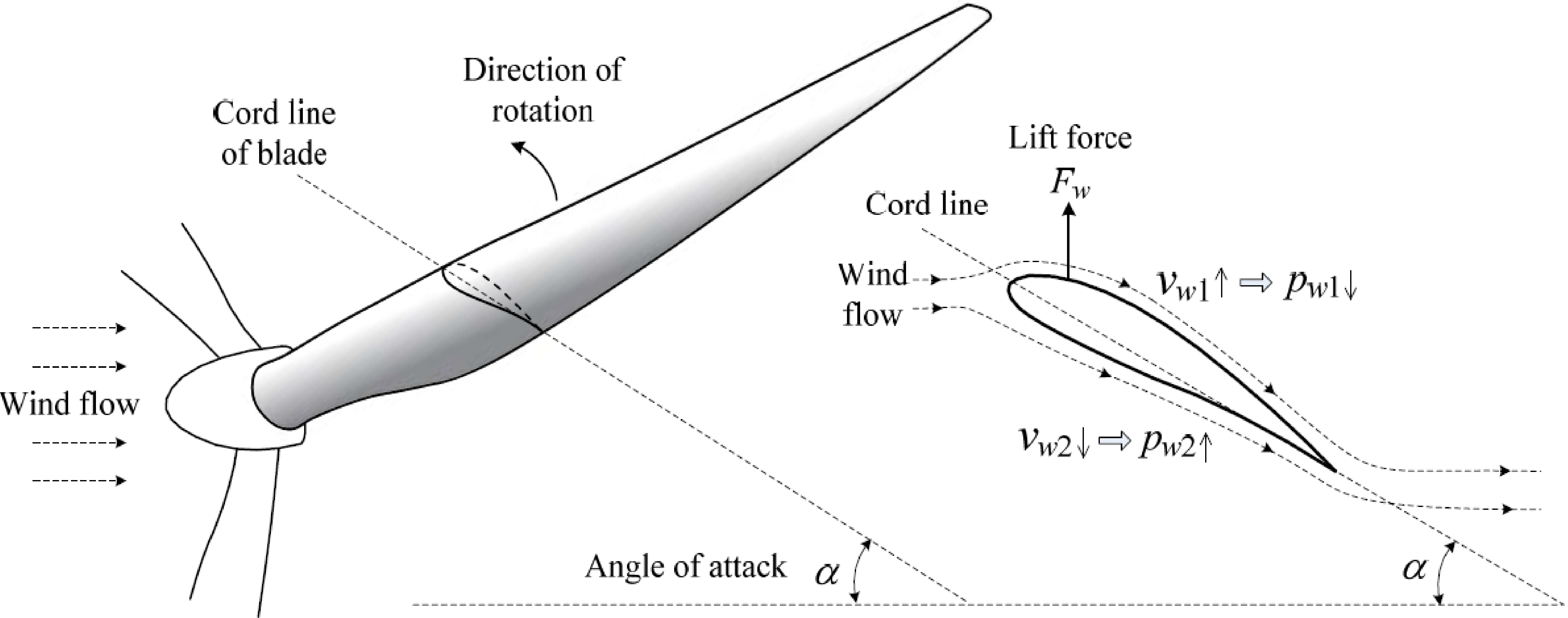
How to control lift force of blade?



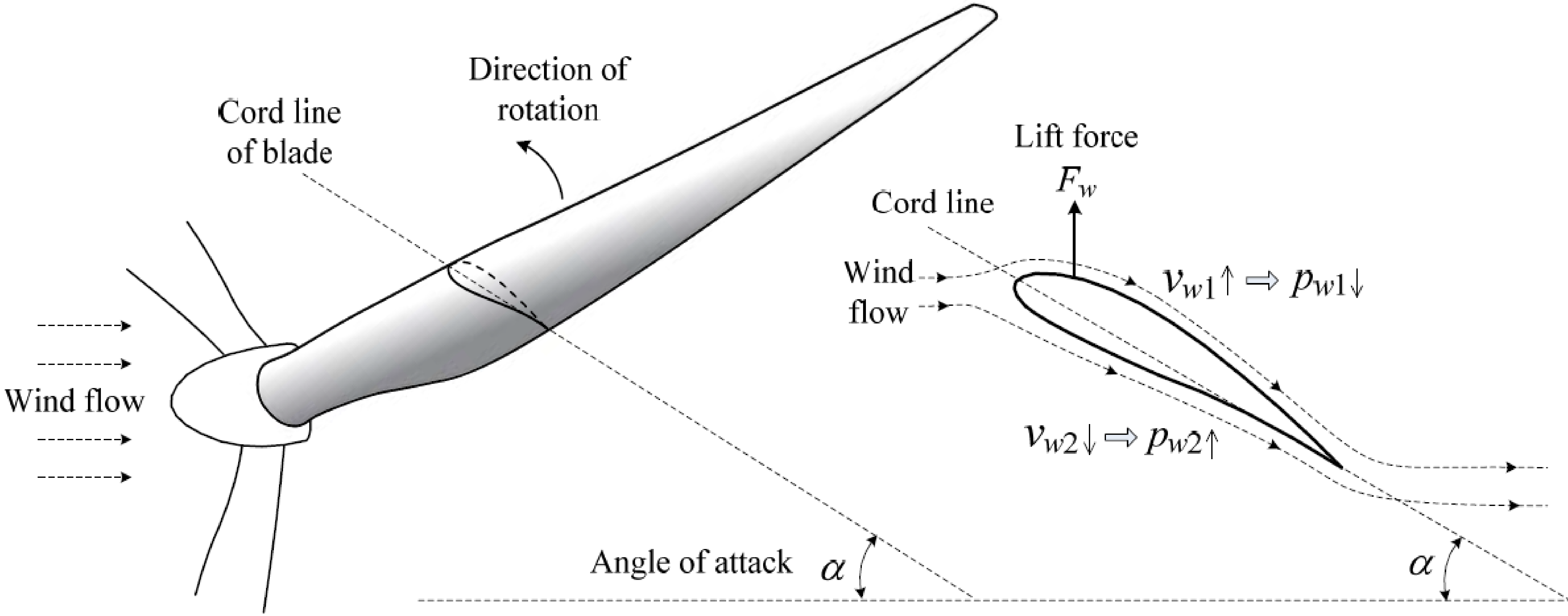
Angle of attack α can control lift force of blade



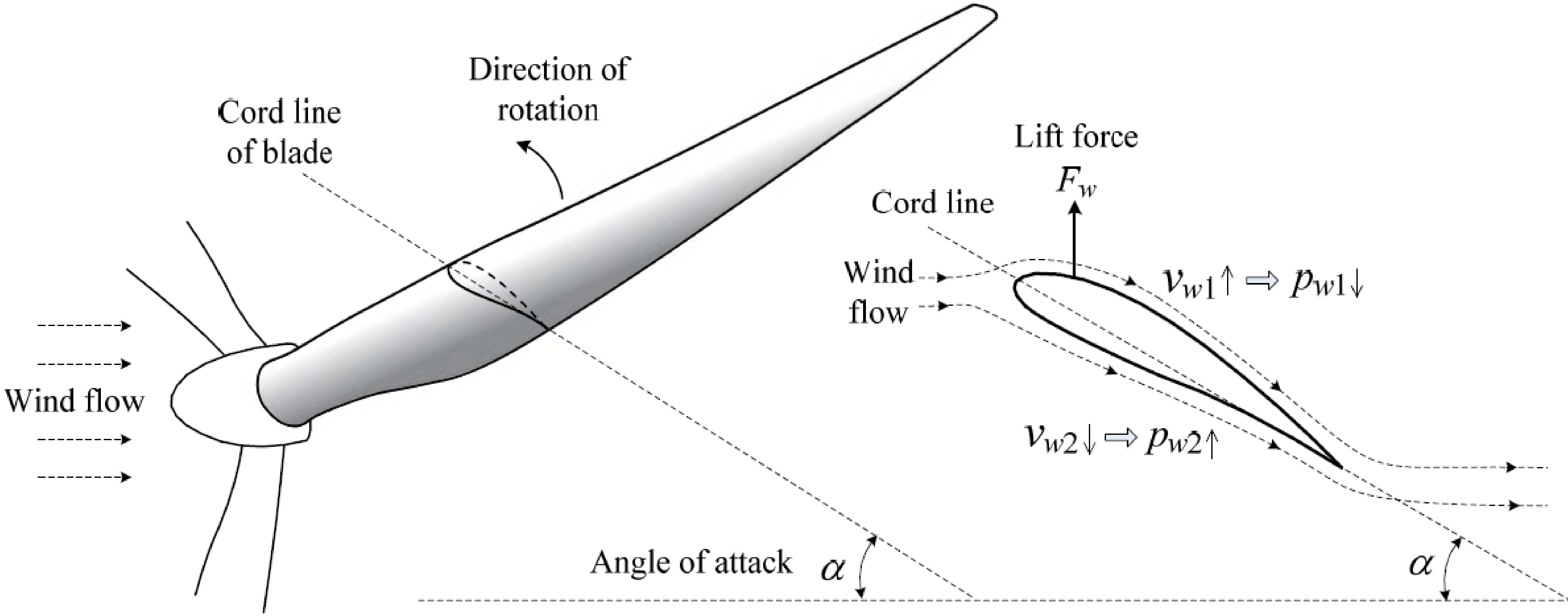
Angle of attack α is an angle between direction of wind speed v_w & cord line of blade



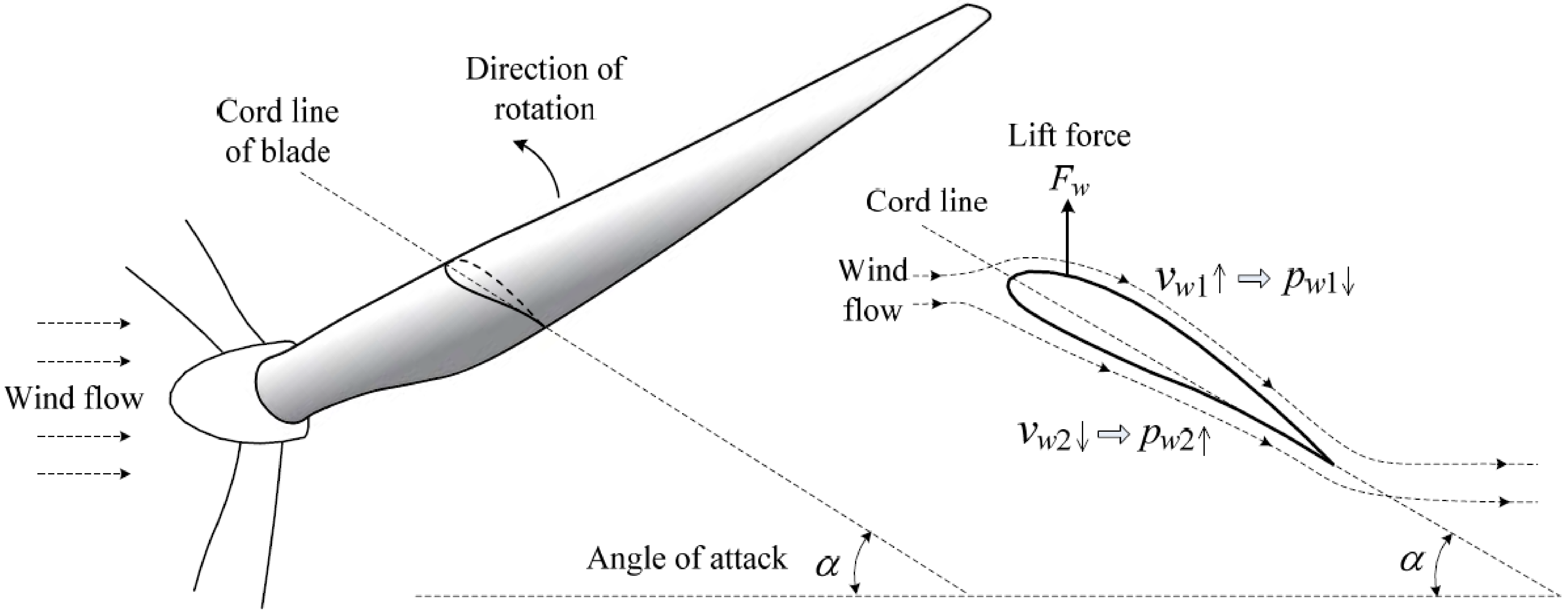
For a given blade, its lift force Fw can be adjusted by α.



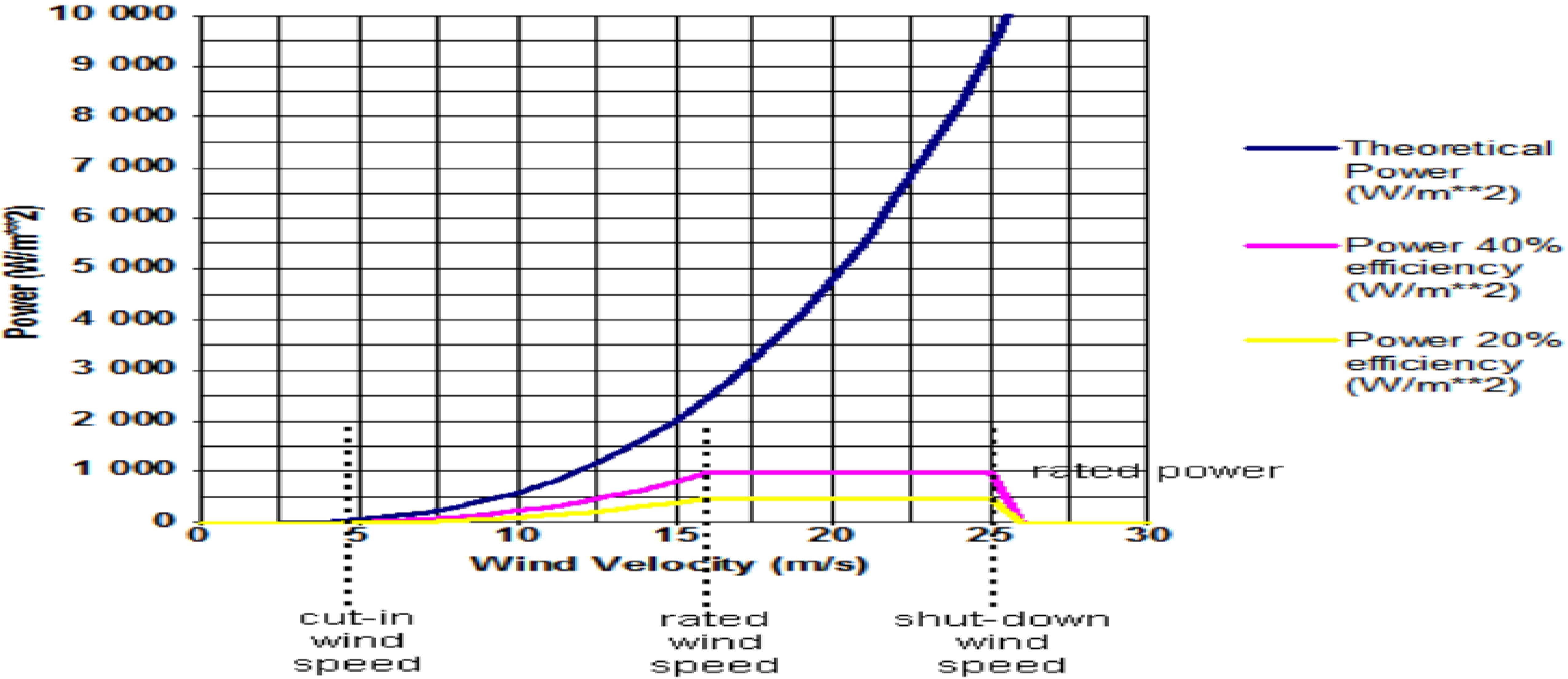
When α=0, lift force or torque will be produced?



α=0 when wind turbine is **stopped (parked) for maintenance or repair.**



The power of an air mass



Power of an air mass flowing at speed v_w through an area A can be calculated by:

$$P_w = \frac{1}{2}\,\boldsymbol{\rho} A v_w^3$$

where ρ is the air density in___?

A is the sweep area in ___& v_w is the wind speed in_____?

.

$$P_w = \frac{1}{2}\,\boldsymbol{\rho} A v_w^3$$

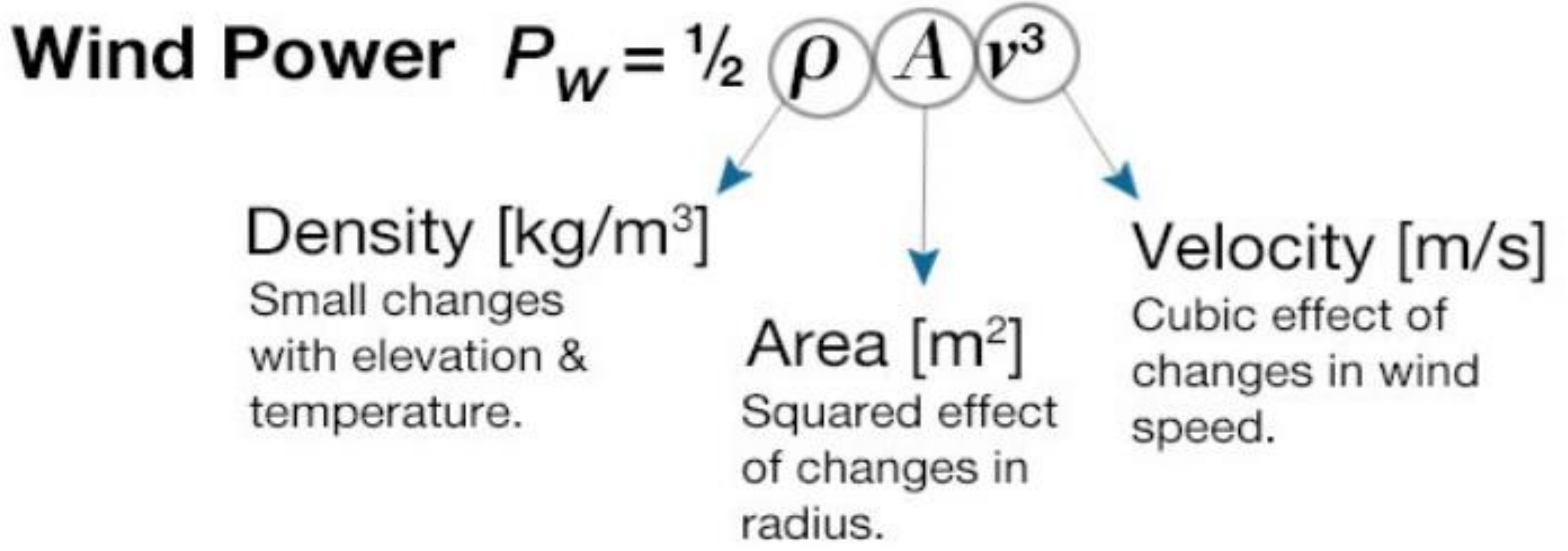
where ρ is the air density in $\frac{Kg}{m^3}$

A is the sweep area in m^2 &

v_w is the wind speed in m/sec.

.

Air density ρ is a function of air pressure & air temperature. At sea level & temperature of 15°C, air has a density of approximately ρ=1.2 $\frac{Kg}{m^3}$



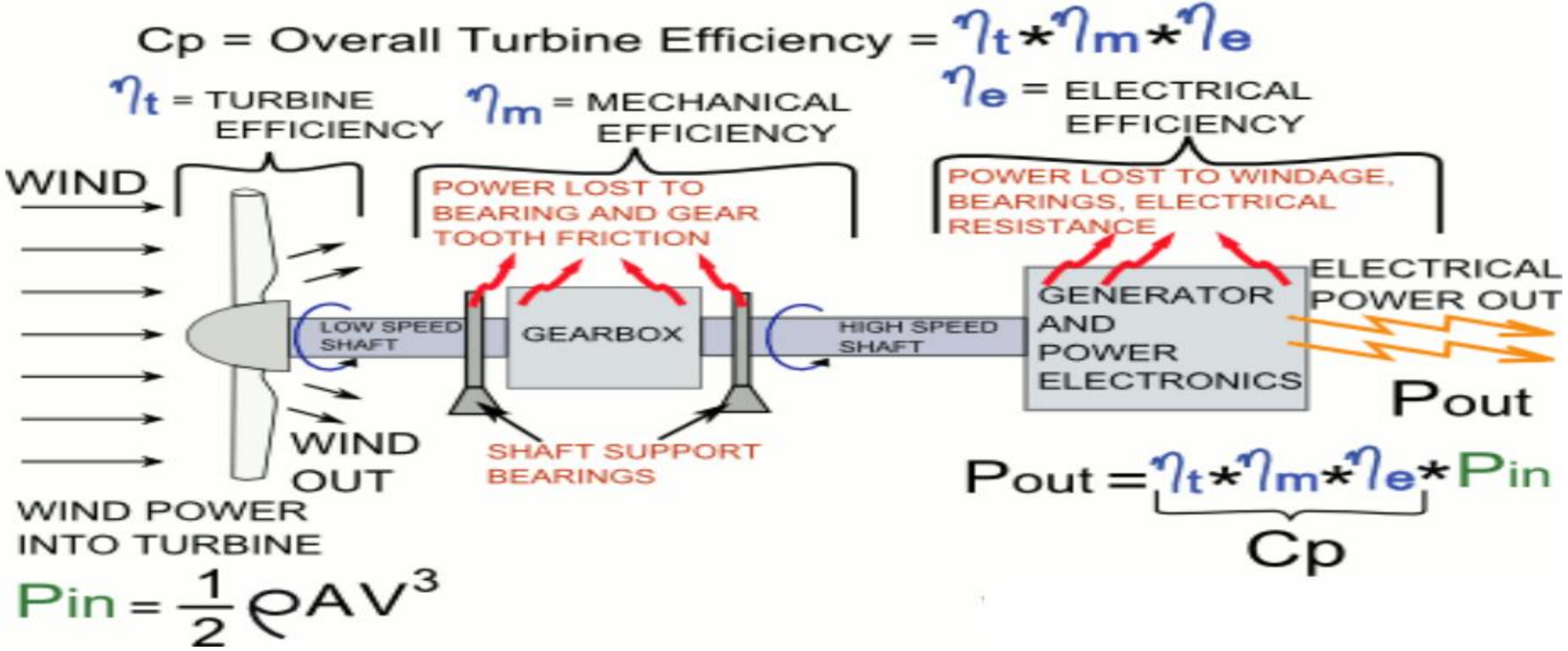
*P*ower coefficient of the blade(*Cp*)

- Wind power captured by blade & converted into mechanical can be calculated by:

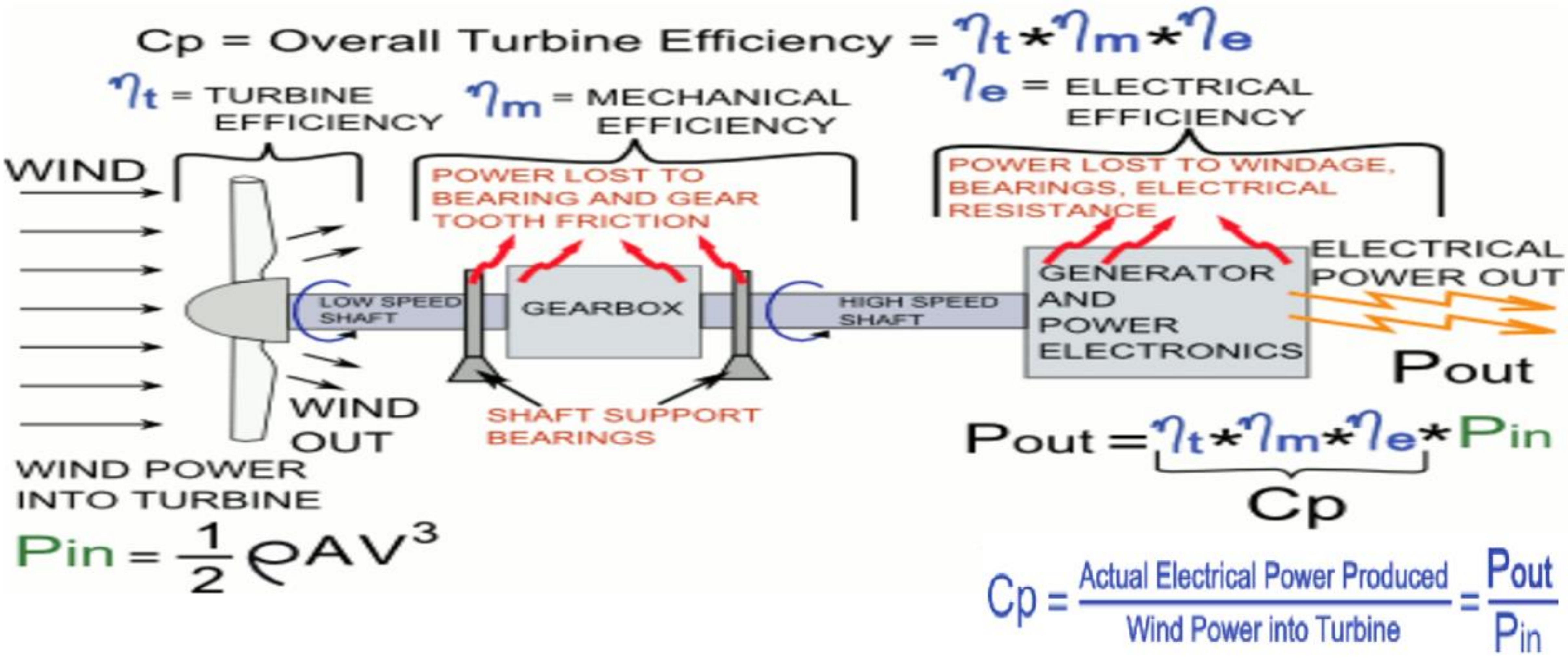
$$P_M = \frac{1}{2}\rho A v_w^3 C_p$$

where *Cp* is power coefficient of the blade.

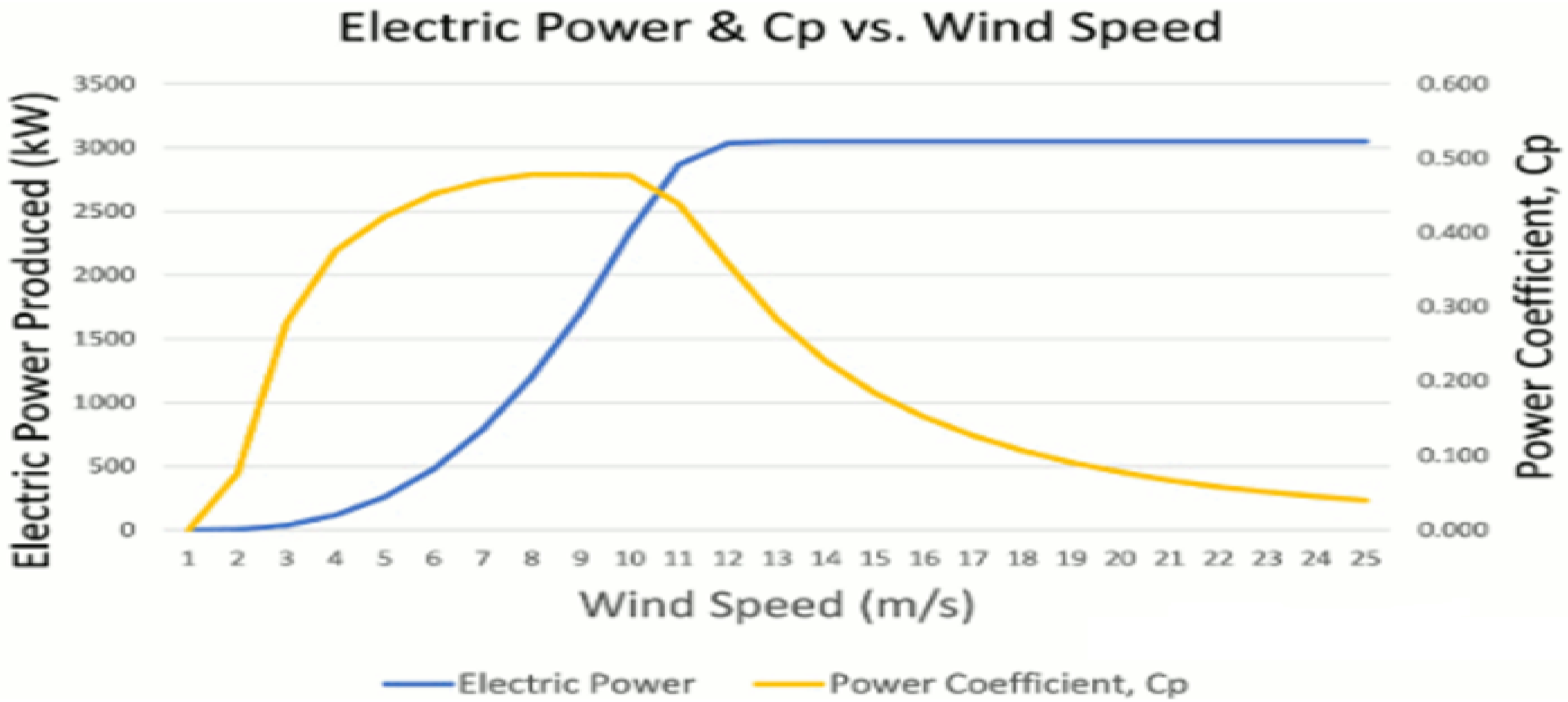
Power Flow in a large wind turbine



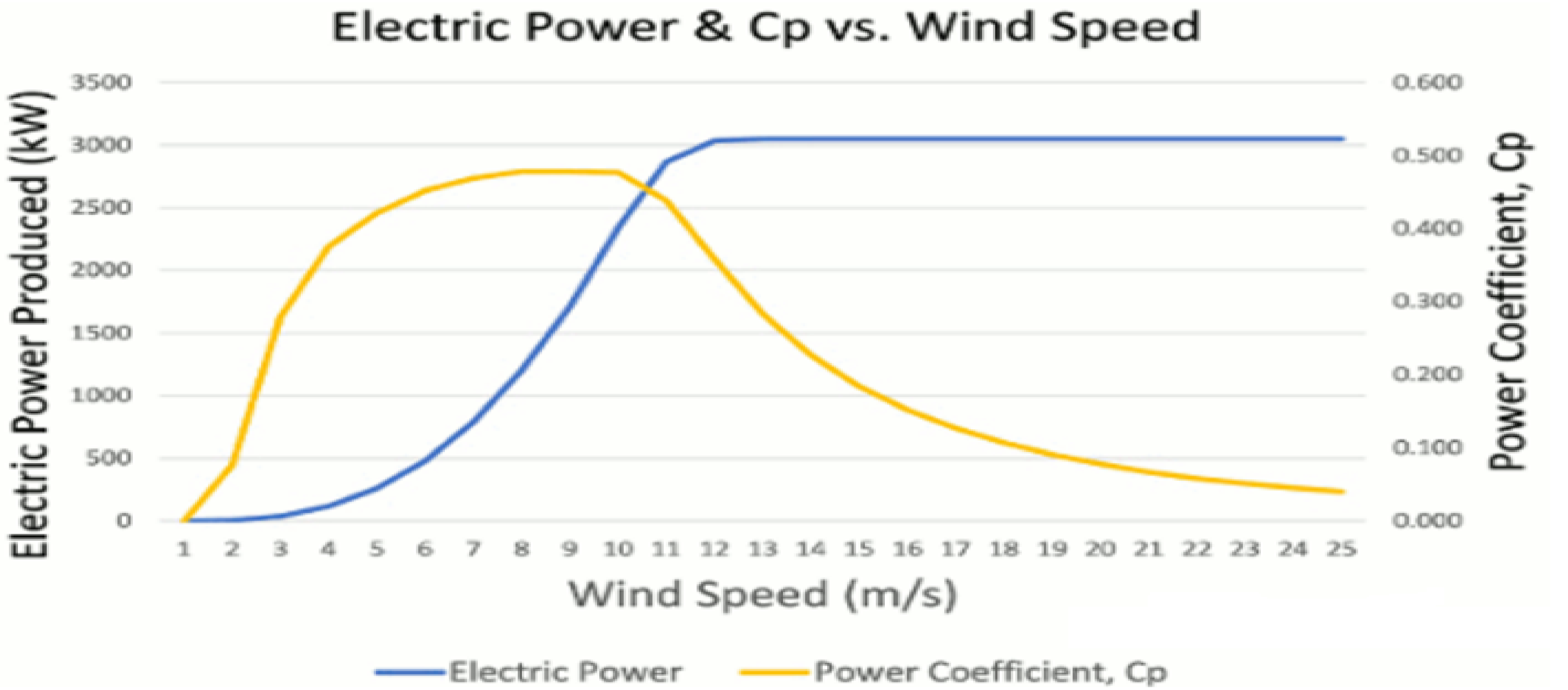
Power Coefficient - An Indicator of Total Wind Turbine System Efficiency



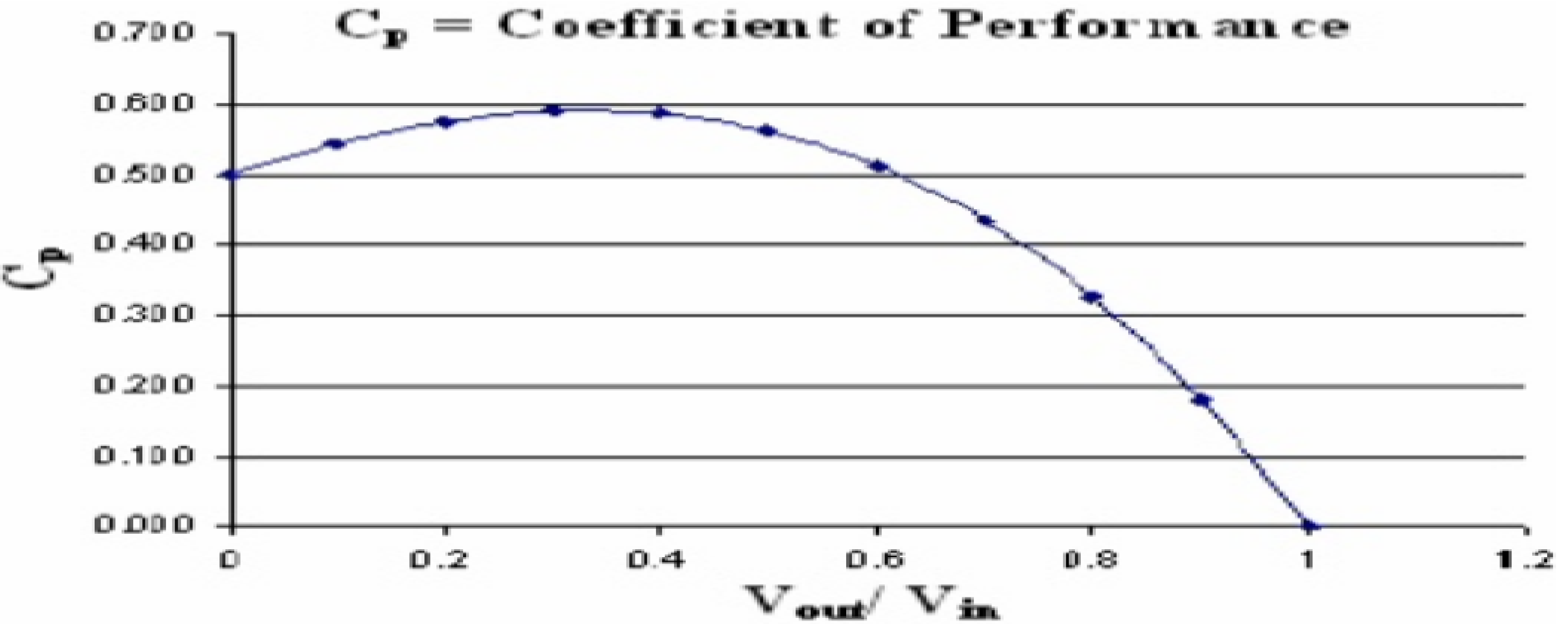
Power Coefficient, Cp, (yellowish line) & Electric Power Out, Pout, (blue line) versus wind speed in meters per second.



With today's technology, power coefficient(Cp) of a modern turbine usually ranges from 0.2-0.5, which is a function of rotational speed & number of blades.



Power coefficient has a theoretical maximum value of 16/27=0.593 according to the Betz limit.



For a 3-blade turbine with a rotor diameter of 82m & power coefficient of $Cp = 0.36$, calculate the captured power in MW at a wind speed of 12 m/sec & air density of $\rho = 1.225\ \frac{Kg}{m^3}$?

Mention 3 possibilities for increasing the captured power P_M by a wind turbine?

$$P_M = \frac{1}{2}\rho A v_w^3 C_p$$

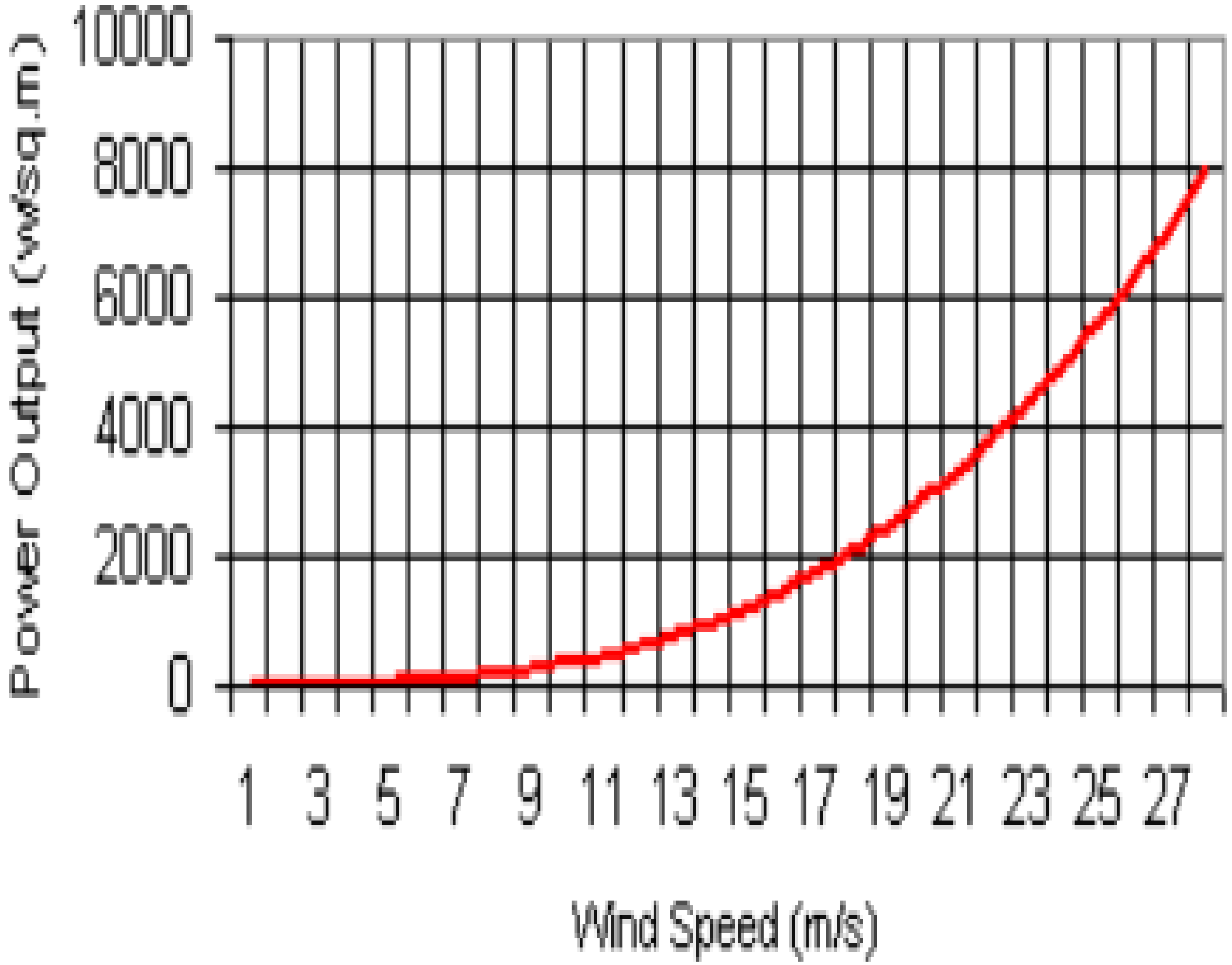
1.Wind speed v_w 2.Power coefficient Cp 3.Sweep area A

$$P_M = \frac{1}{2}\rho A v_w^3 C_p$$

Since wind speed cannot be controlled, only way to increase wind speed is to locate turbines in regions with higher average wind speeds e.g.

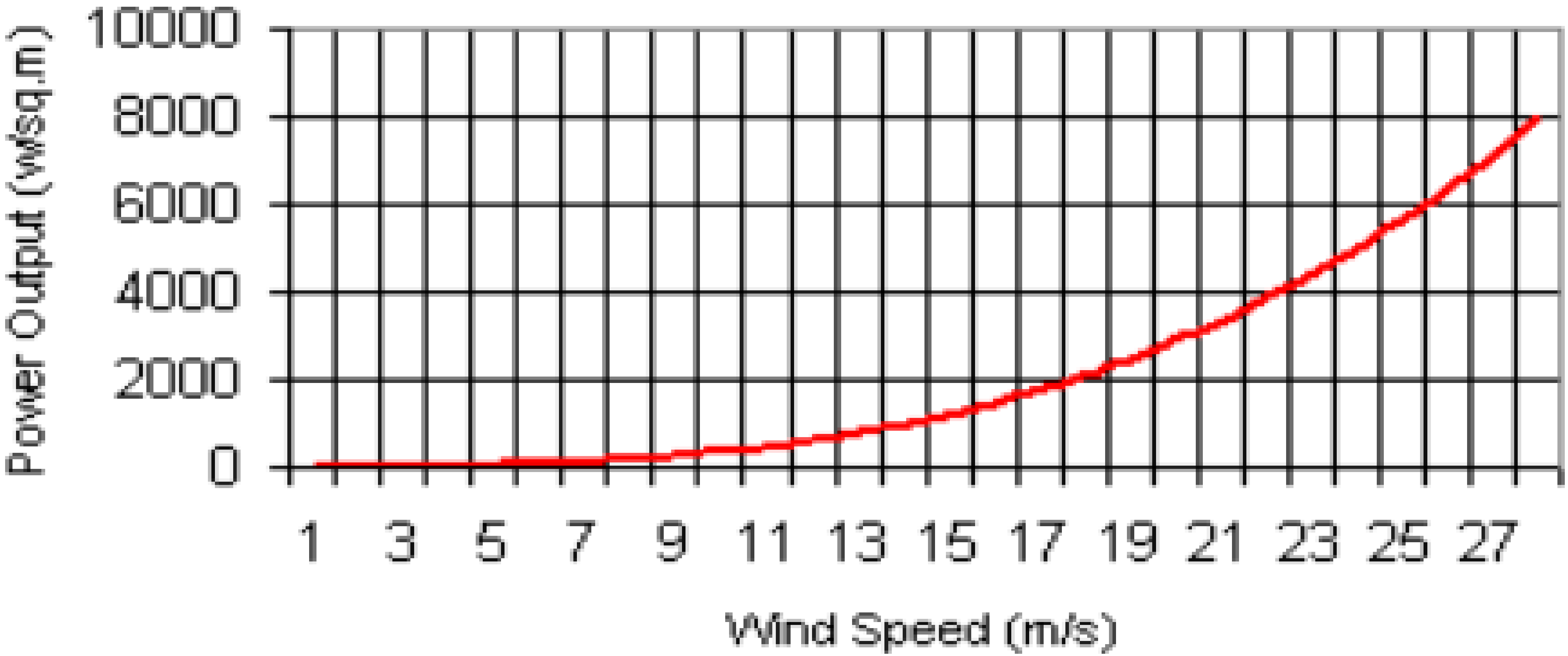
- Offshore wind farms, where wind speed is usually higher & steadier than that on-land.
- Captured power is a cubic function of the wind speed.

$$P_m \propto \omega_r^3$$



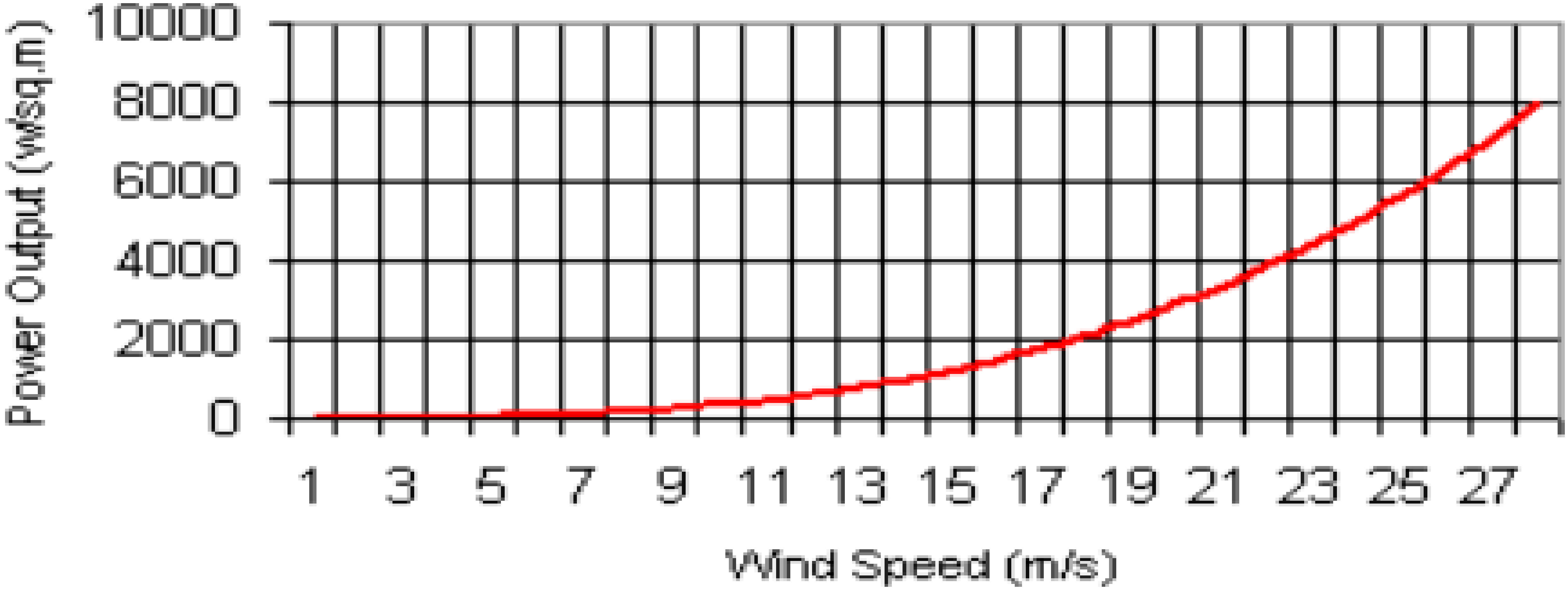
Doubling average wind speed would increase wind power by______times?

$$P_m \propto \omega_r^3$$

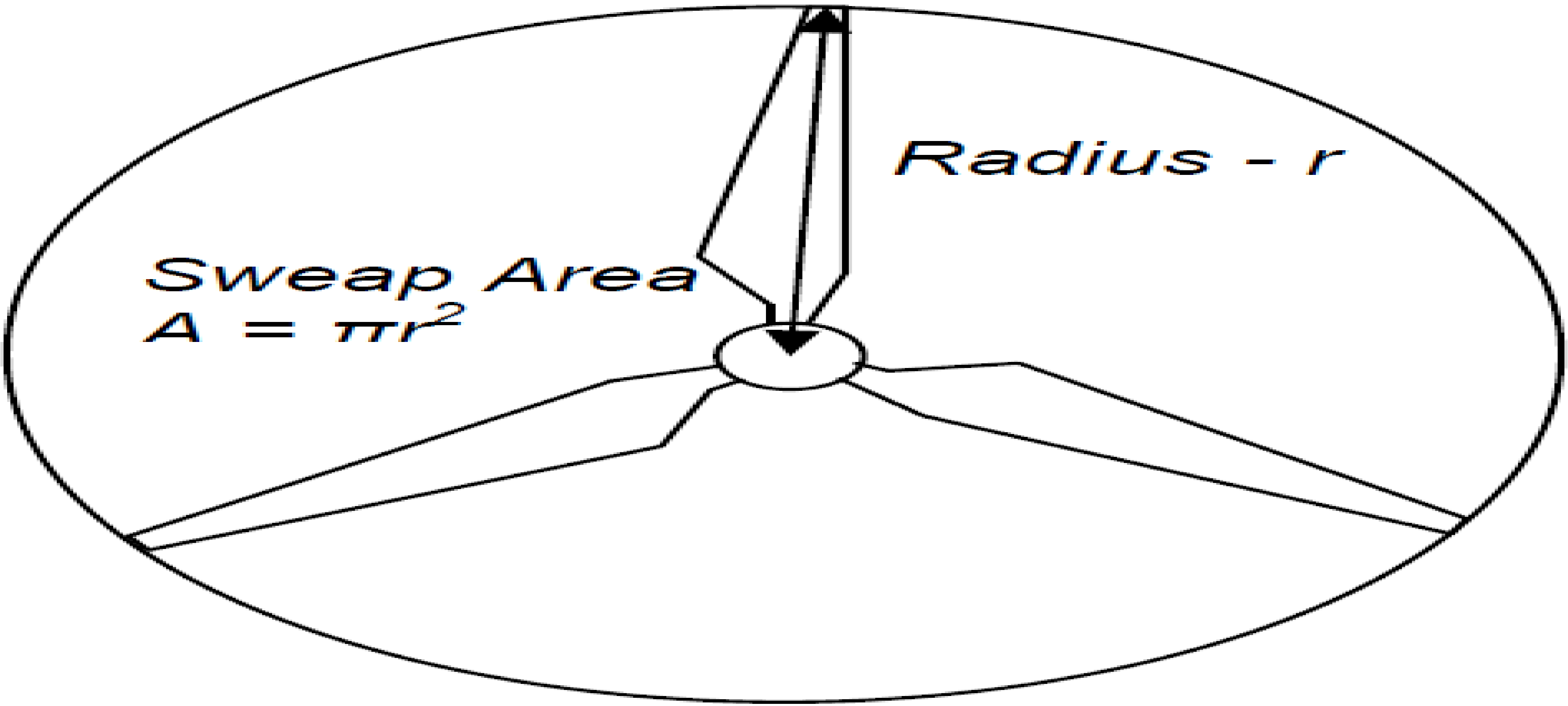


Doubling average wind speed would increase wind power by 8 times.

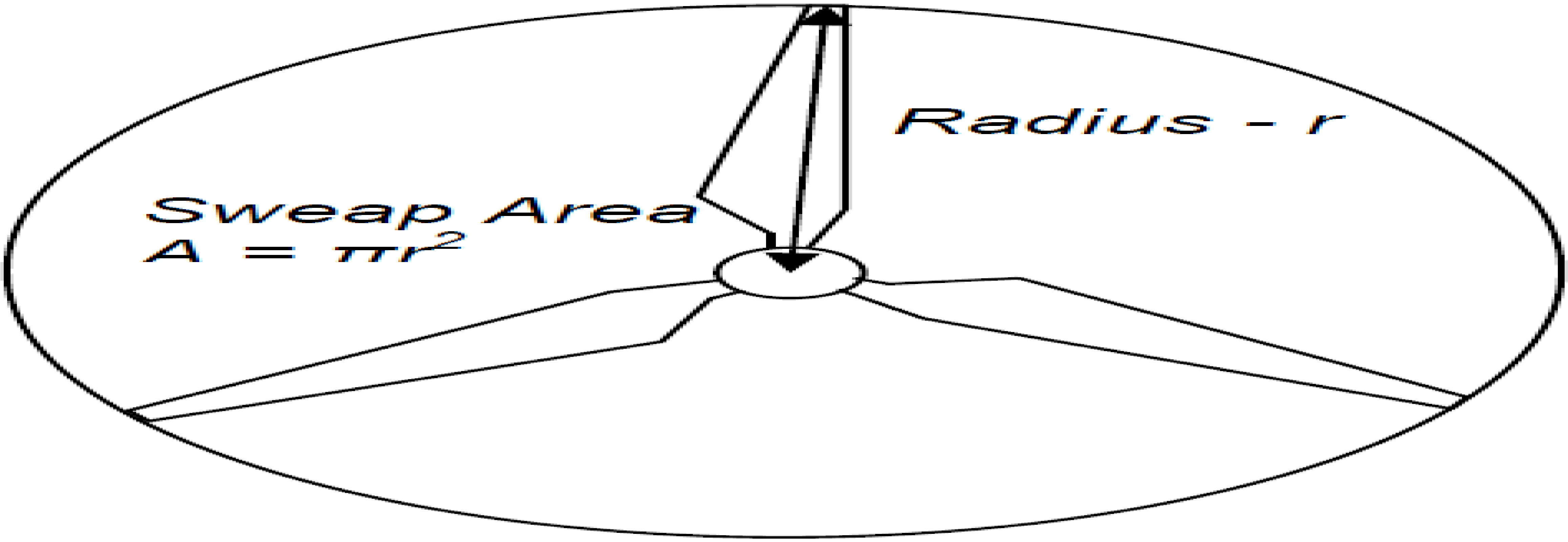
$$P_m \propto \omega_r^3$$



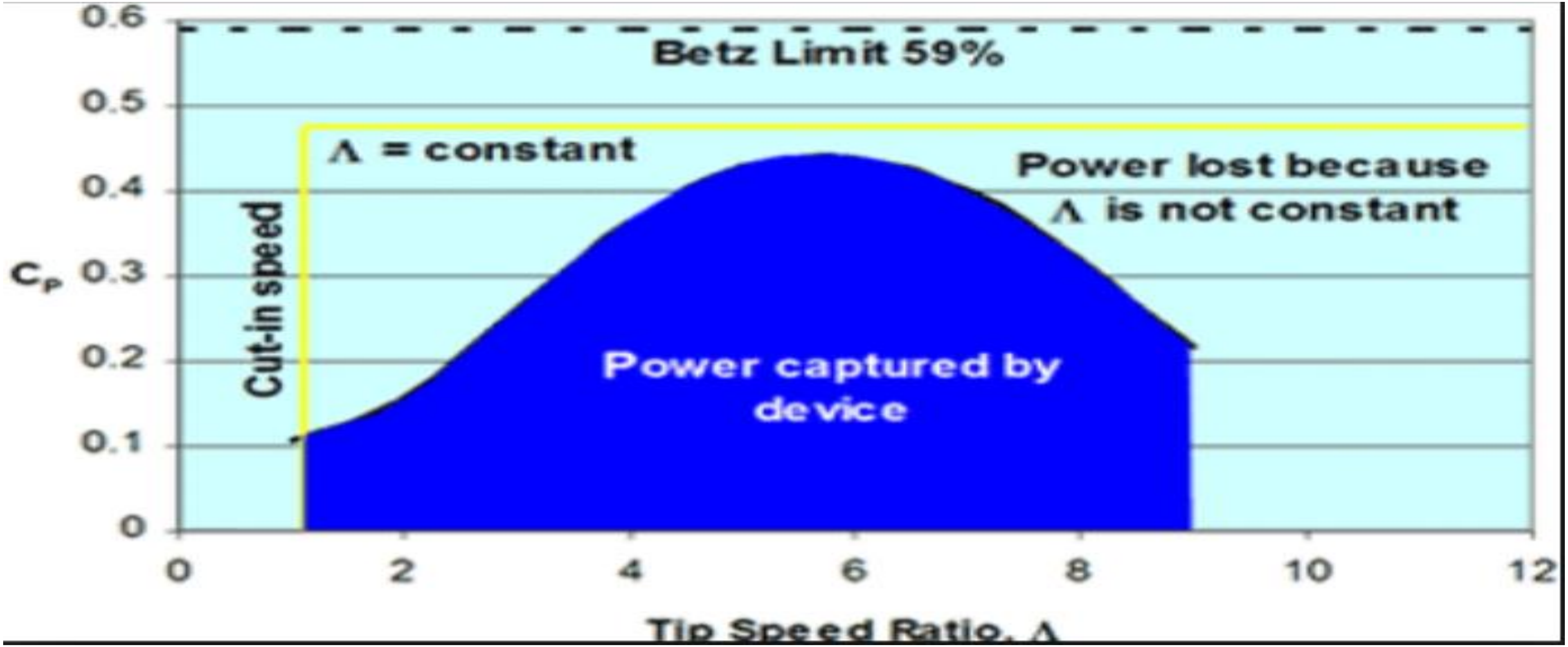
Wind turbine can be designed with larger sweep area (i.e., longer blades) to capture more power.



Sweep area $A = \pi l^2$ where l is blade length. An increase in blade length has a quadratic effect on sweep area & captured power. This explains trend of increasing rotor diameter experienced during last decade.



3rd way of increasing captured power is by improving power coefficient *Cp* of blade through a better aerodynamic design.

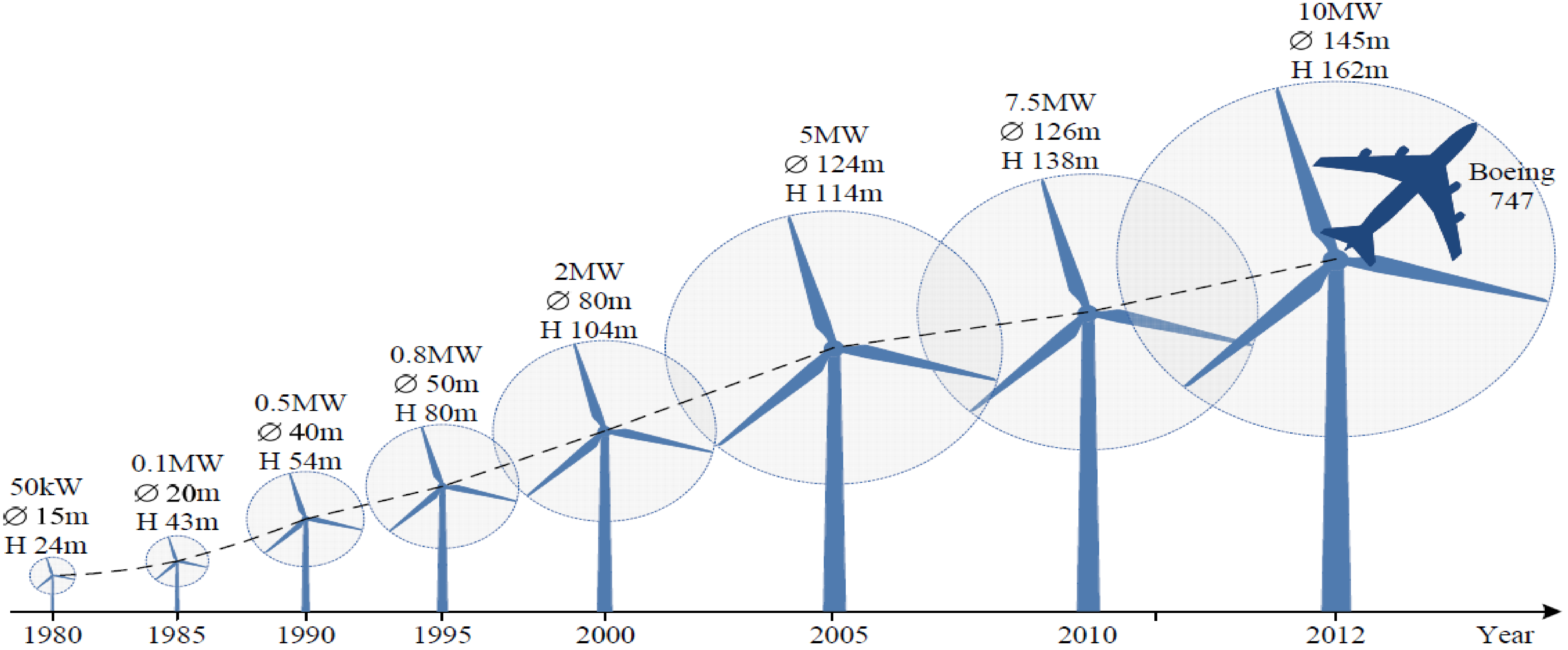


Additional blade requirements make blade design a challenging task.

1. Lightning protection
2. Audible noise reduction
3. Transportation
4. Optimum shape & weight
5. As well as manufacturability.

Blade manufacturing is a tedious process & requires careful planning & large factory space.

Considering that blade length of a 10MW wind turbine is as long as a Boeing 747,one can appreciate complexity & potential manufacturing issues.



Blade transportation & installation are other great challenges.