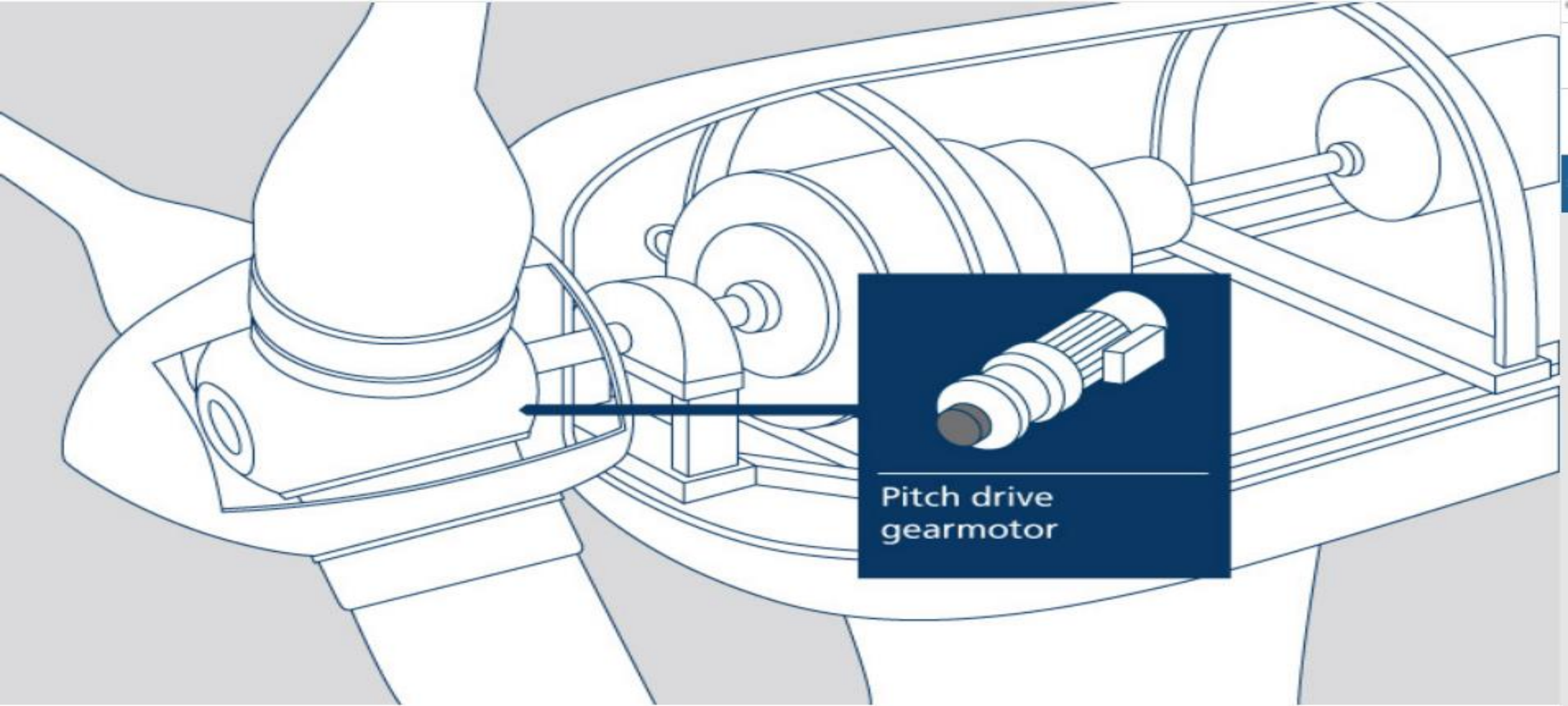
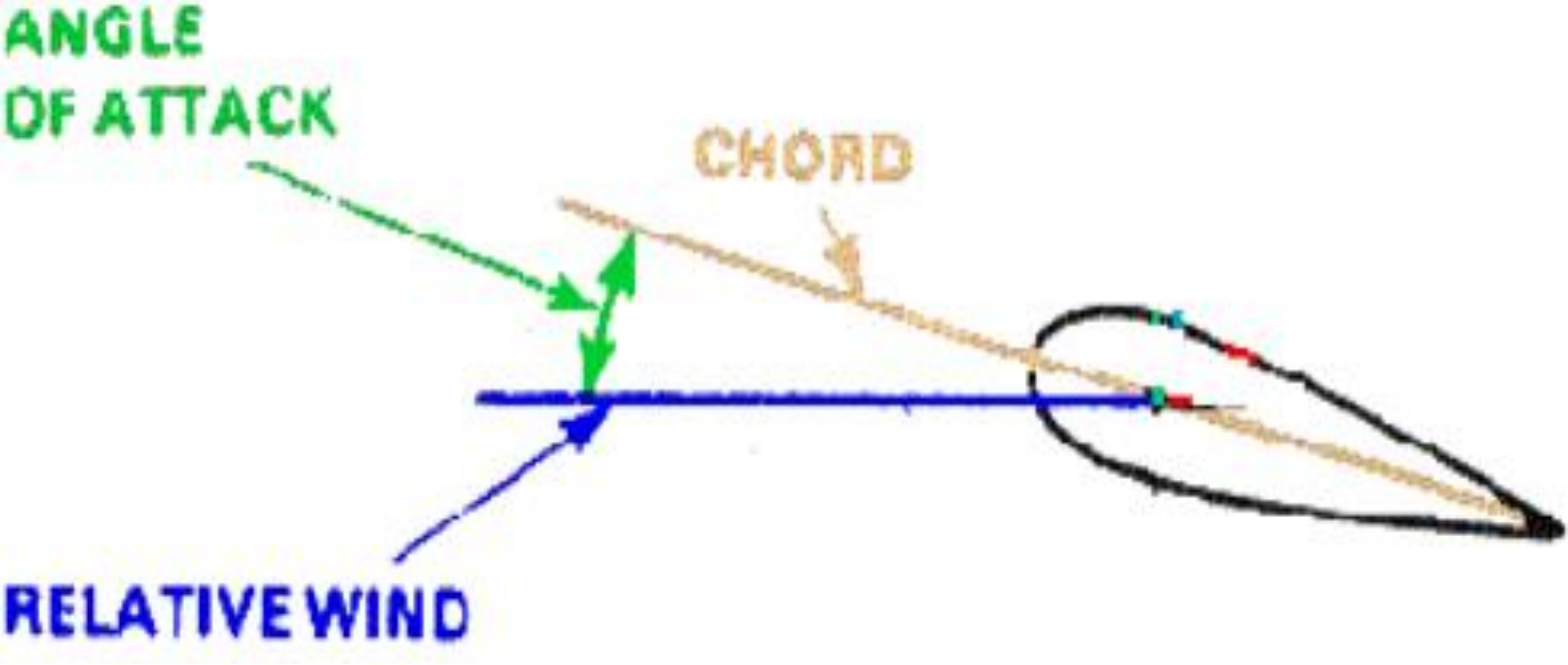
Lecture#04

2.2.2 Pitch Mechanism



Pitch mechanism turns angle of attack of blades into or out of wind to control production or absorption of power



Pitch mechanism in large wind turbines enables rotation of blades on their longitude axis.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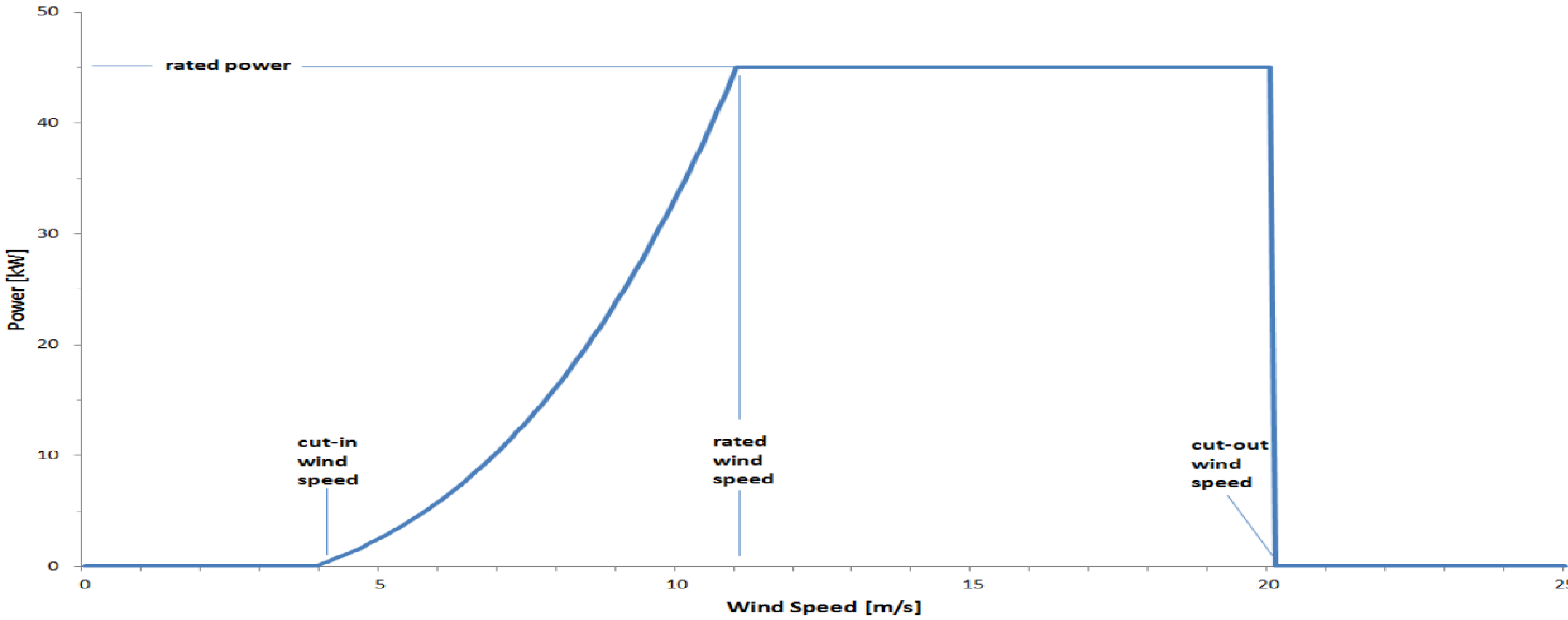
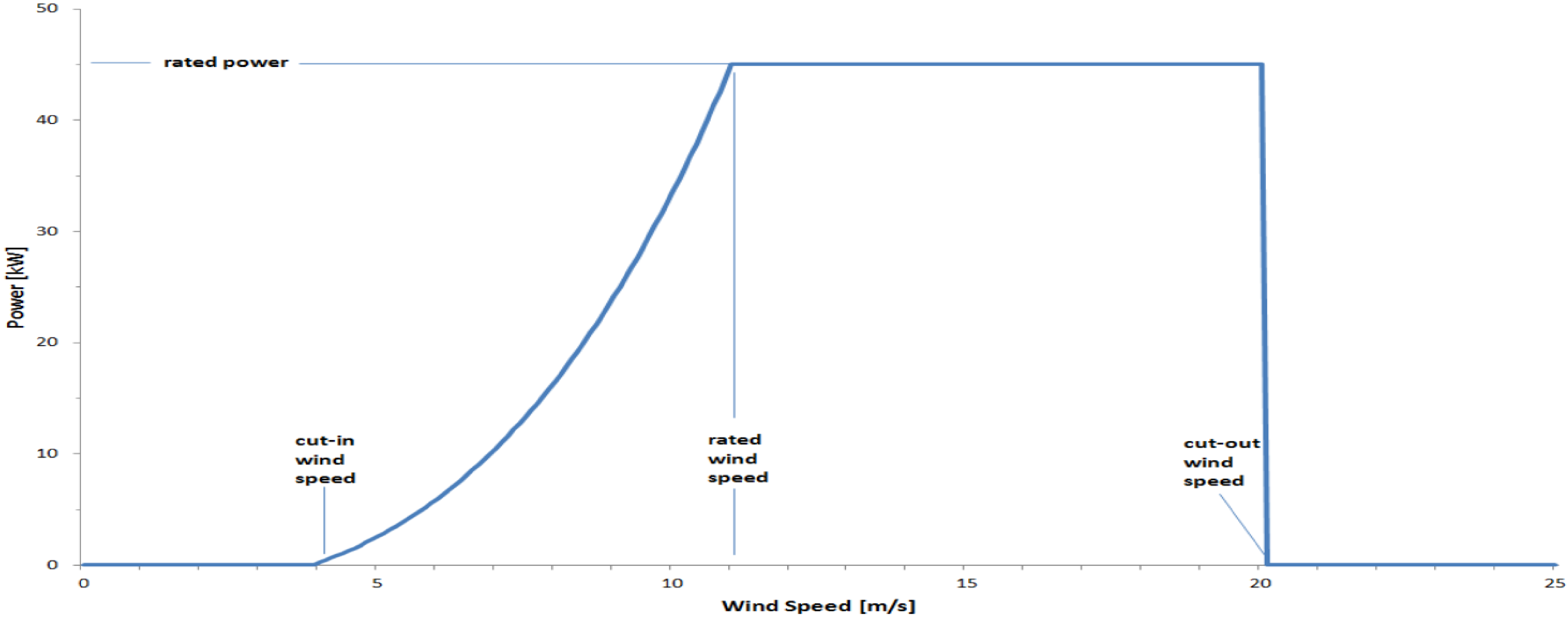
When wind speed is at or below its rated value, angle of attack of blades are kept at an optimal value, at which turbine can capture maximum power available from wind.



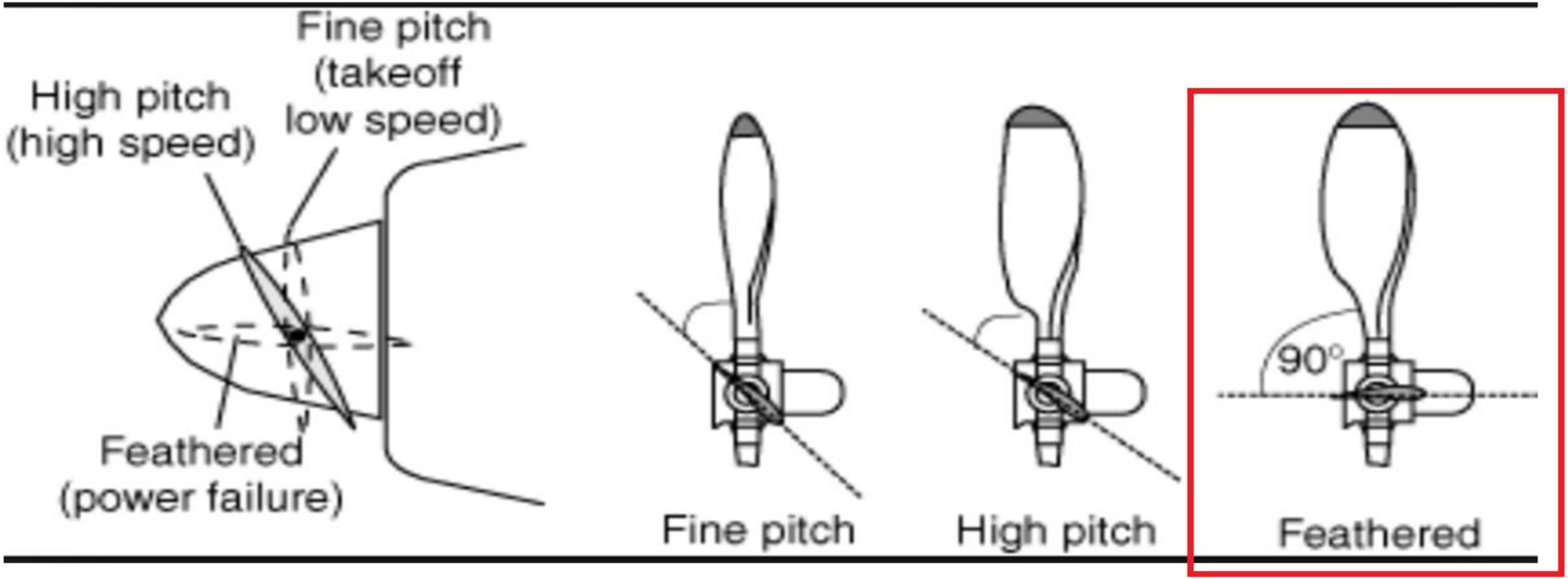
With wind speed exceeded rated value, pitch mechanism is activated to regulate & limit output power thus keeping power output within designed capability.



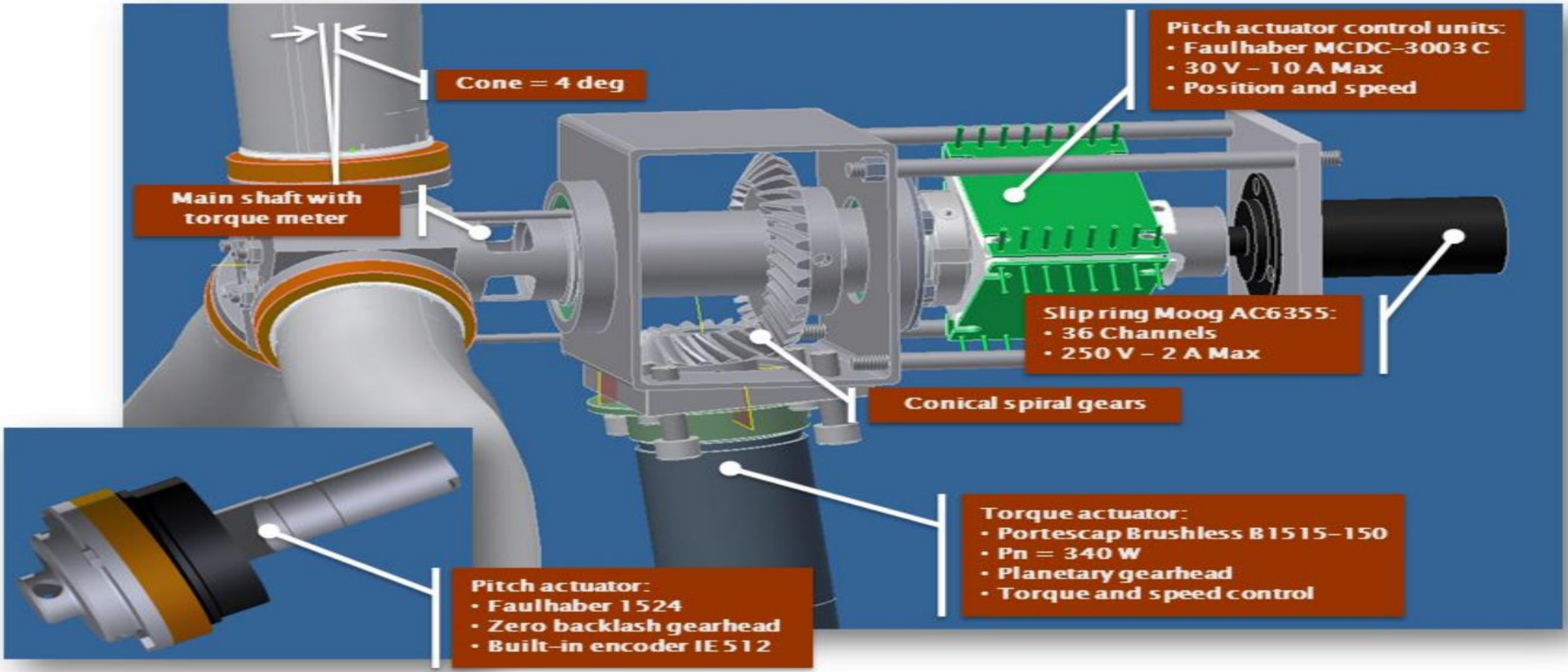
Pitch range should be______degrees.

Pitch range should be 20-25 degrees.

When wind speed increases further & reaches limit of turbine, blades are completely pitched out of wind (fully pitched or feathering)



Pitch mechanism can be either hydraulic or electric. Electric pitch actuators are more common nowadays since they are simpler & require less maintenance.

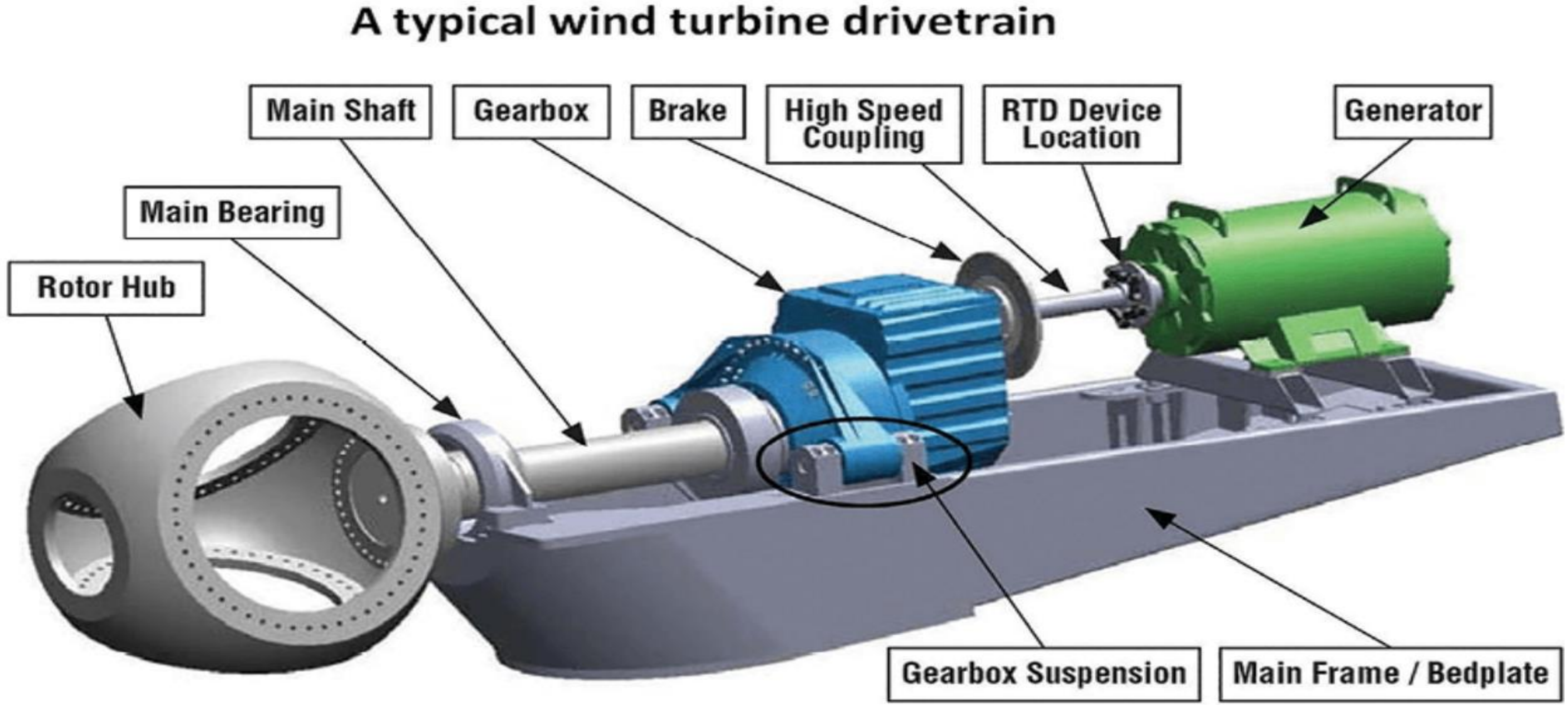


Modern wind turbines are designed to pitch each blade individually, for an independent control of blades & offering more flexibility.

Blade pitch system with 3 pitch drives & gears inside rotor hub

Pitch system is usually placed in rotor hub together with a backup energy storage system for safety purposes (an accumulator for hydraulic type or a battery for electric type).

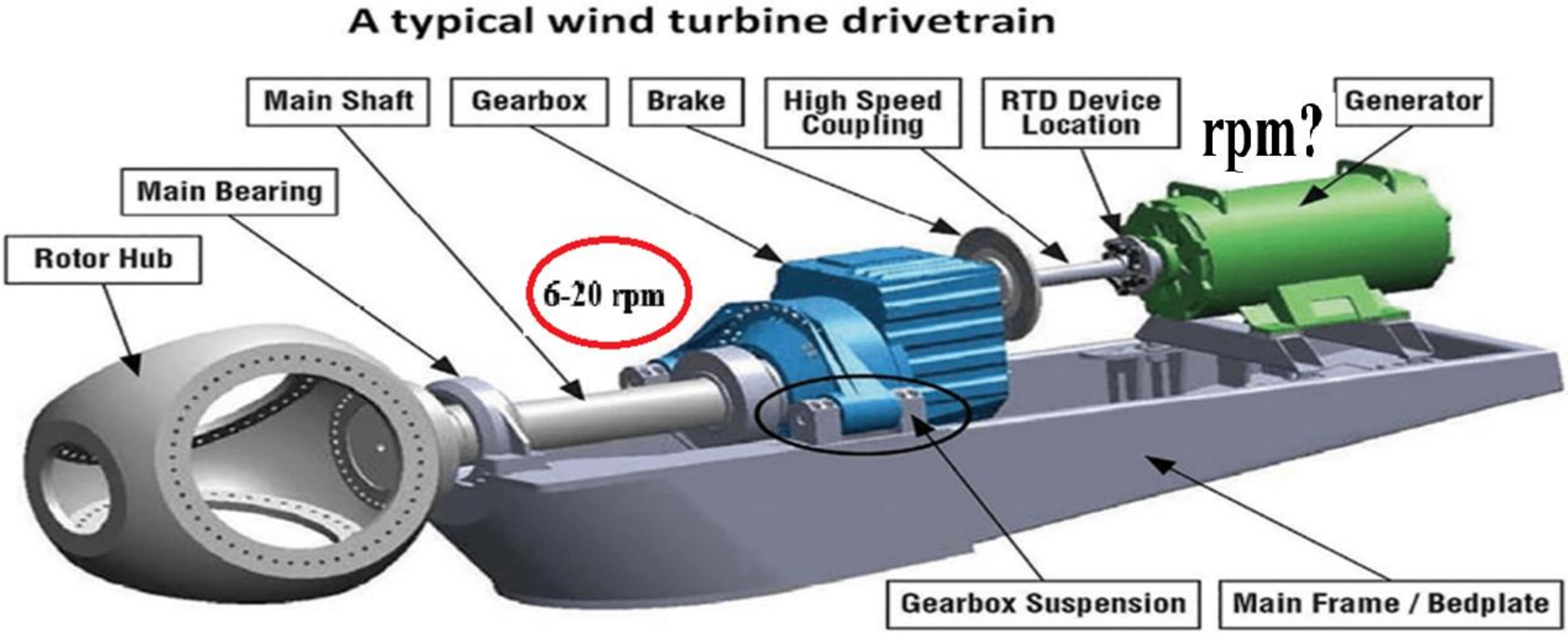
2.2.3 Gearbox


A typical wind turbine drivetrain
Main Shaft
Gearbox
Brake
High Speed Coupling
RTD Device Location
Generator
Main Bearing
Rotor Hub
Gearbox Suspension
Main Frame / Bedplate

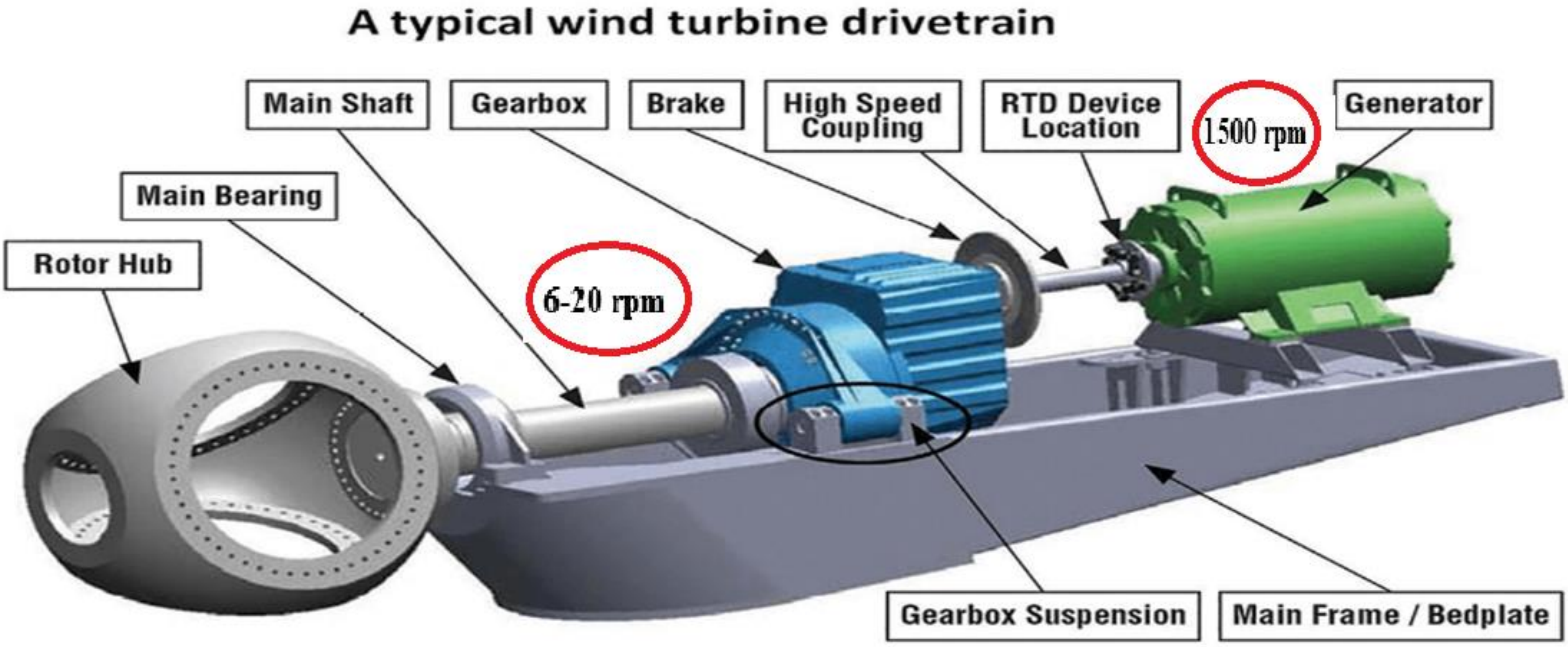
Rotor of a large 3-blade wind turbine operates in a speed range ________rpm?

Rotor of a large 3-blade wind turbine operates in a speed range _______rpm?

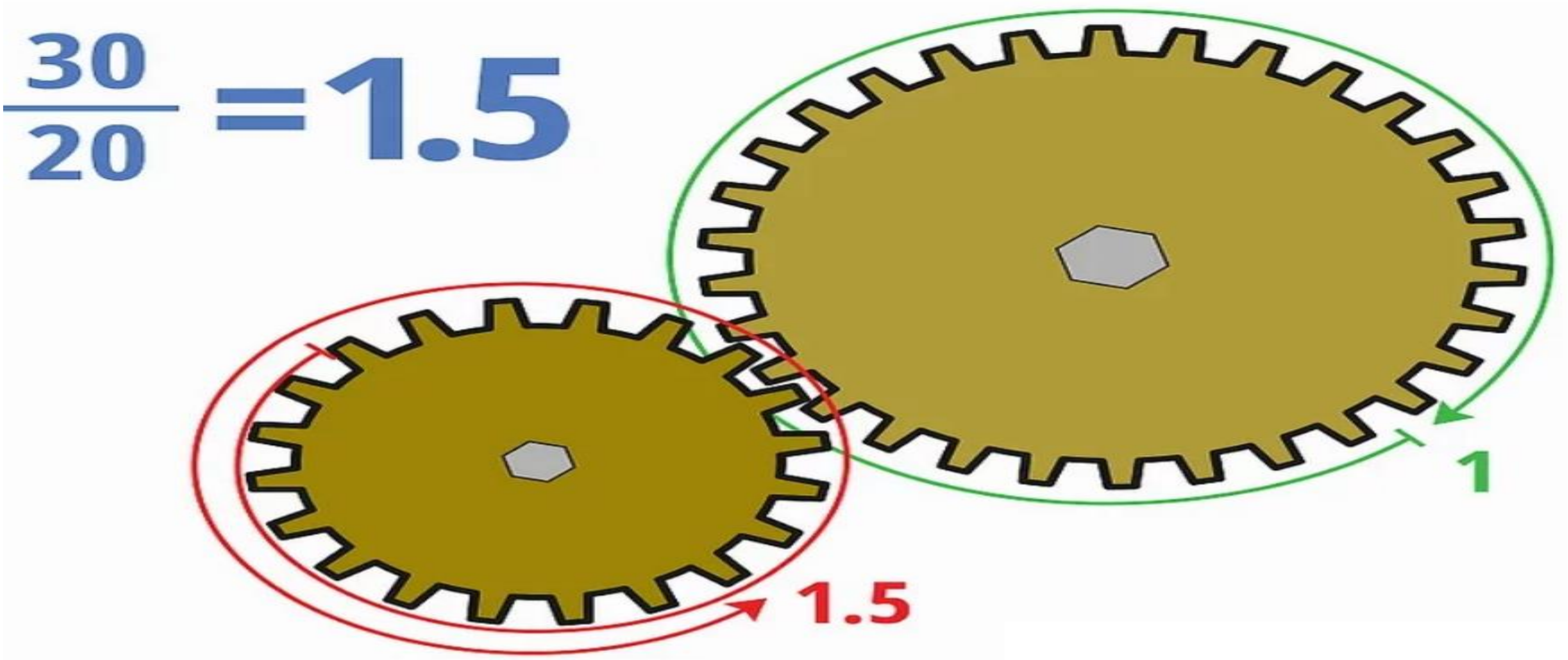
Standard 4 pole wind generator with 50 Hz stator frequency have rated speed of ____**rpm?**



Therefore a gearbox is necessary to adapt low speed of turbine rotor to high speed of generator.



Gearbox conversion ratio r_{gb} or gear ratio, is designed to match high-speed generator with low-speed turbine blades.



For a given rated speed of generator & turbine, gearbox ratio can be determined by:

$$r_{gb} = \frac{n_m}{n_M} = \frac{(1-s)\cdot 60\cdot f_s}{P\cdot n_M}$$

$$r_{gb} = \frac{n_m}{n_M} = \frac{(1-s)\cdot 60 \cdot f_s}{P \cdot n_M}$$

- where n_m & n_M are generator & turbine rated speeds in rpm
- *s* is rated slip
- *fs* is rated stator frequency in Hz &
- *P* is number of pole pairs of generator.

Rated slip is usually <1% for large induction generators.

$$r_{gb} = \frac{n_m}{n_M} = \frac{\overset{\text{Rated slip } <1\%}{(1-\boxed{s})} \cdot 60 \cdot f_s}{P \cdot n_M}$$

Rated slip for synchronous generators is ?

Rated slip =?

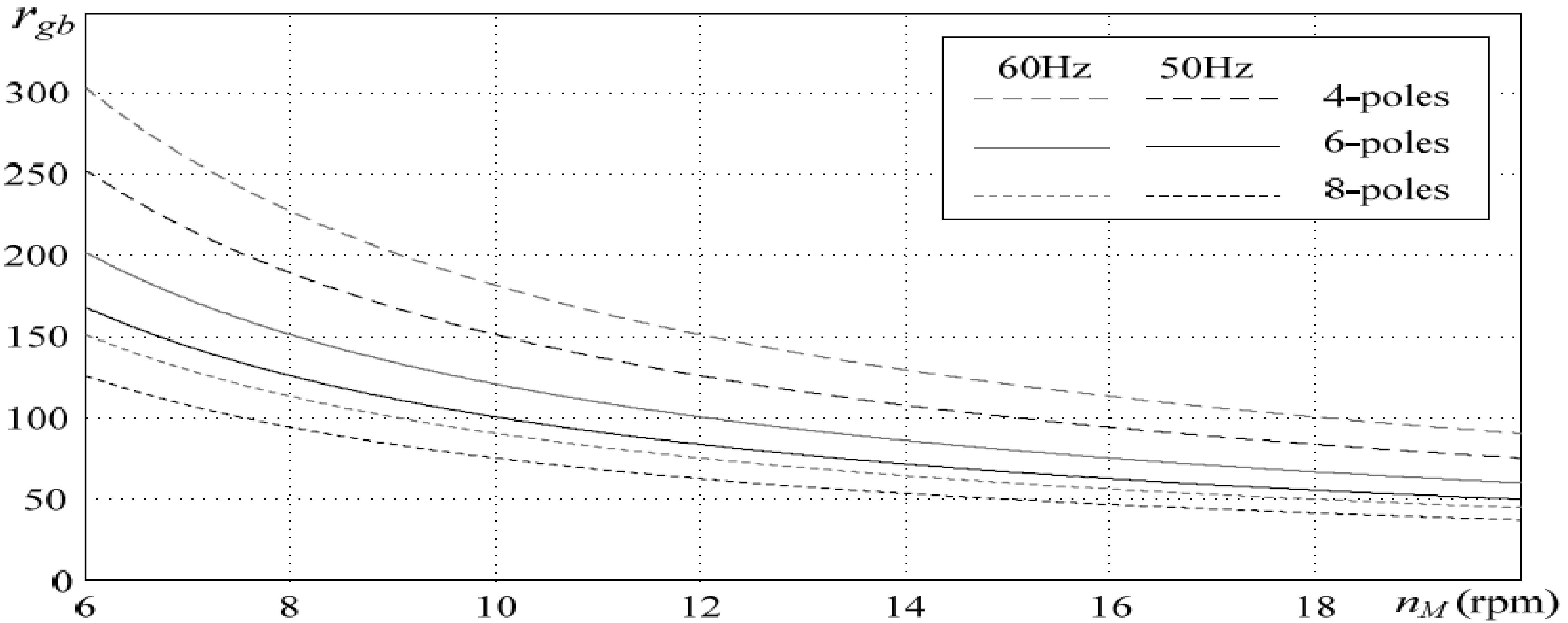
$$r_{gb} = \frac{n_m}{n_M} = \frac{(1-\boxed{s})\cdot 60 \cdot f_s}{P \cdot n_M}$$

Rated slip for synchronous generators is=0

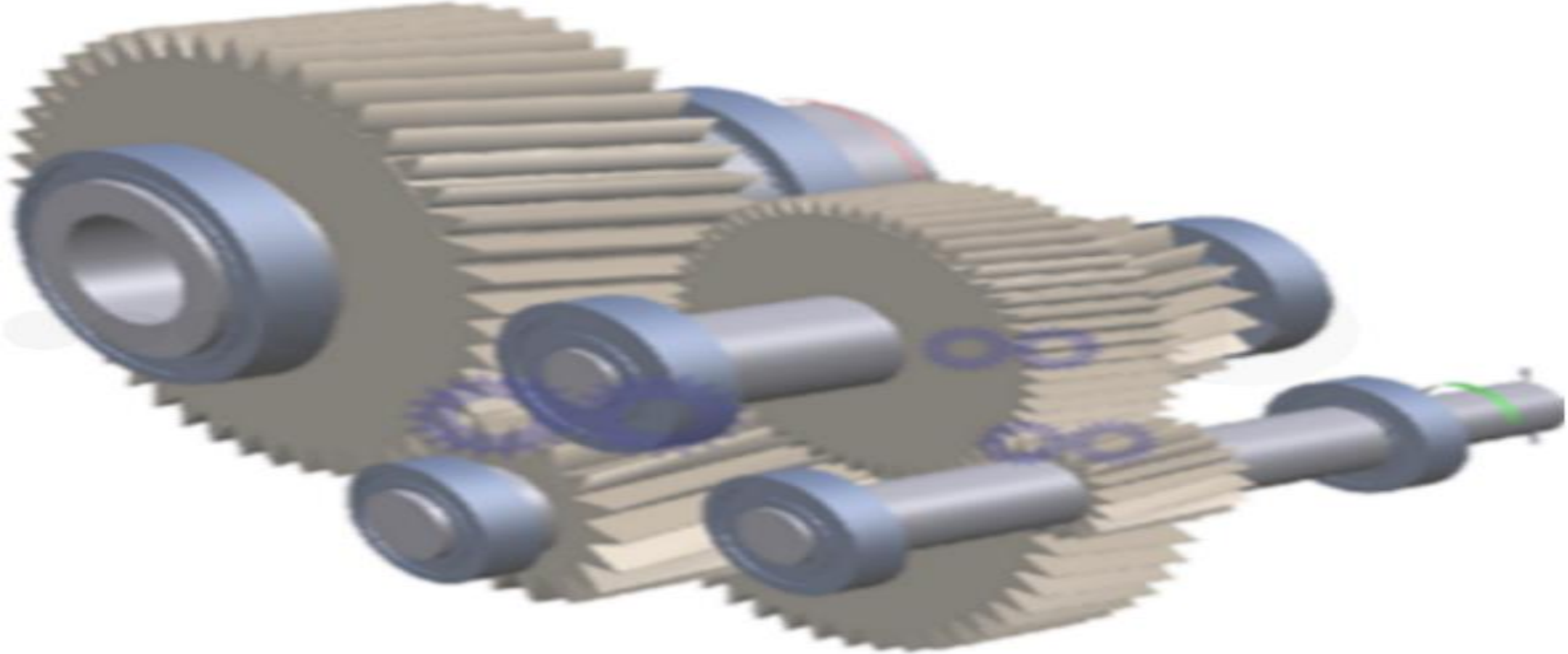
Rated slip =?

$$r_{gb} = \frac{n_m}{n_M} = \frac{(1-\boxed{s})\cdot 60 \cdot f_s}{P \cdot n_M}$$

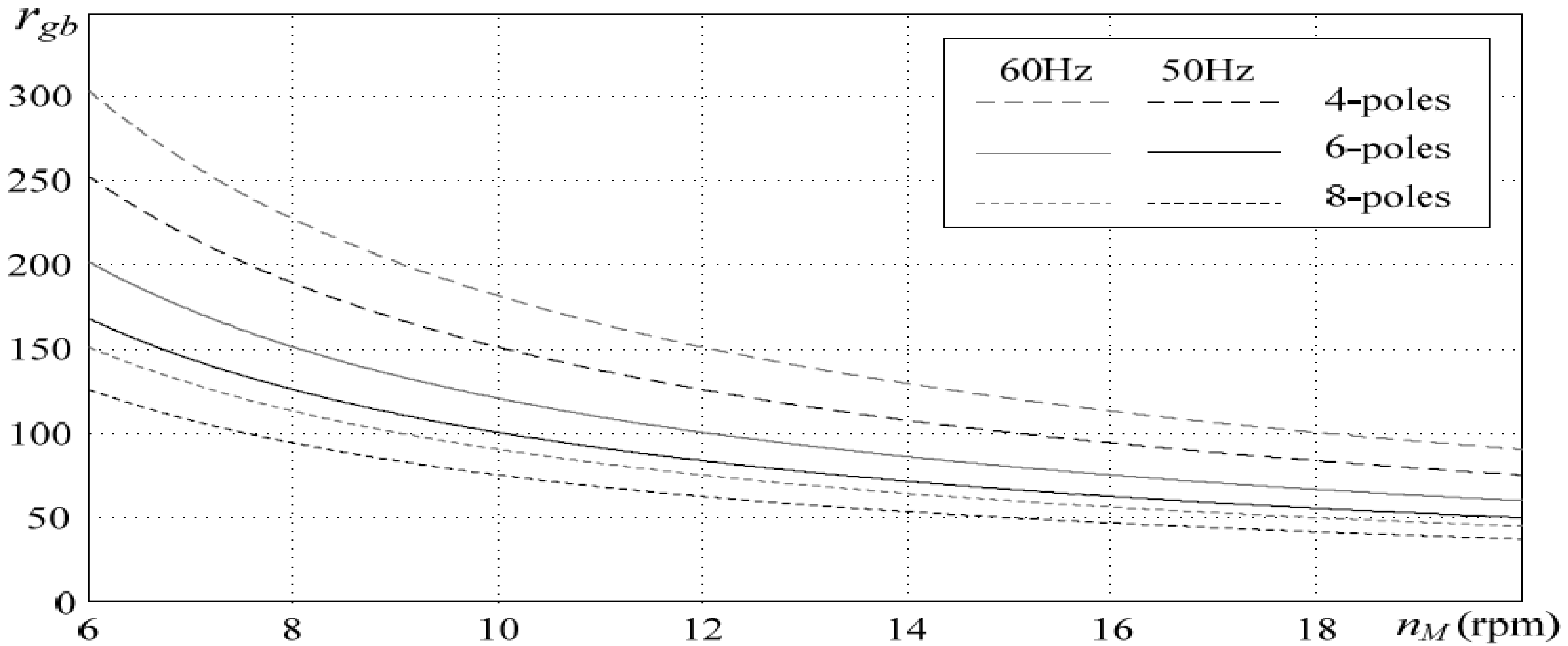
Rated slip of -1% for an induction generator, gear ratio as a function of rated turbine speed for different pole numbers & rated stator frequencies



Wind turbine gearboxes have multiple stages to achieve high conversion ratio needed to couple turbine rotor & generator.



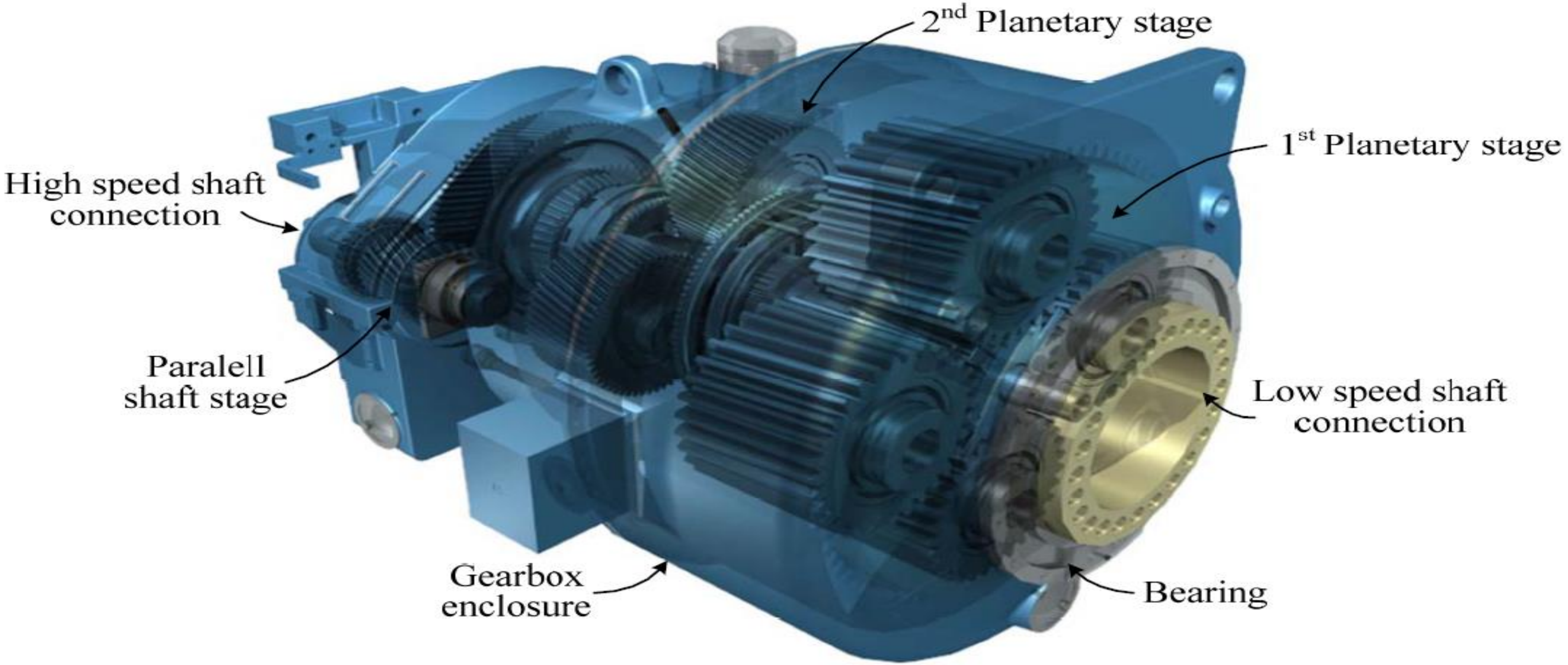
For example, with rated turbine rotor speed of 15 rpm & a 4-pole 50Hz induction generator, a gear ratio of 100 is needed according to Fig. which is difficult to achieve by 1 gear stage.



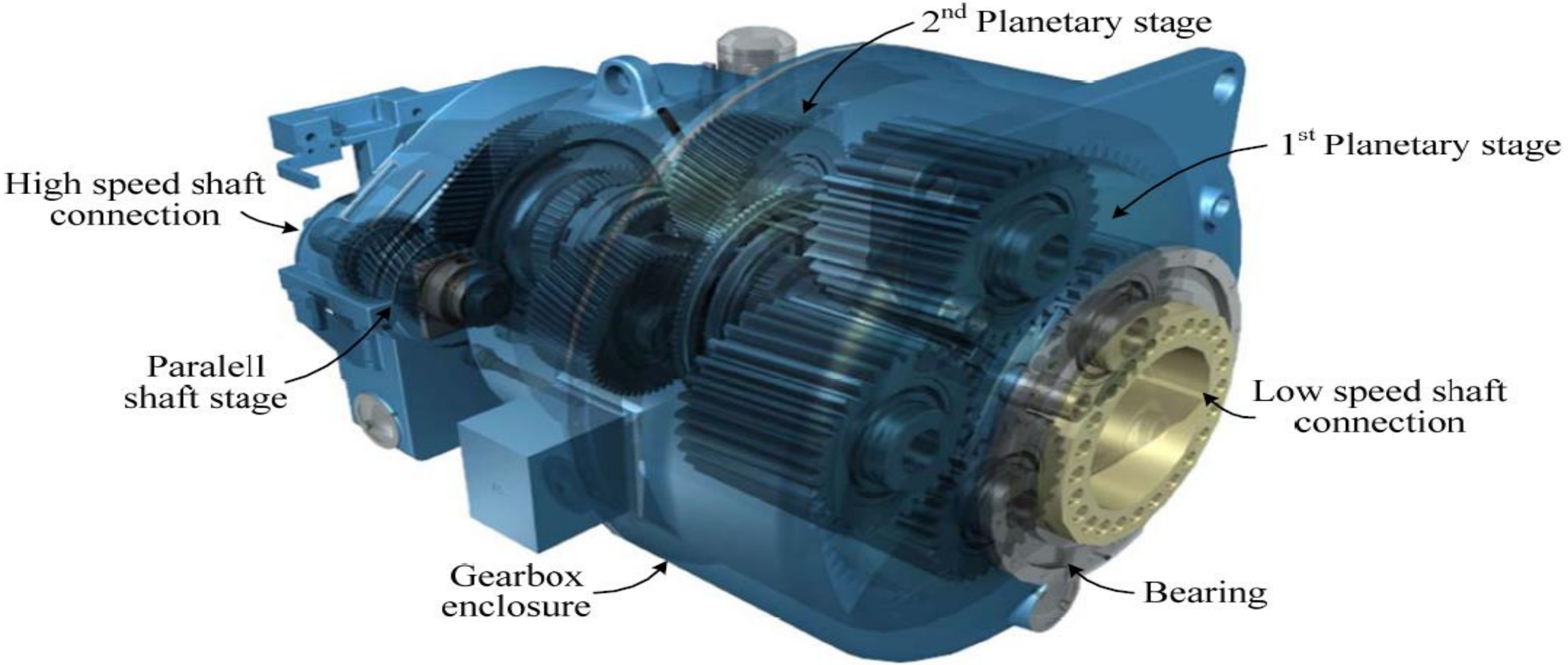
Type of gear stages

1. Planetary
2. Helical
3. Parallel shaft
4. Spur &
5. Worm

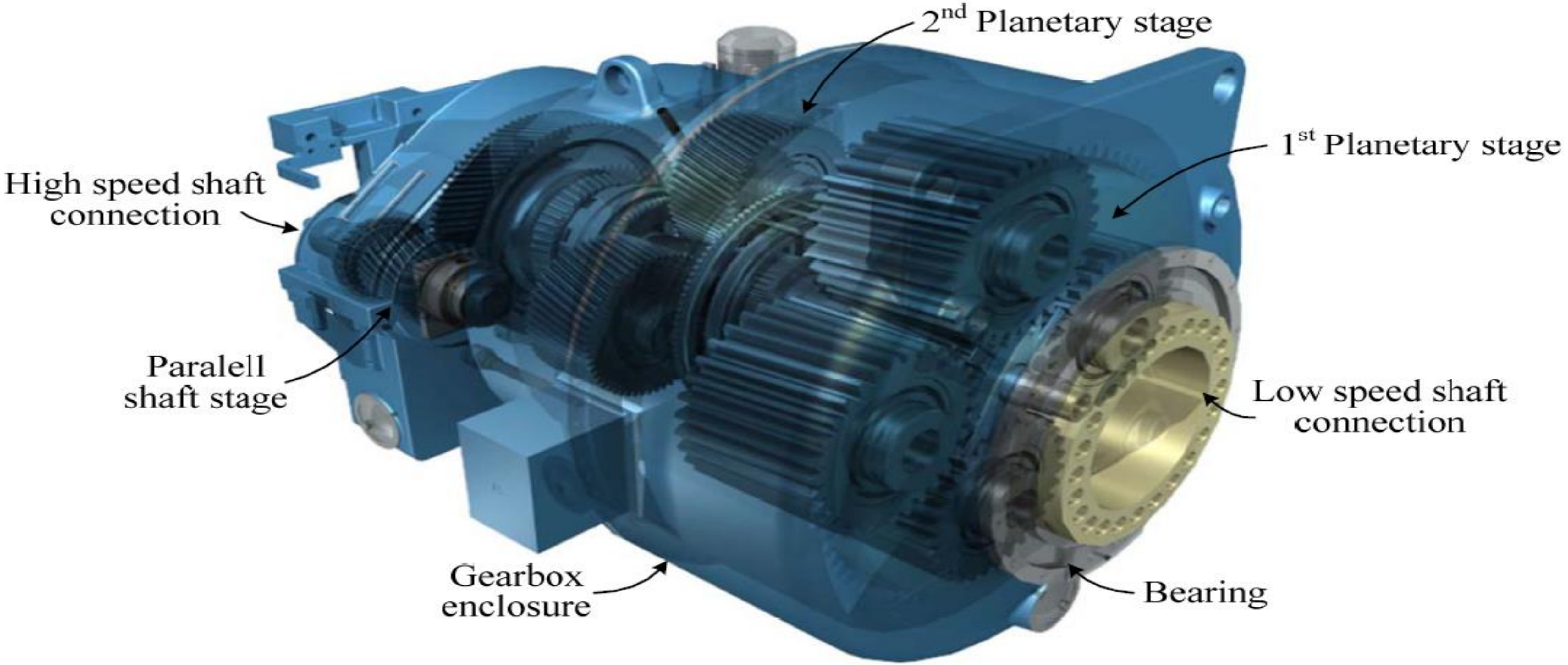
2 or more gear types may be combined in multiple stages.



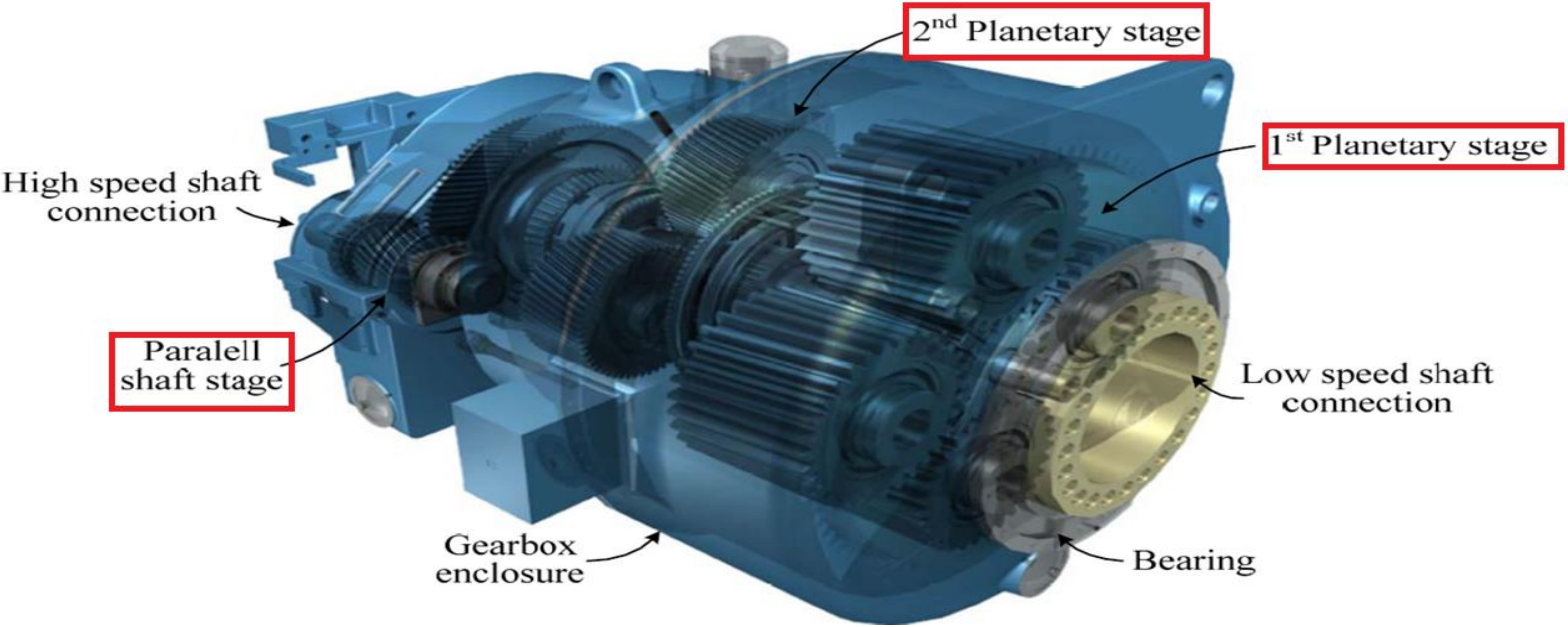
Gearboxes are made of ?



Gearboxes are made of superior quality Aluminium alloys, stainless steel & cast iron.

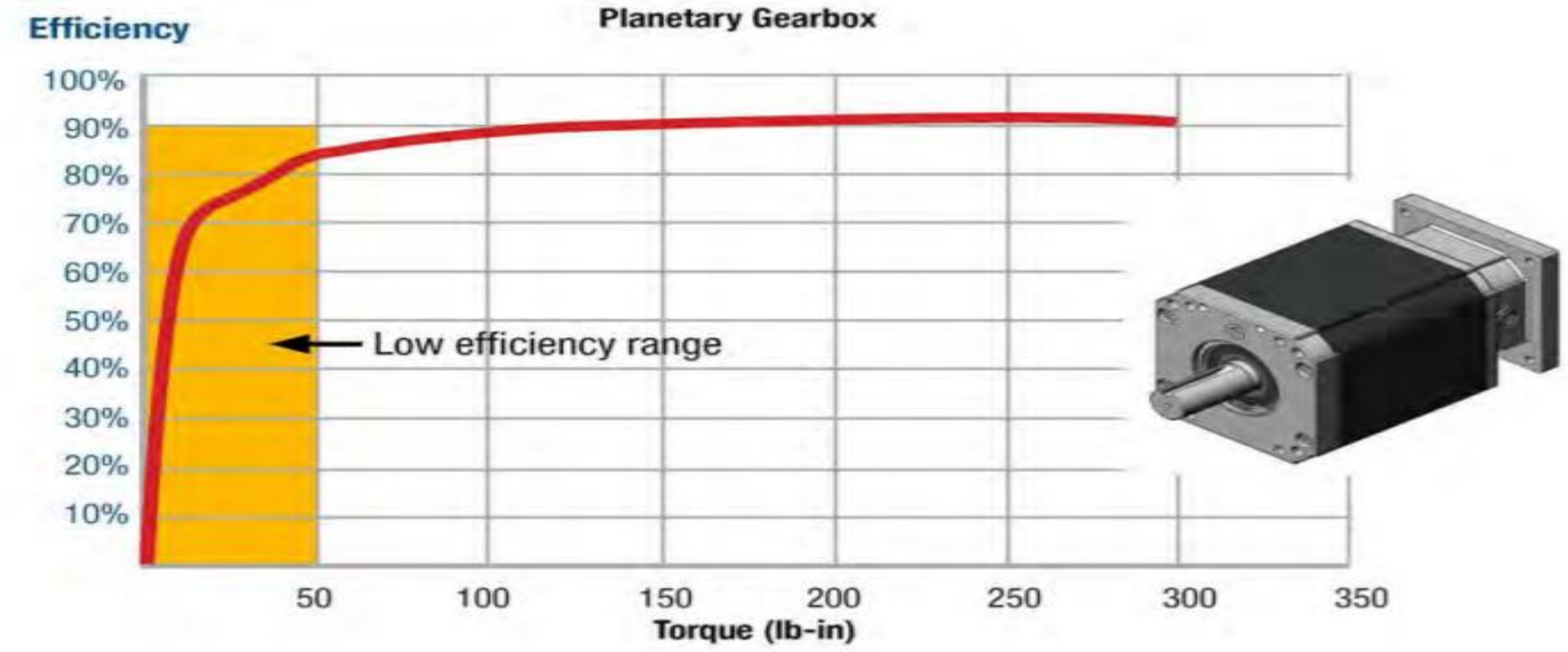


Multistage gearbox has 2 planetary stages & 1 parallel shaft stage with a gear ratio of 78:1 or 136:1 designed for a MW wind turbine.



Gearbox usually generates a high level of audible noise. Noise mainly arises from meshing of individual teeth.

Efficiency of gearbox normally varies between 95% & 98%.

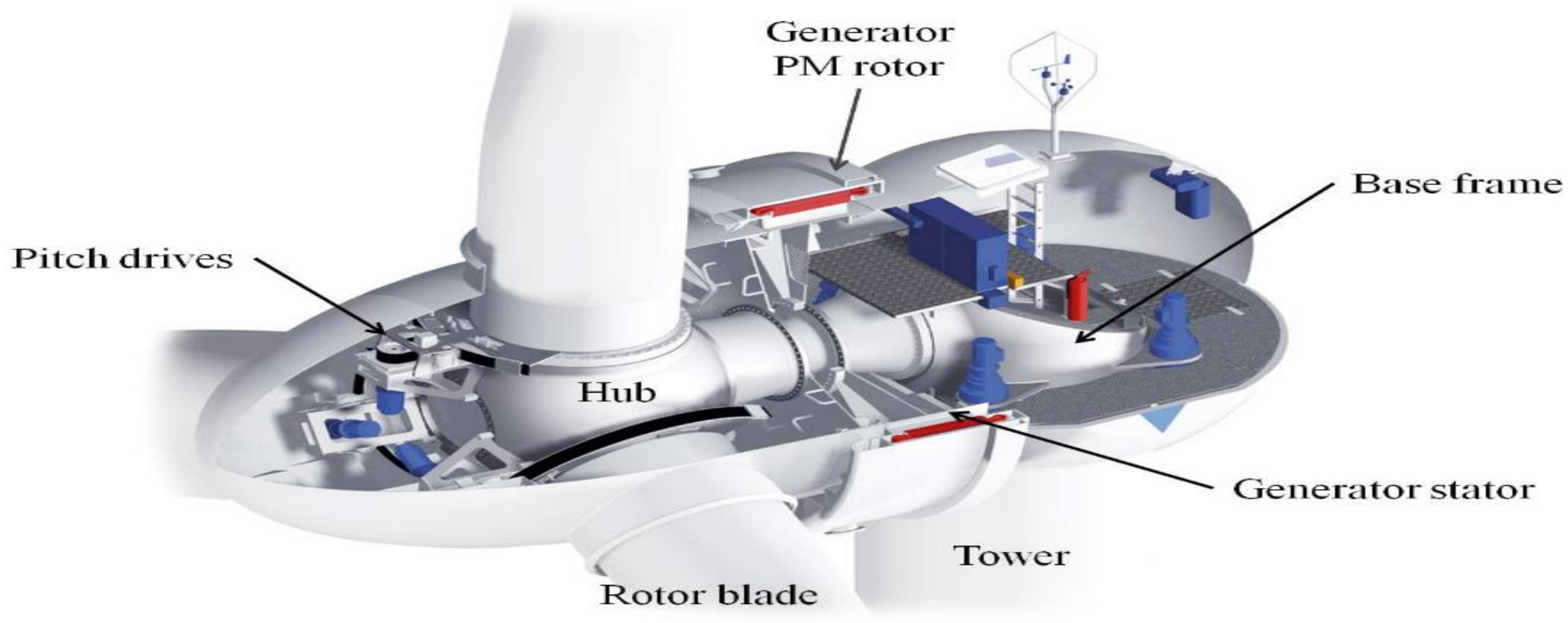


Gearbox is a major contributor to cost of wind turbine in terms of initial investment & maintenance.

Gearbox needs regular maintenance

- Random change in wind speed & strong wind gusts result in sudden load variations on gearbox.
- These sudden changes produce wear & tear on gearbox reducing its life span.

Elimination of gearbox contributes to reliability improvements & cost reduction.

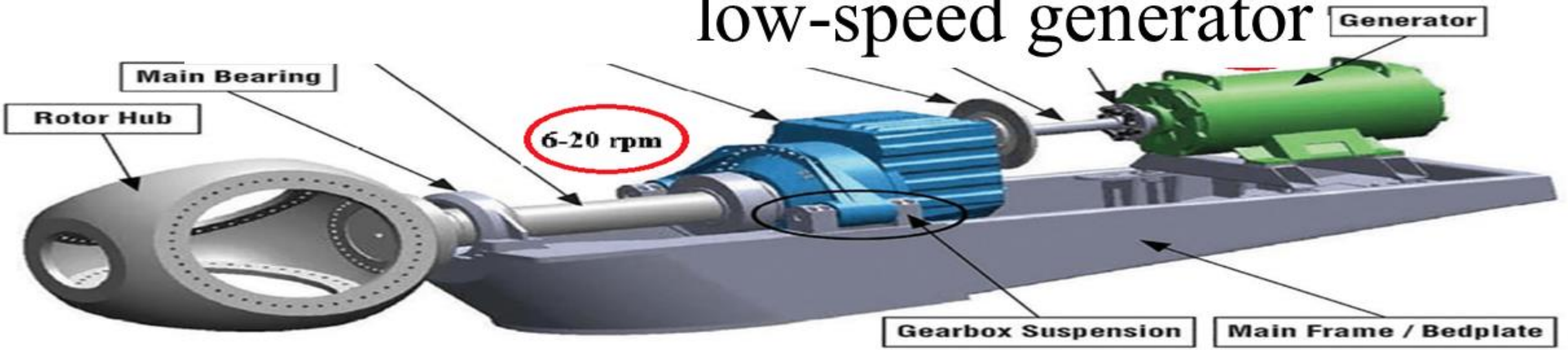


In order to eliminate gearbox, what strategy we can apply?

In order to eliminate gearbox, what strategy we can apply?

- A generator with same rated rotational speed of turbine rotor is required. This can be achieved by a low-speed generator(n=120f/P).

low-speed generator



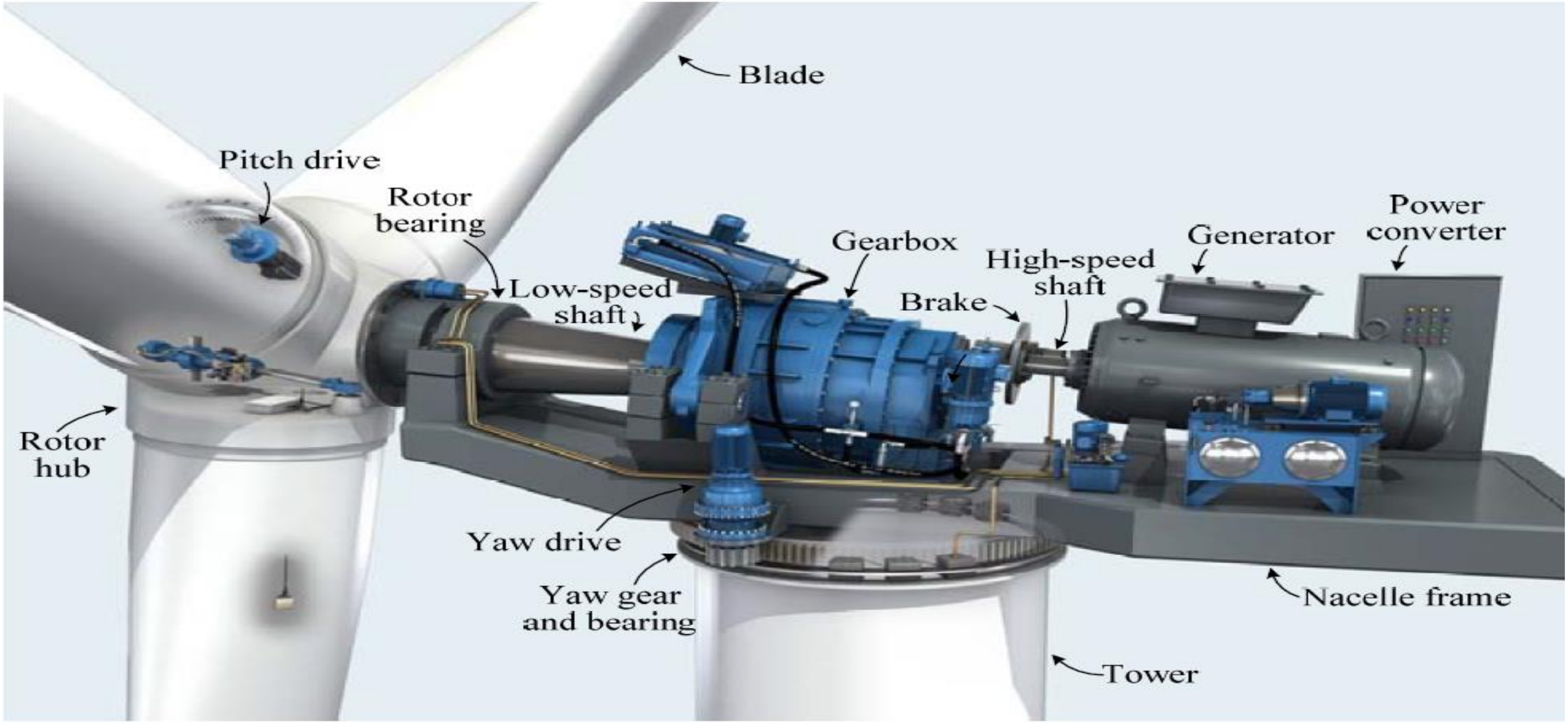
Gearless configurations have been adopted by several manufacturers due to the:

1. Reduced cost,
2. Maintenance,
3. Audible noise &
4. Power losses.

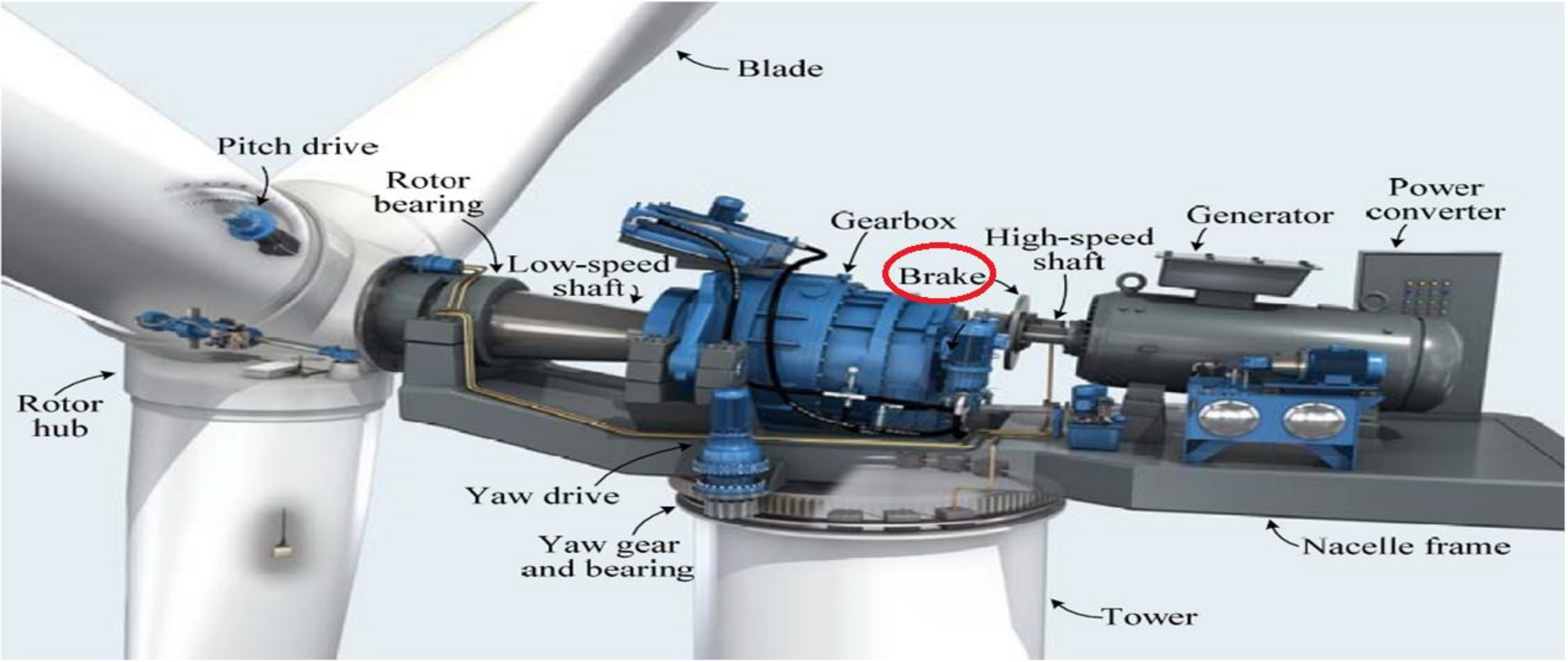
Single-stage gearbox has also been used in practical wind turbines.

- This is achieved by using a special medium-speed generator that has a proper number of poles & operates at certain stator frequencies.
- Compared with multi-stage gearbox, the reliability of single-stage gearbox is improved & its cost is reduced.

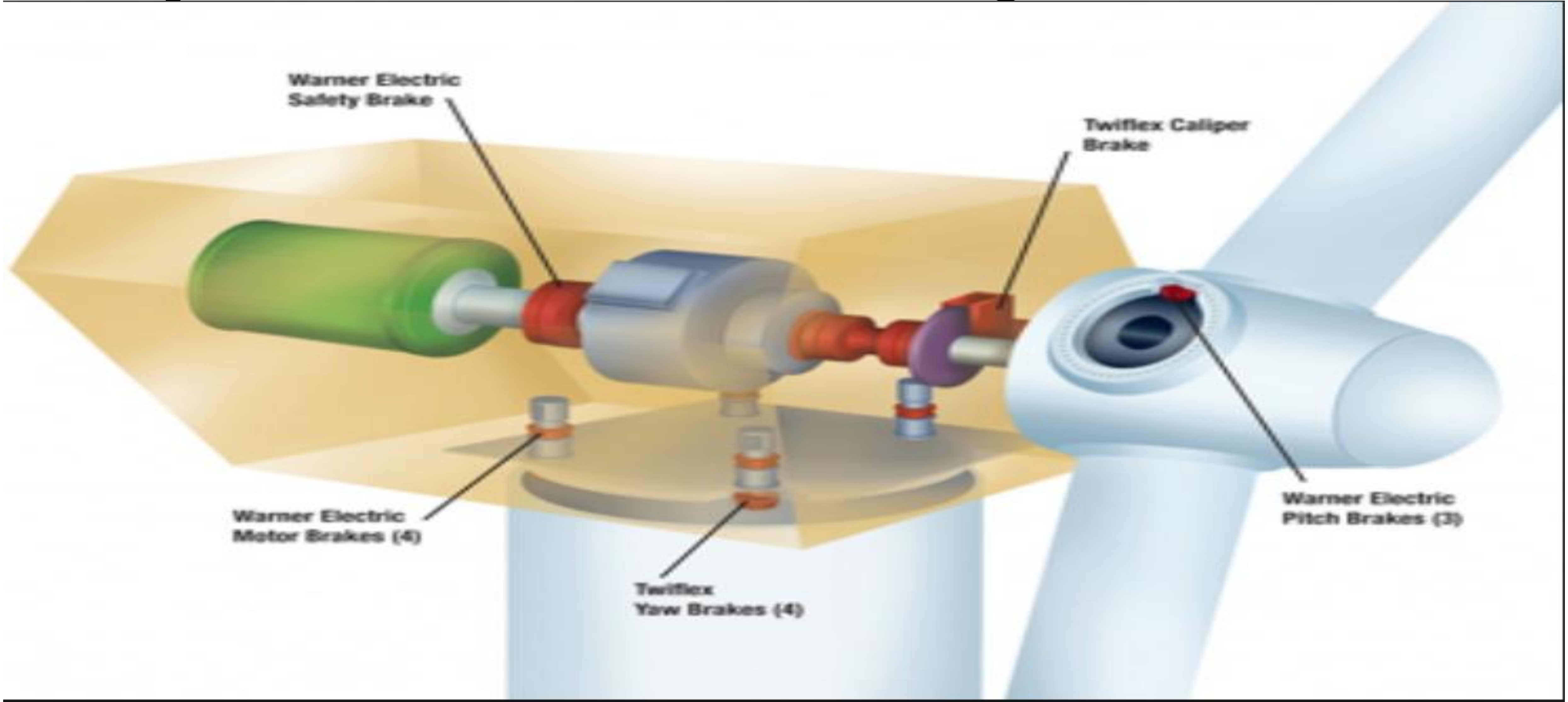
2.2.4 Rotor Mechanical Brake



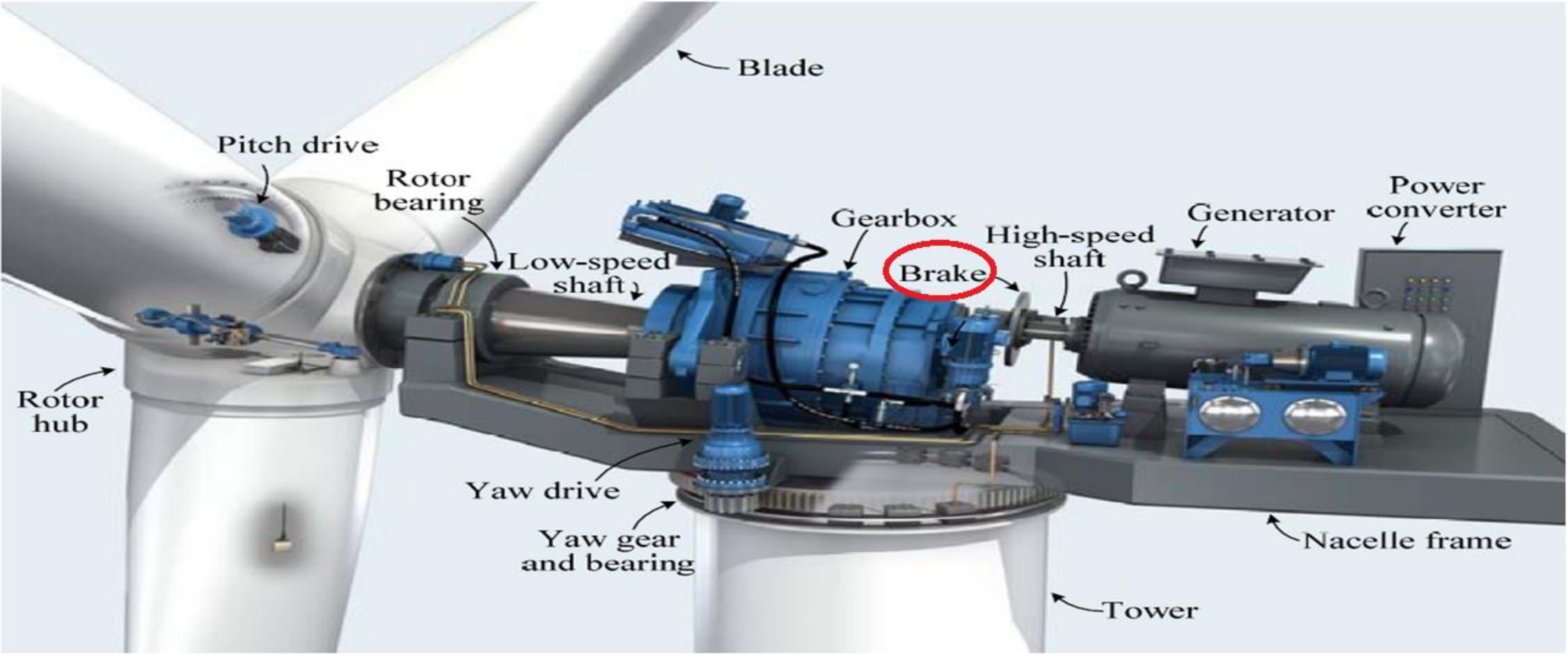
Mechanical brake is placed on high-speed shaft between gearbox & generator



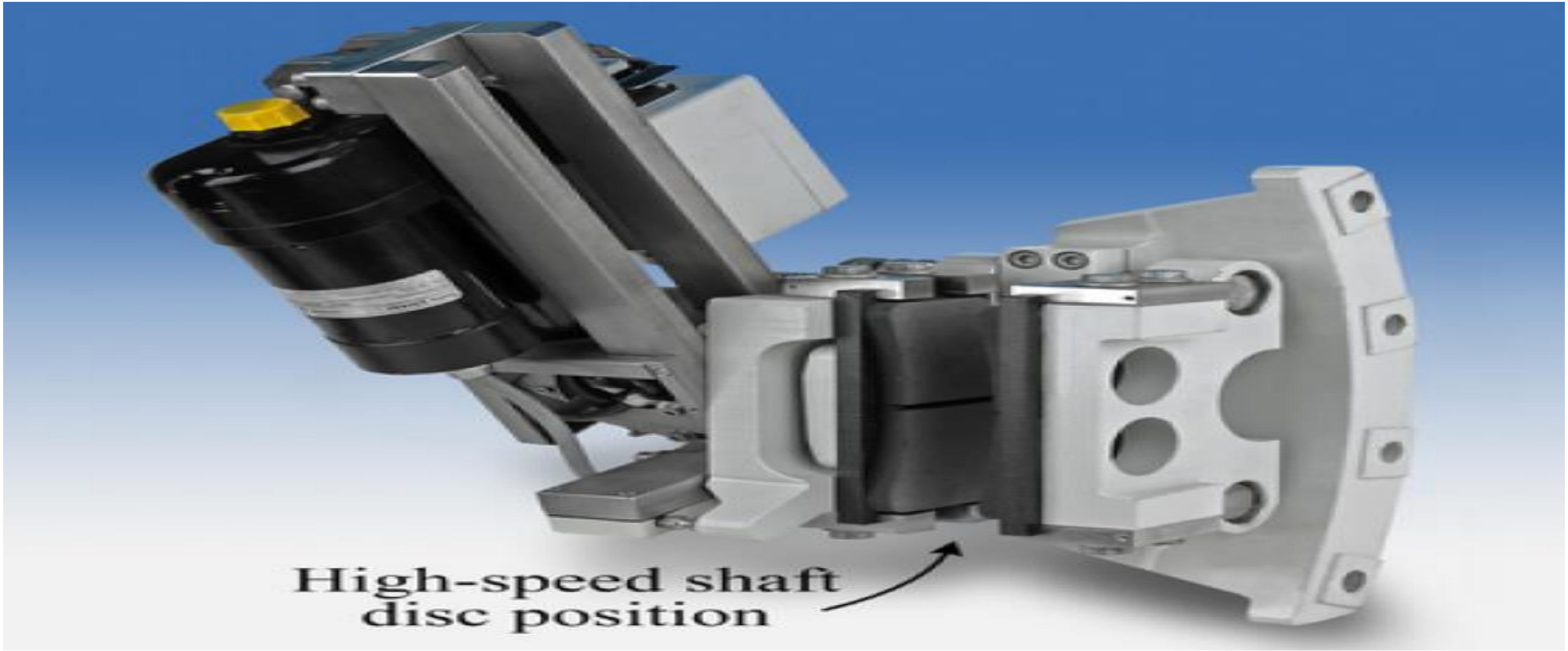
But there are some turbines where brake is mounted on low-speed shaft between turbine & gearbox.



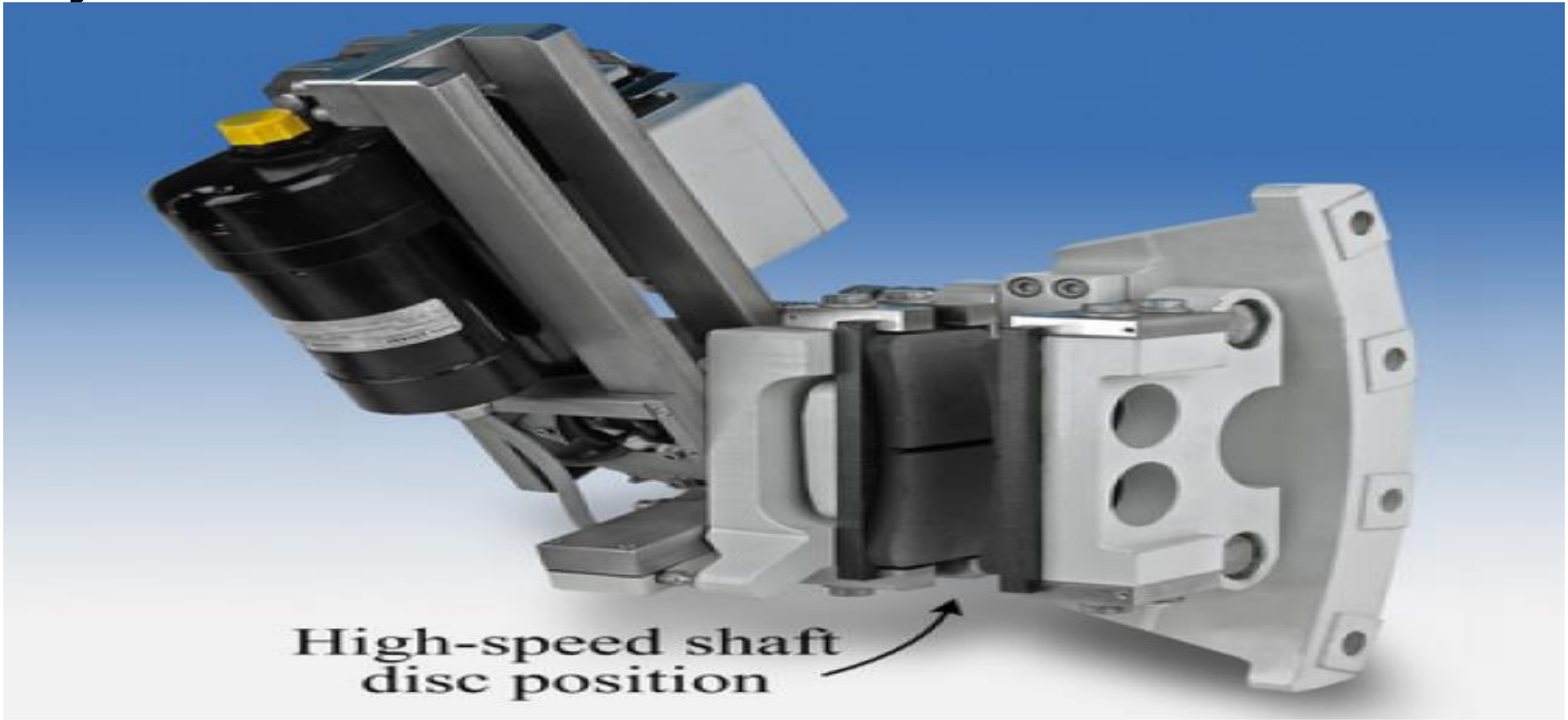
Main advantage of placing brake on high-speed shaft is that it handles much lower braking toque.



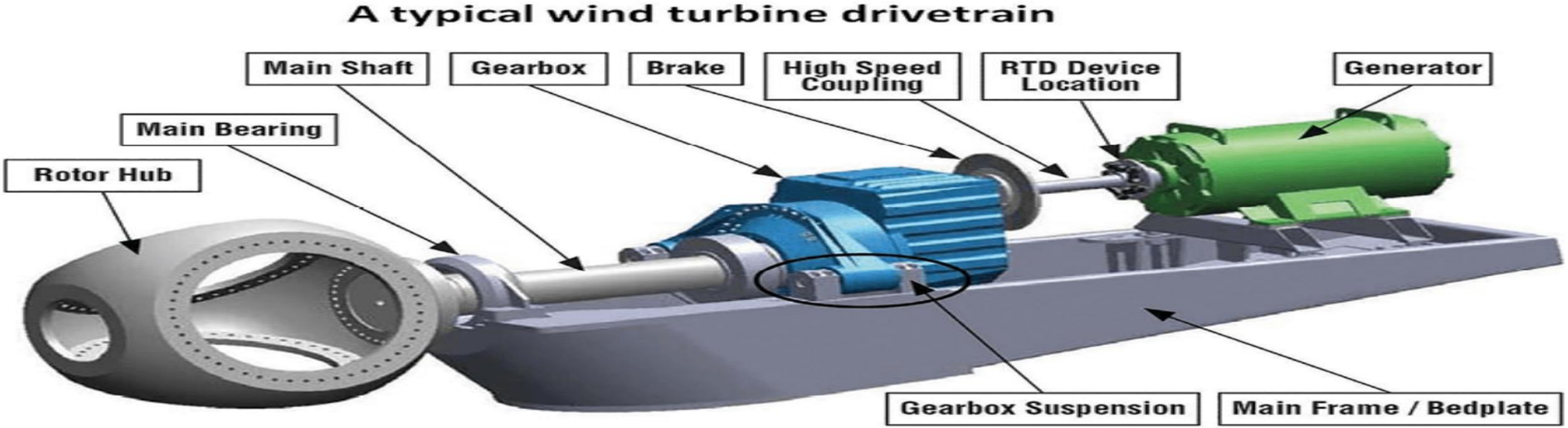
Brake is used to aid aerodynamic power control (stall or pitch) to stop turbine during high speed winds or to lock turbine into a parking mode during maintenance.



Hydraulic & electromechanical disc brakes are used



To minimize wear-and-tear on brake & reduce stress on drive train during braking process:



Most large wind turbines use aerodynamic power control to reduce turbine speed to a certain level or 0 & then mechanical brake to stop or lock wind turbine.

2.2.5 Wind Generator

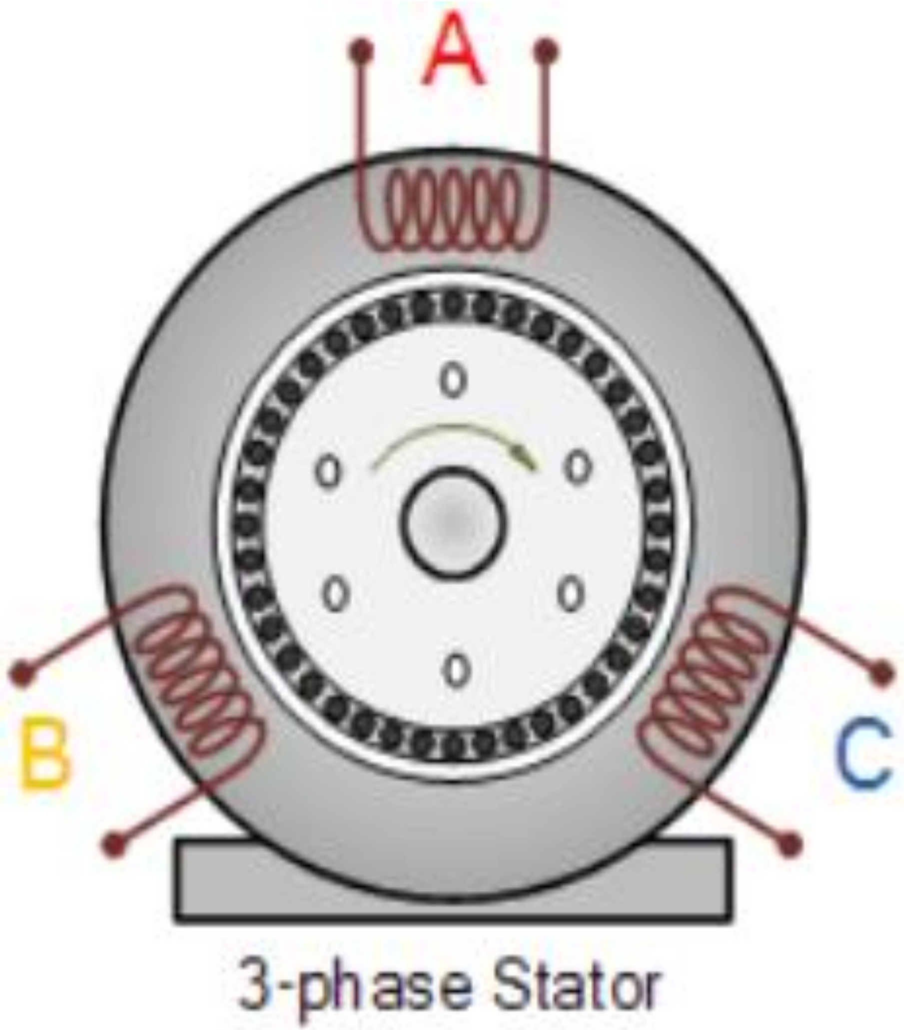
Wind generators include?

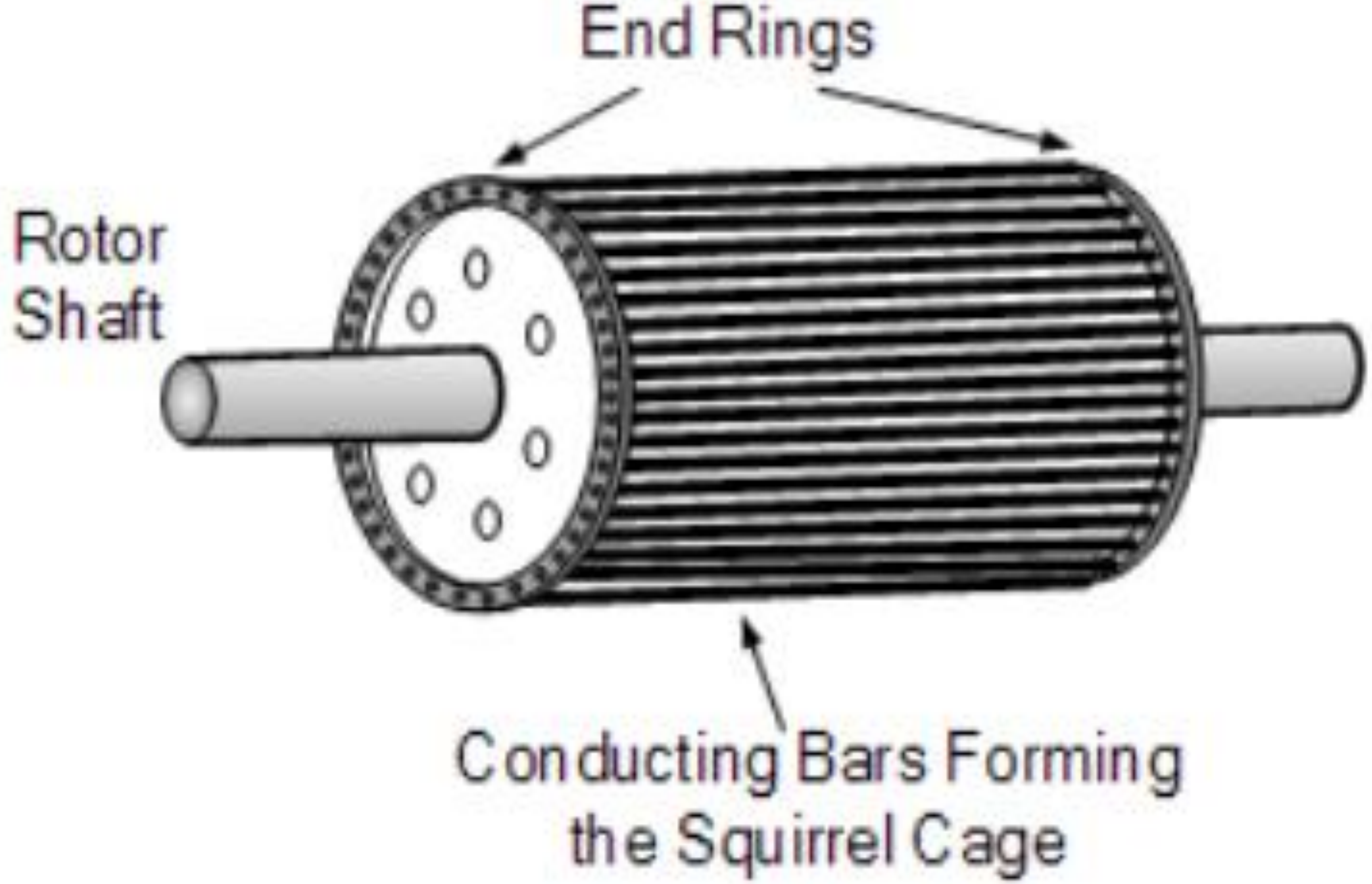
1. Squirrel Cage Induction Generator (SCIG),

2.Doubly Fed Induction Generator (DFIG) &

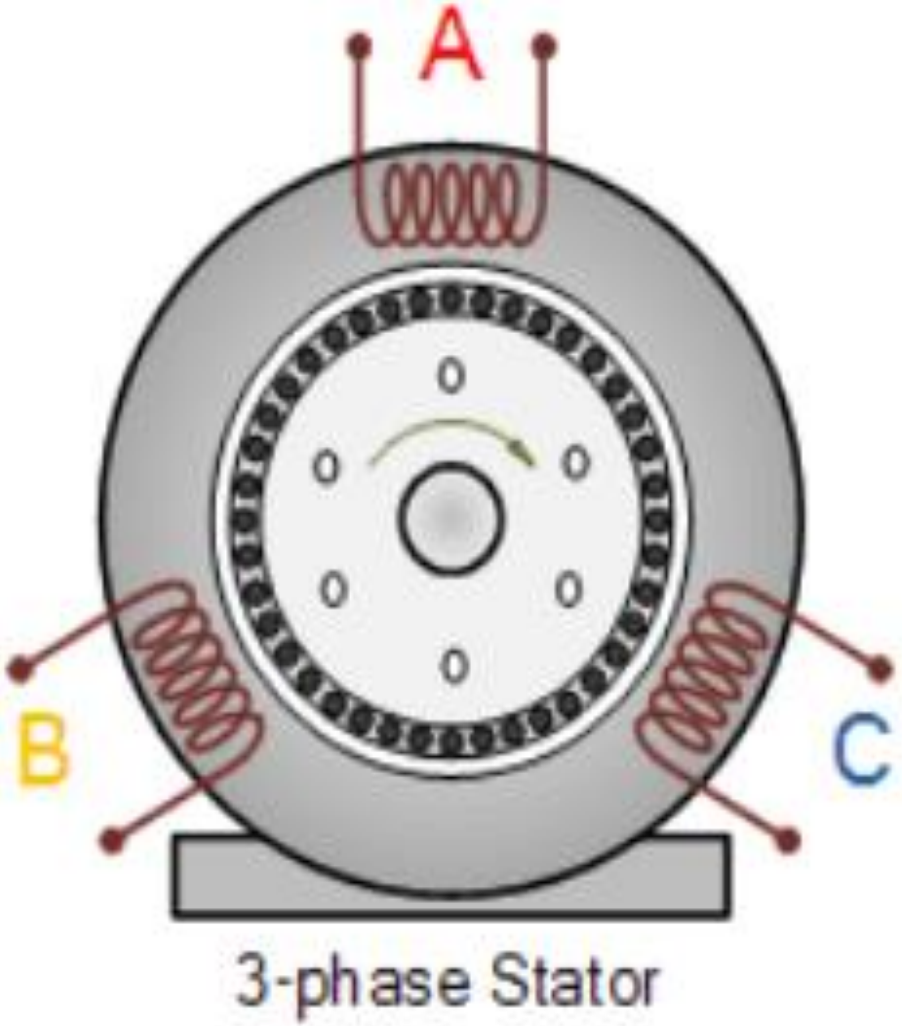
3. Synchronous Generators (SG) (wound rotor & permanent magnet)

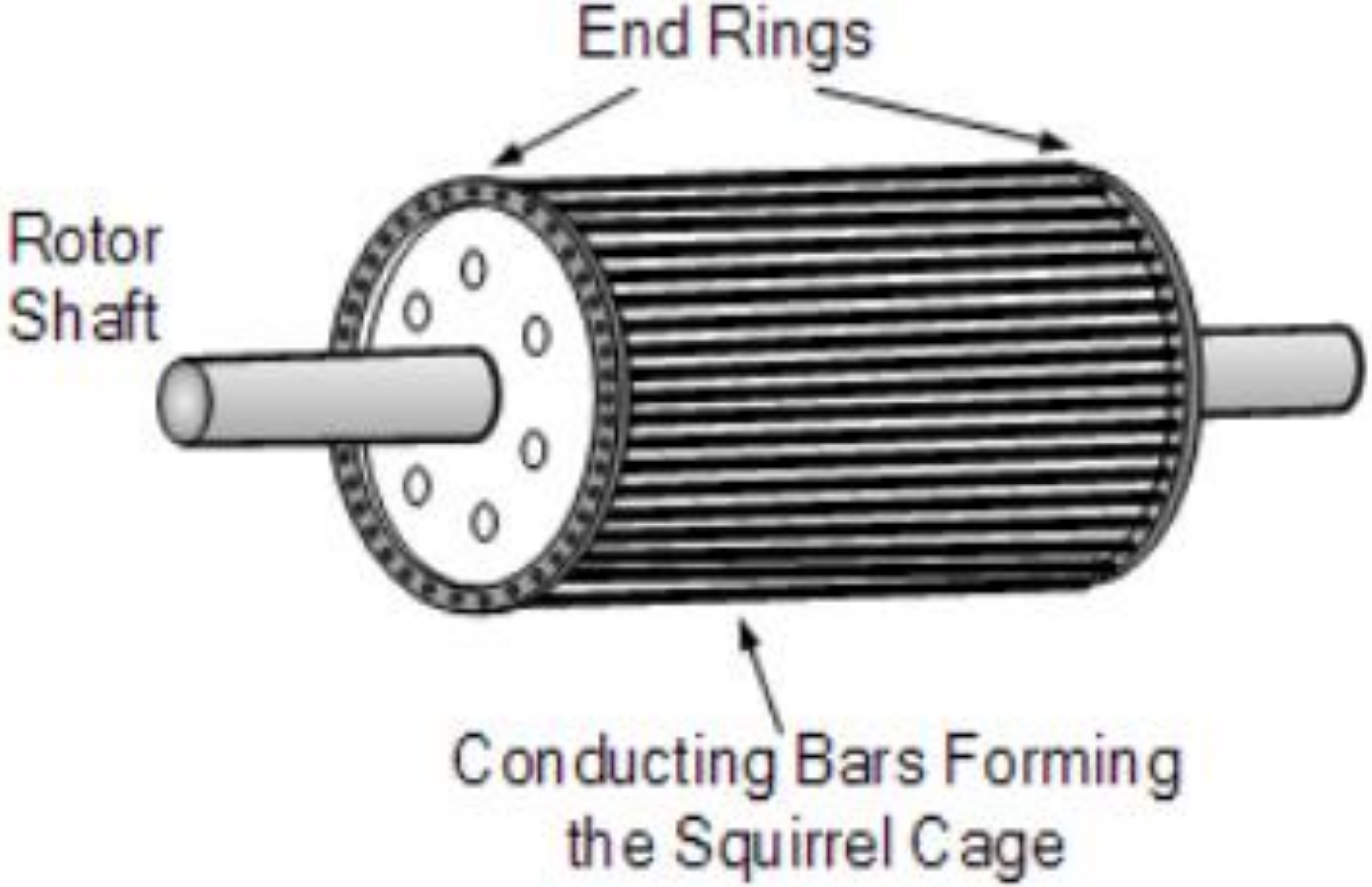
SCIG is simple & rugged in construction. It is relatively inexpensive & requires minimum maintenance.



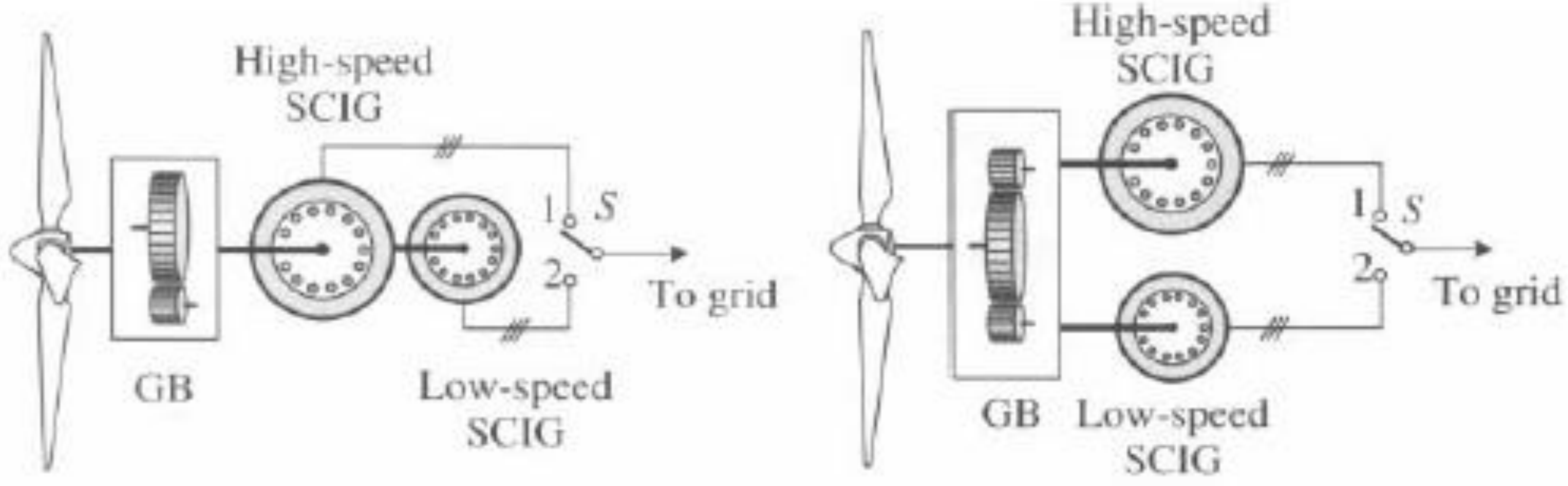


Traditional direct grid-connected wind energy systems are still available in today’s market. They use SCIGs & operate at a fixed speed.





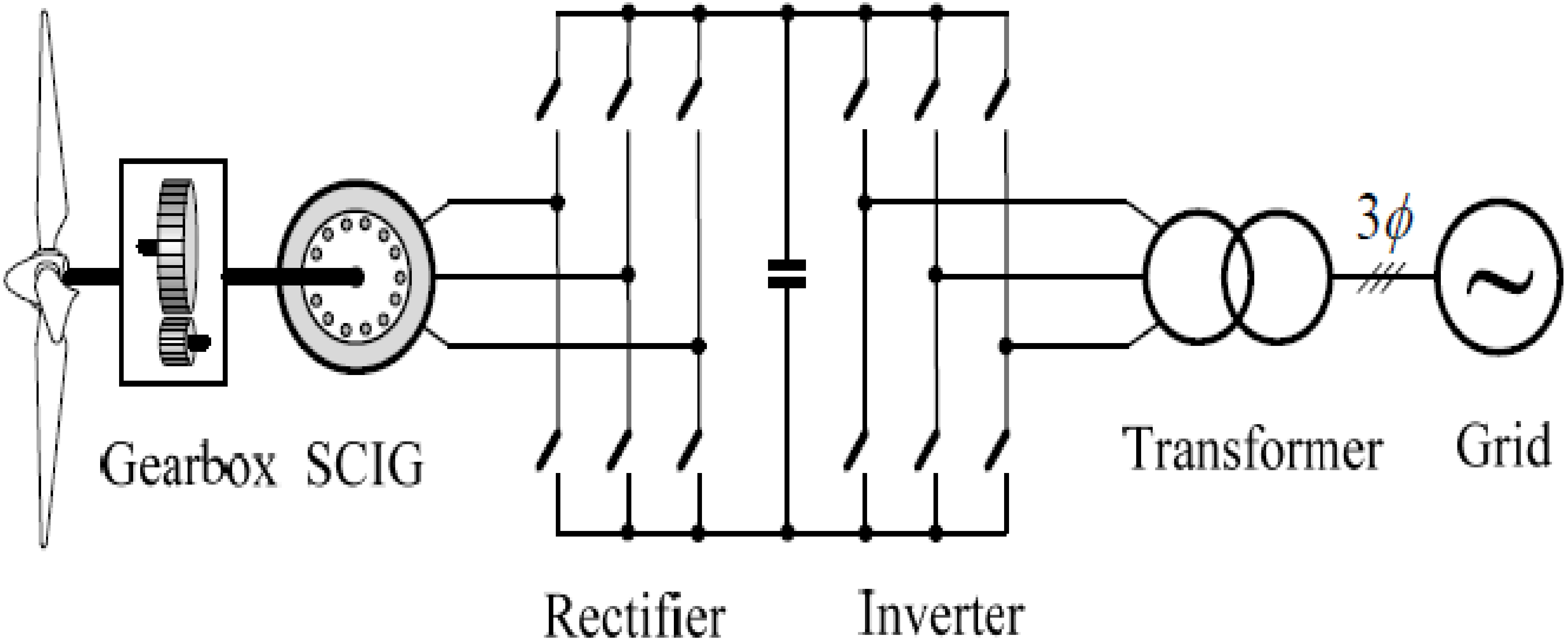
Two-speed SCIGs are also commercially available, in which a tapped stator winding can be adapted to change pole pairs to allow 2-speed operation.



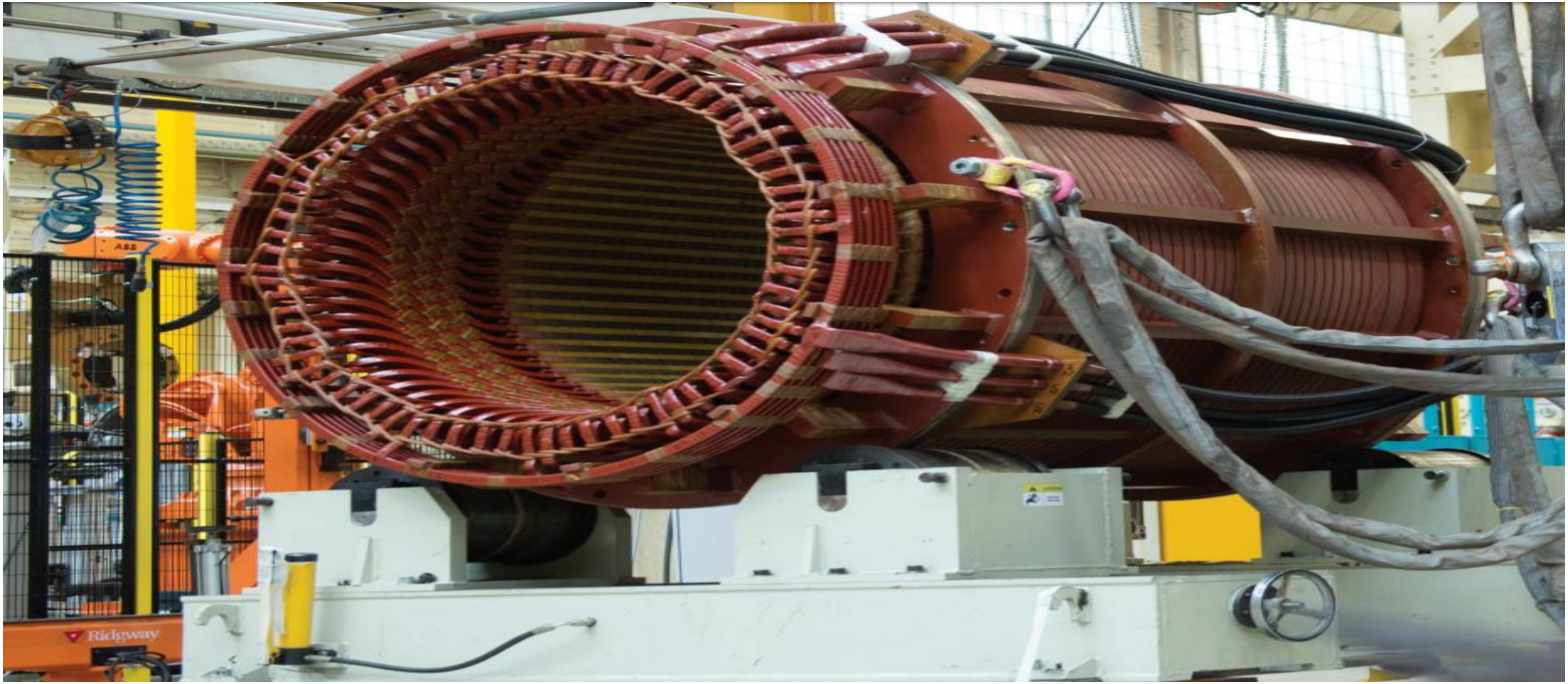
(a) Single-shaft configuration (b) Dual-shaft configuration

2MW 2-speed SCIG with 6/4 poles rated at 1000/1500 rpm.

SCIGs are also employed in variable-speed wind energy systems.



To date, largest SCIG wind energy system is around 3.5 MW in offshore wind farms.



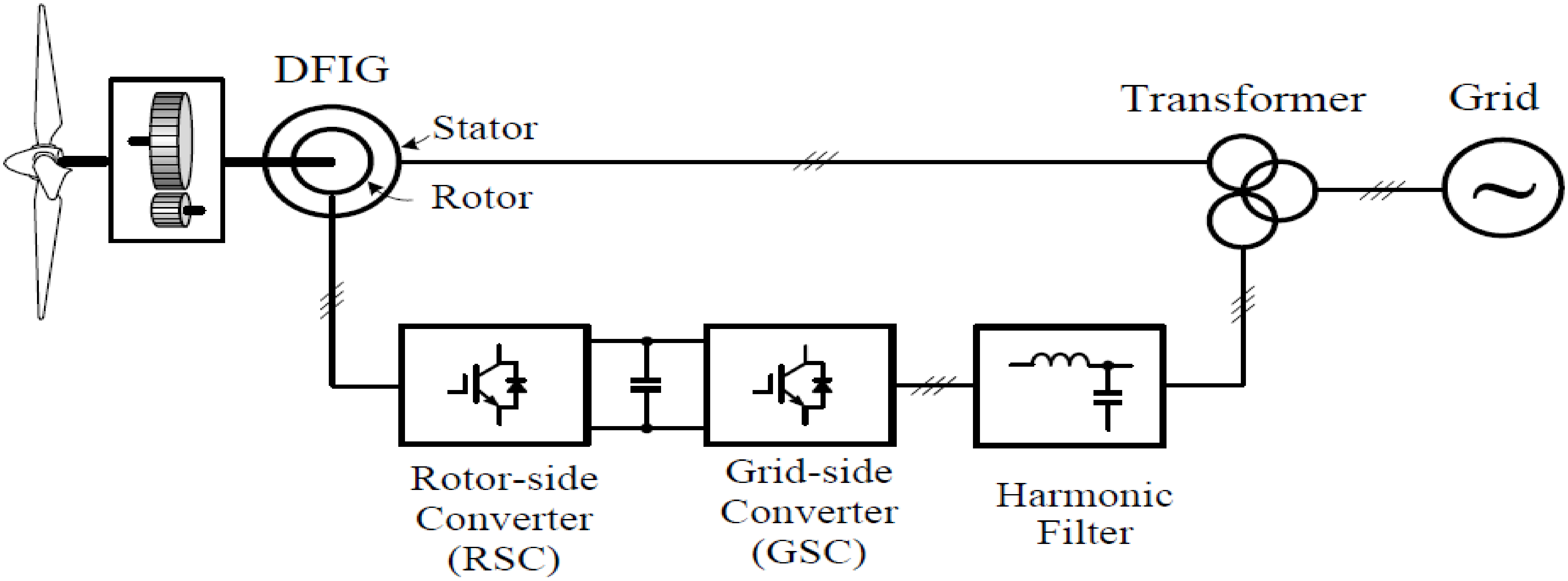
Doubly Fed Induction Generator (DFIG)

Q. Why Doubly Fed Induction Generator (DFIG) widely accepted in today's wind energy industry?

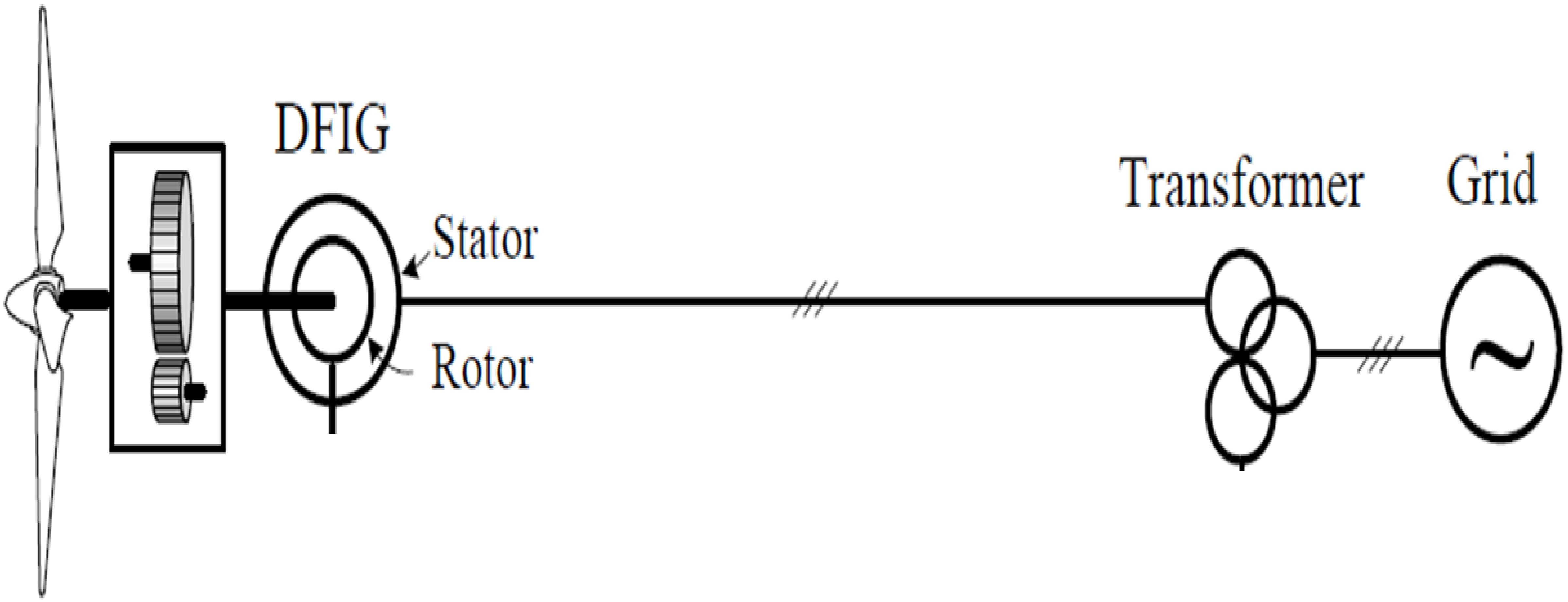
DFIG’s features make it prominent for widely acceptance in today’s wind energy industry.

DFIG’s features

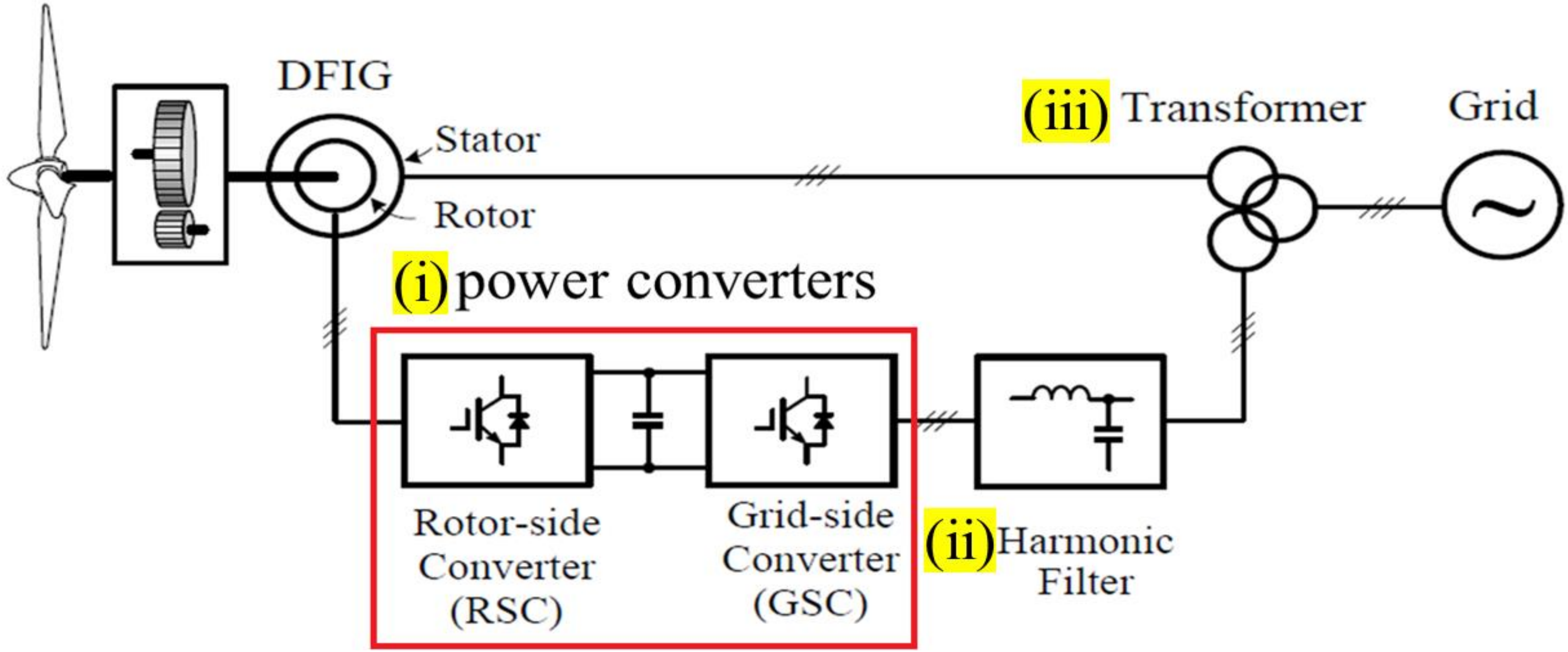
DFIG is a wound rotor induction generator. Rotor circuit is controlled by external devices to achieve variable speed operation.



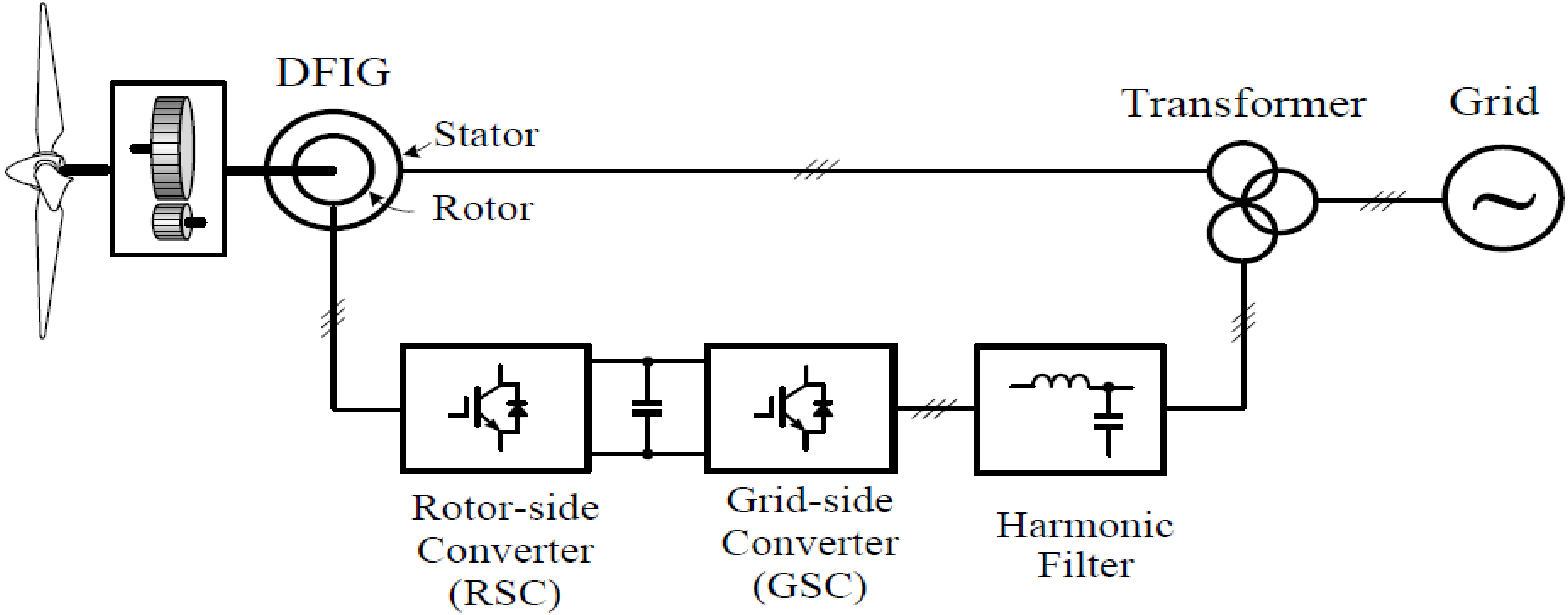
Stator of generator is connected to grid through a transformer



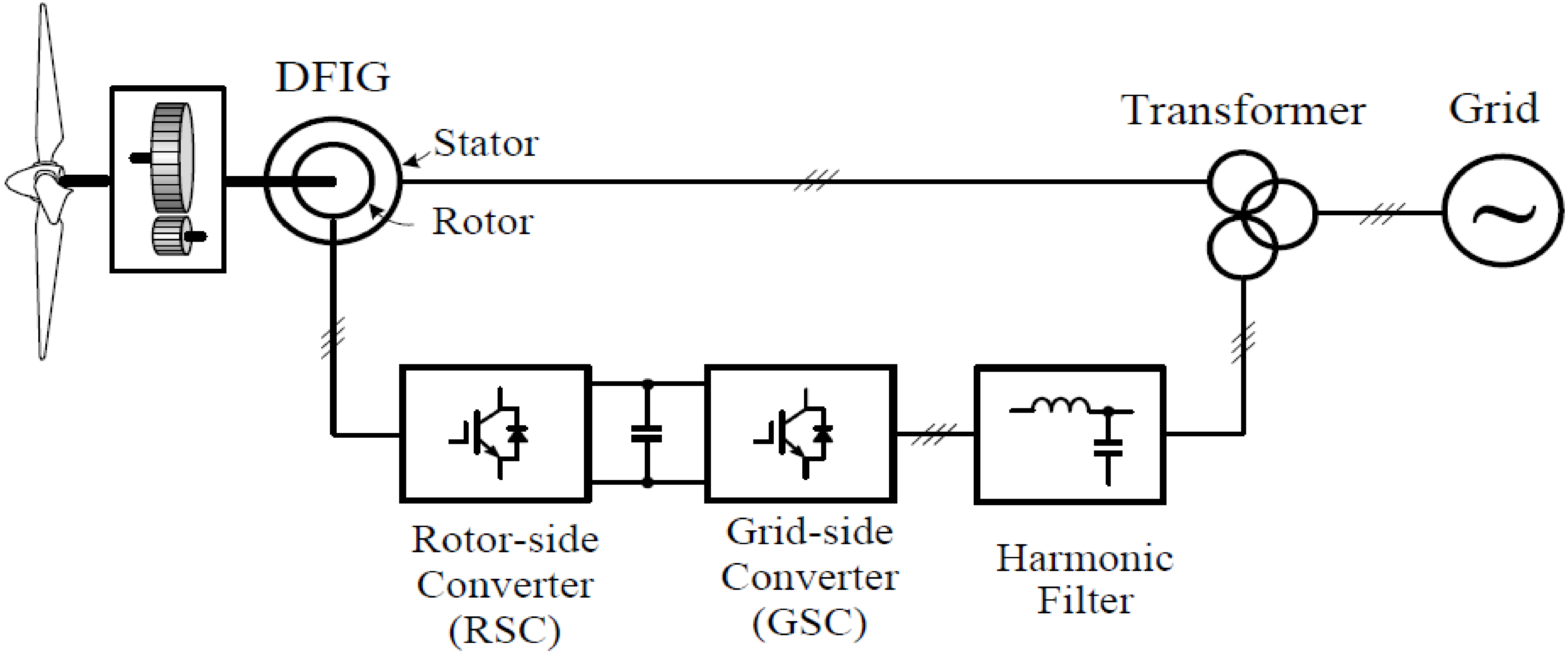
Rotor is connected to grid through (i)power converters, (ii)harmonic filter & (iii) transformer.



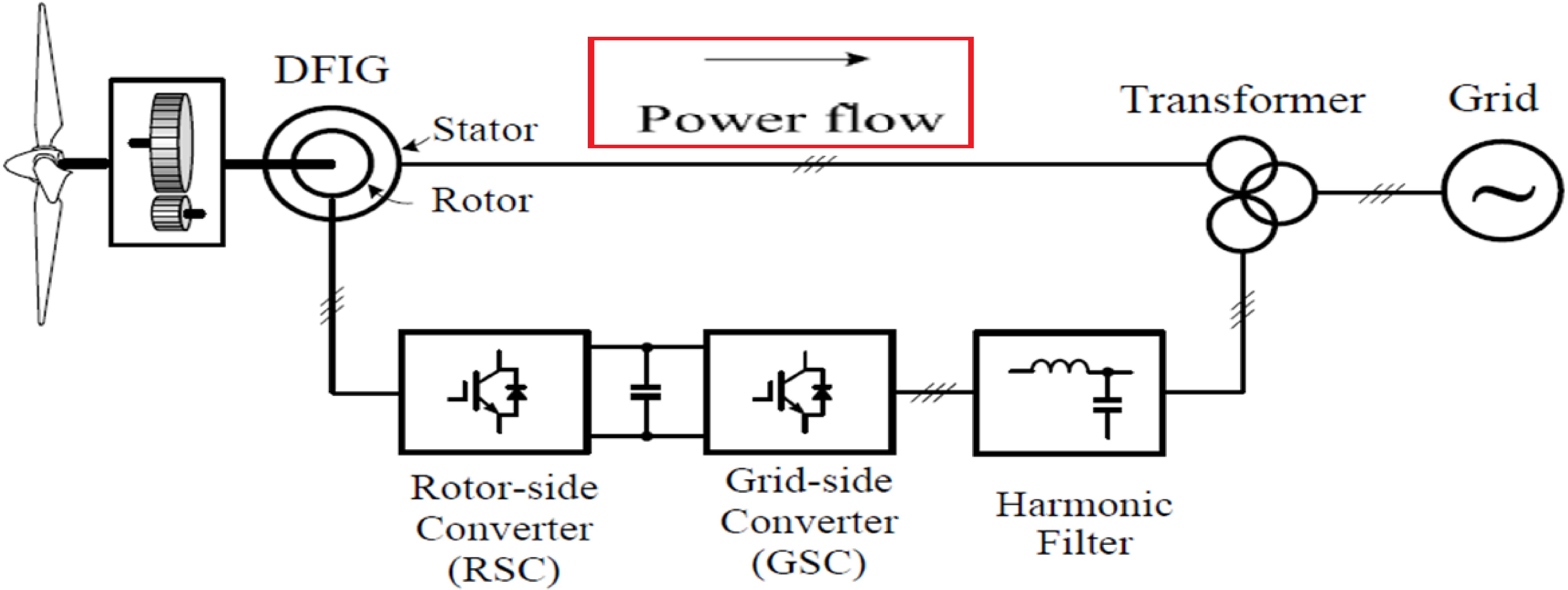
Power rating for DFIG is normally in range of a few hundred KW to several MW



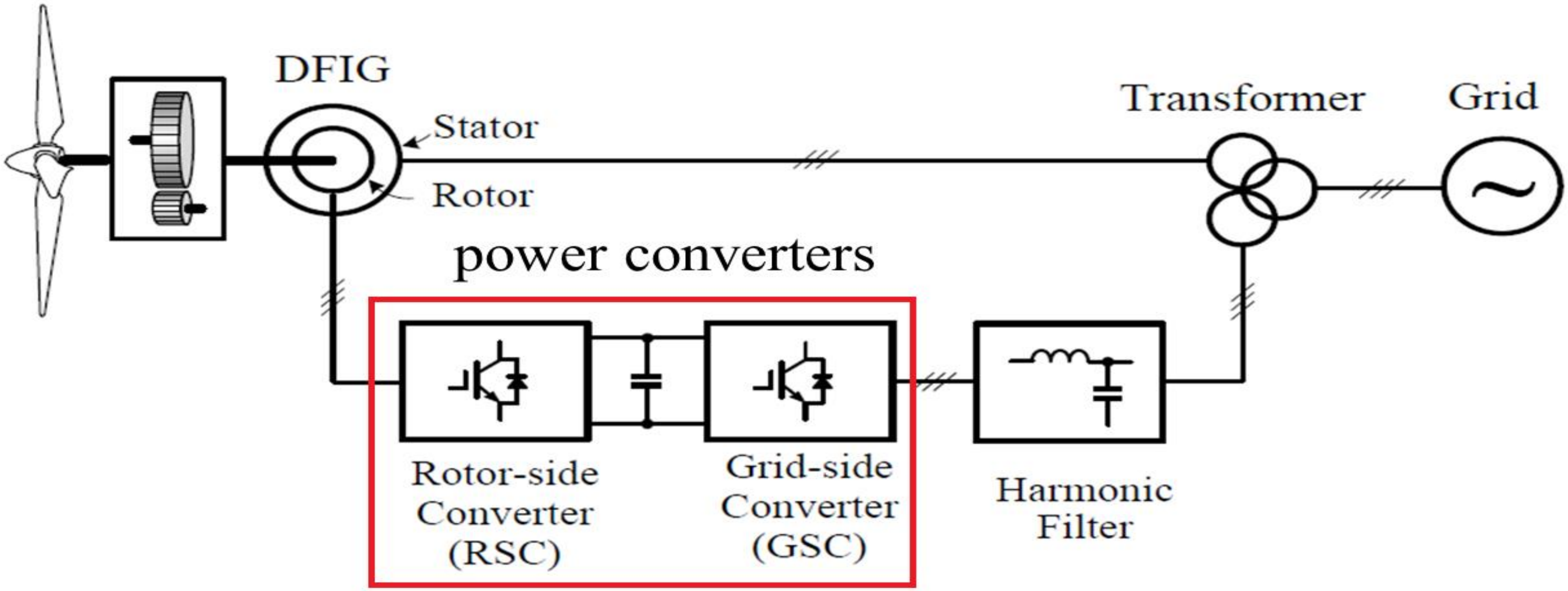
Q. Power flow in stator circuit is unidirectional?



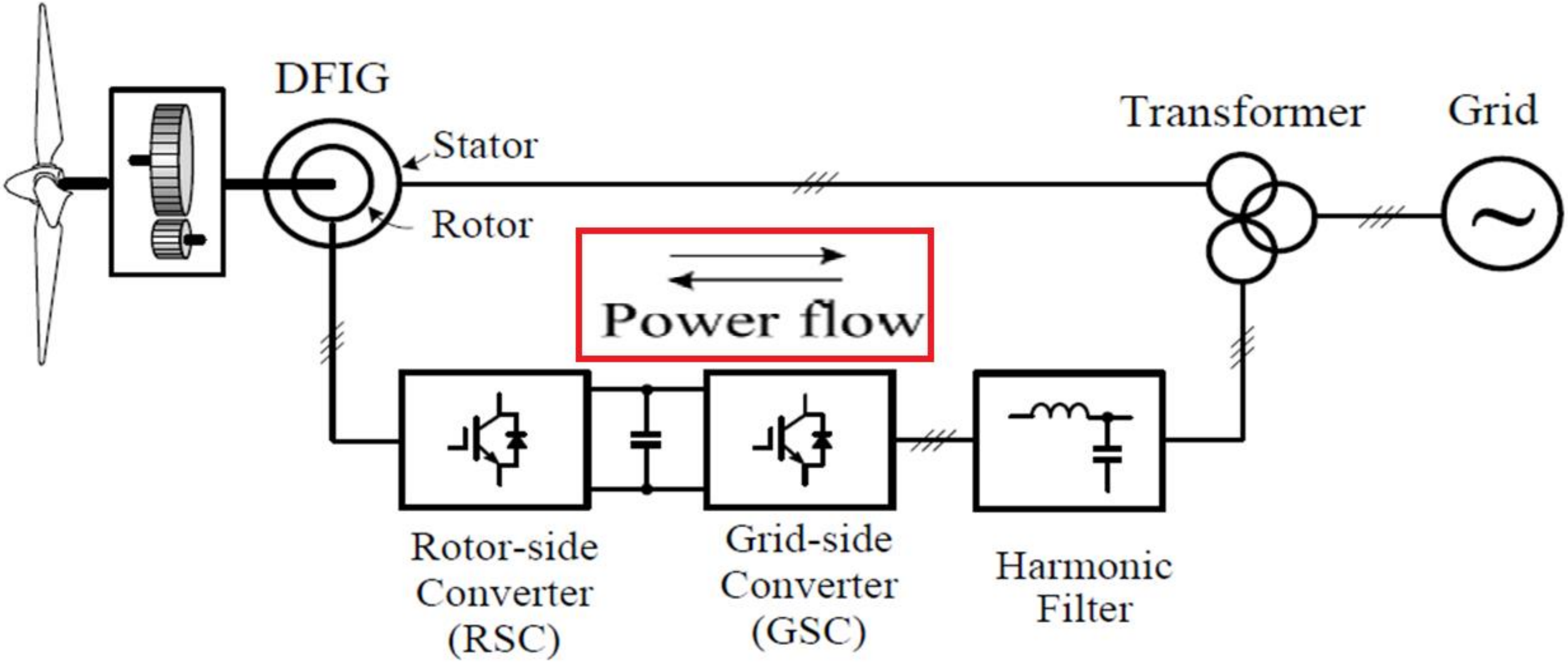
Stator of generator delivers power from wind turbine to grid & therefore power flow is unidirectional.



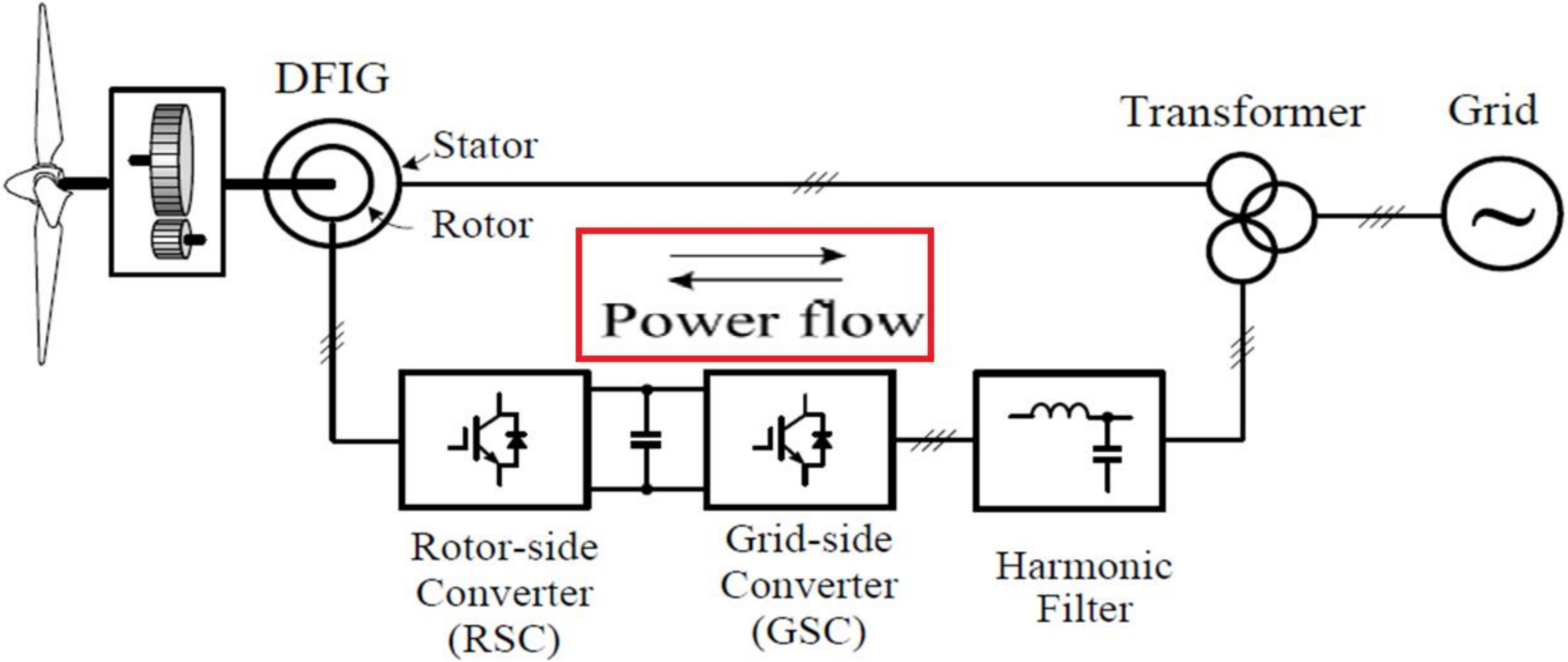
Q. Power flow in rotor circuit is bidirectional?



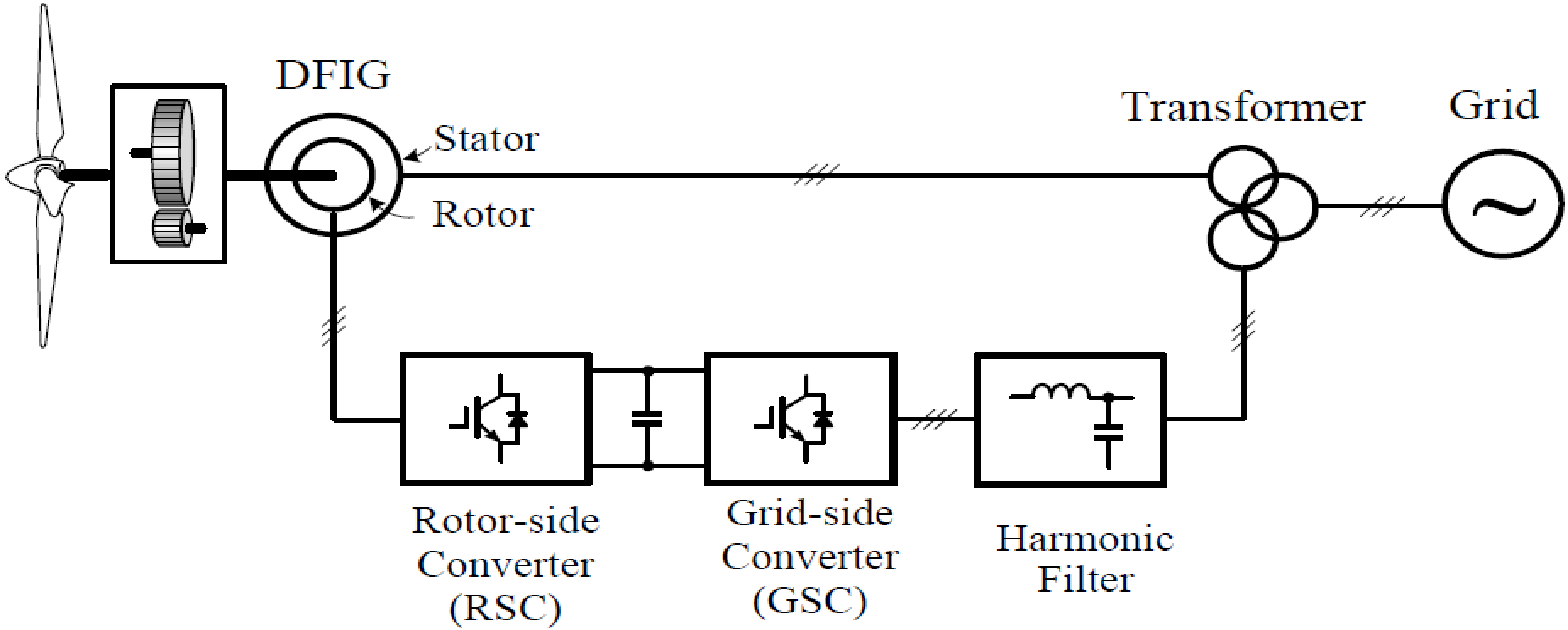
Power flow in rotor circuit is bidirectional, depending on operating conditions.



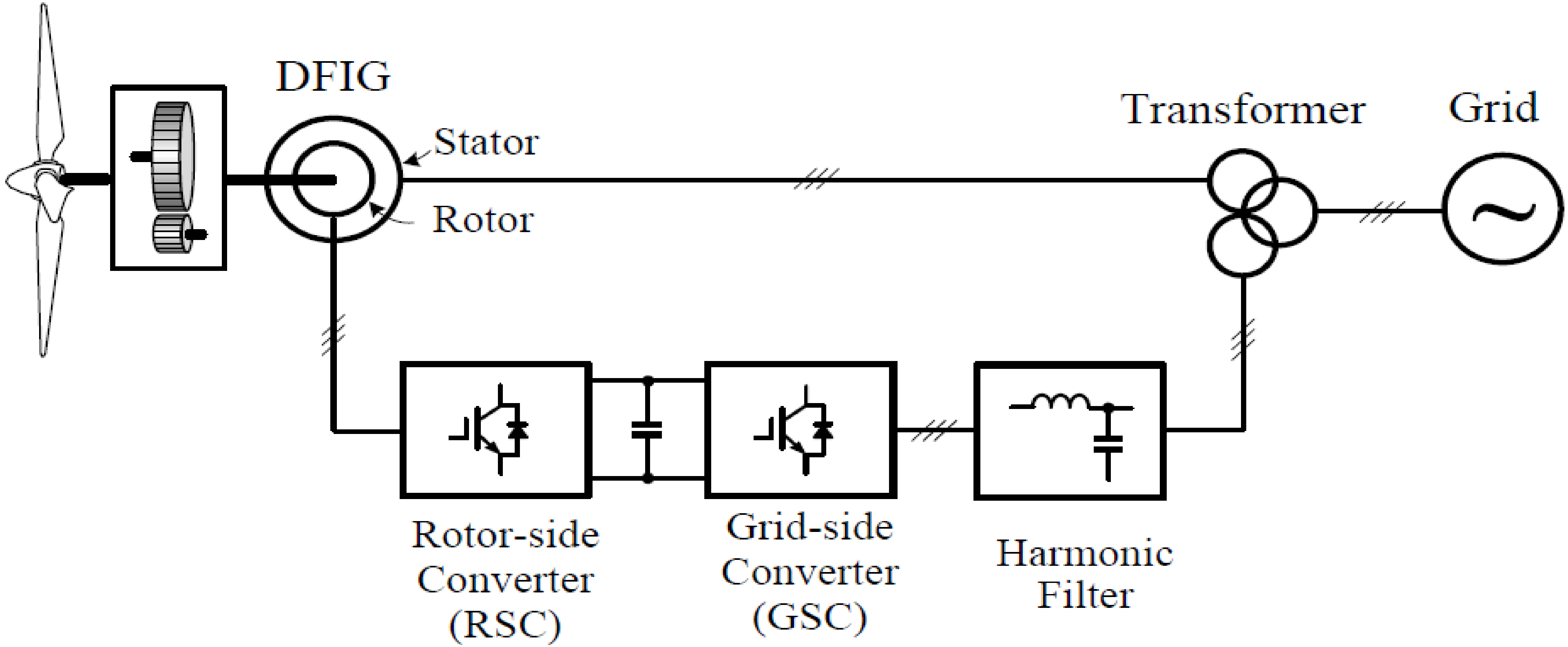
Power can be delivered from rotor to grid & vice versa through Rotor-side Converter (RSC) & Grid-side Converter (GSC).



Power rating of converters in DFIG based WECS is reduced in comparison to WECS with full-capacity converters?

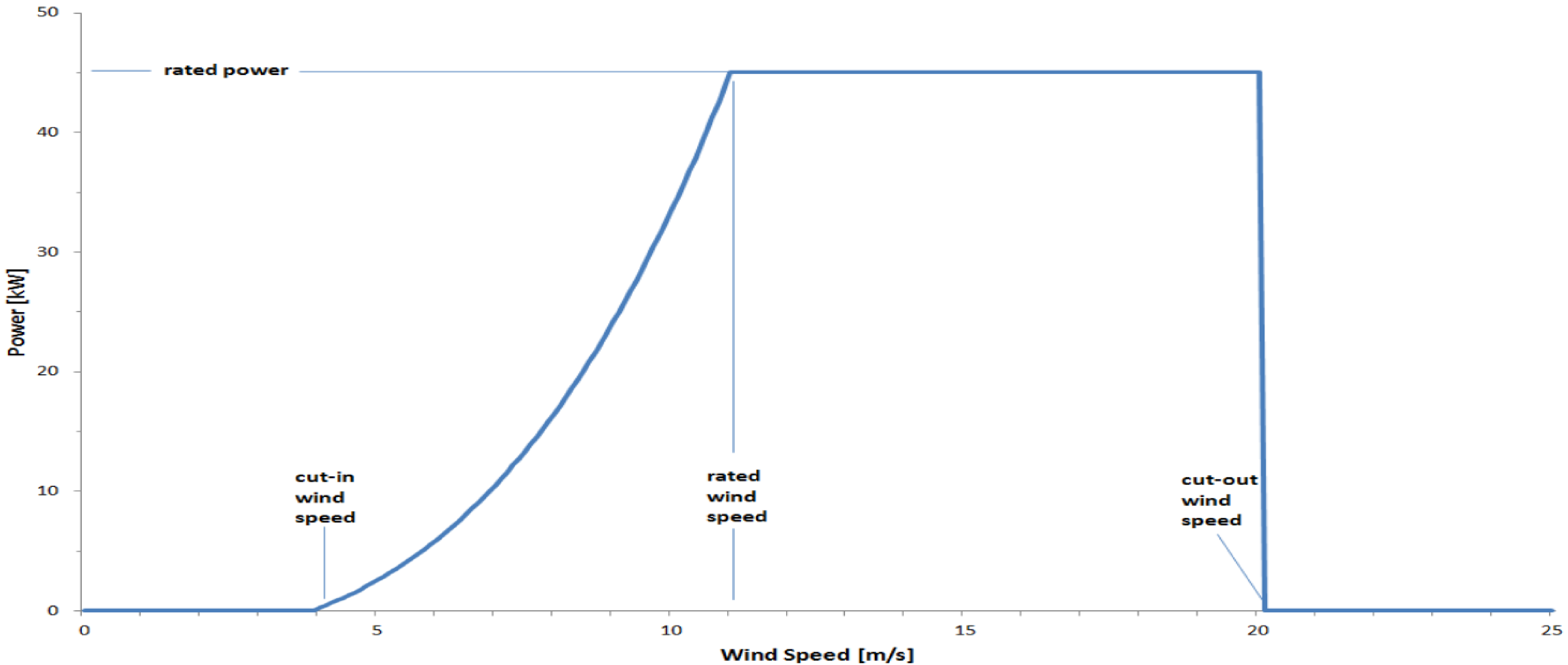


Since maximum rotor power=30% of rated stator power:



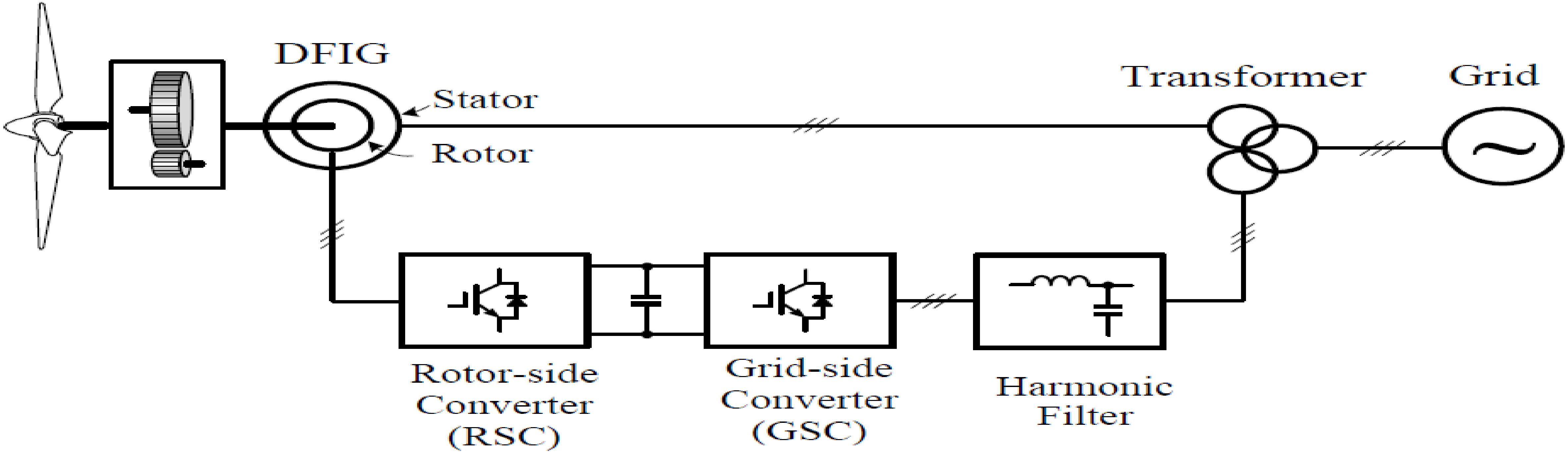
DFIG versus fixed speed WECS

With variable speed operation, a DFIG based WECS can harvest more energy from wind than a fixed speed WECS of same capacity when wind speed is below its rated value.



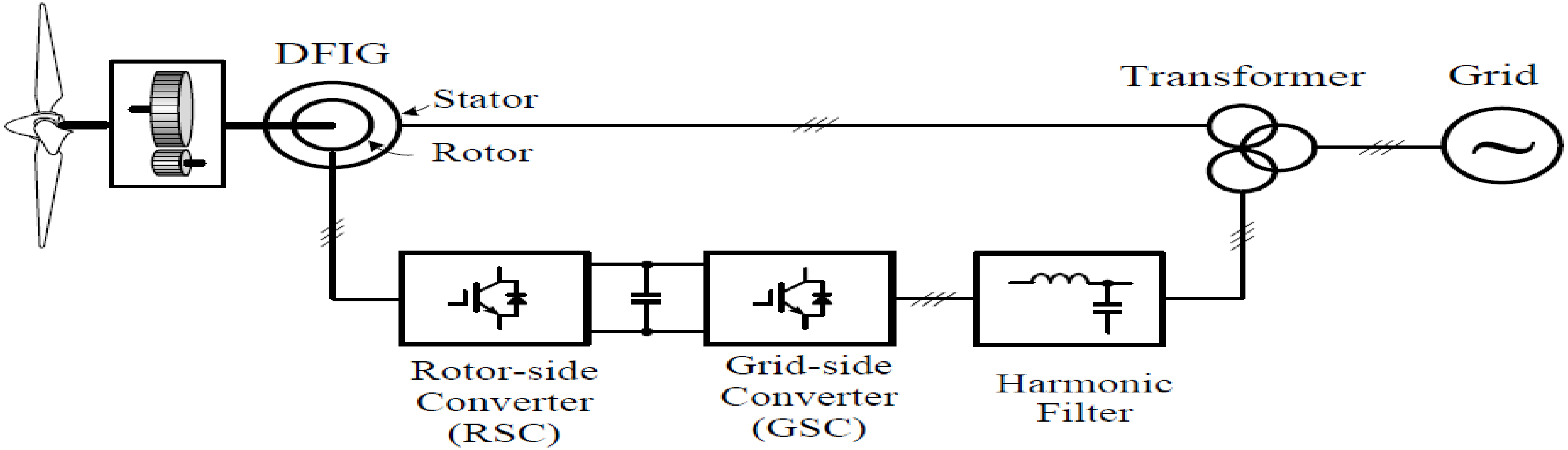
Cost of power converters & harmonic filters is lower than that in WECS with full-capacity converters.

- Power losses in converters are also lower, leading to improved overall efficiency.



System can also provide leading or lagging reactive power to grid without additional devices.

- These features have made DFIG wind energy system one of the preferred choices in wind energy market.



Synchronous generator

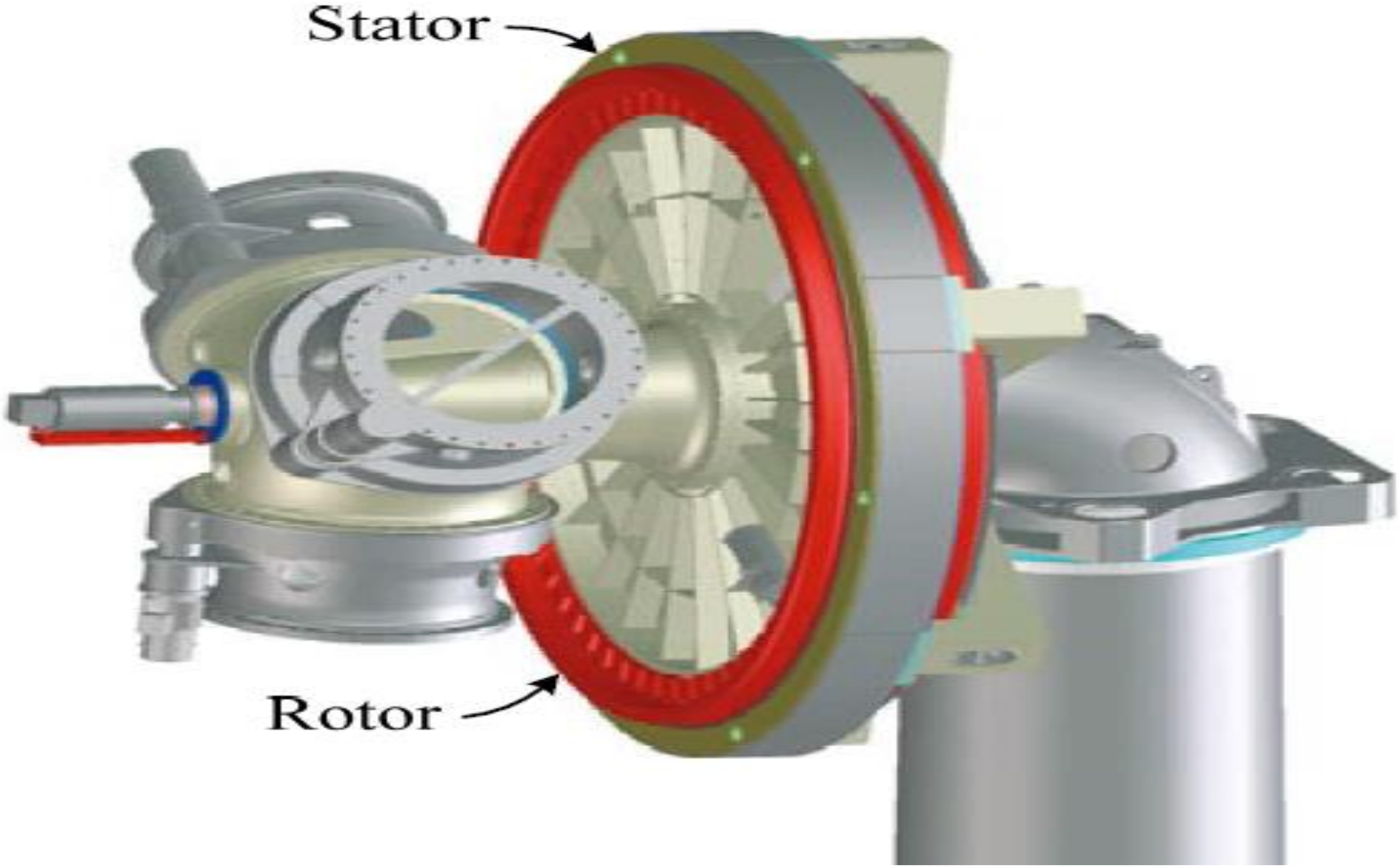
- Synchronous generator is very well-suited for direct drive wind turbines.
- Wound rotor synchronous generator (WRSG) & permanent magnet synchronous generator (PMSG) are used in wind energy systems with a maximum power rating up to 7.5MW.

Synchronous generator

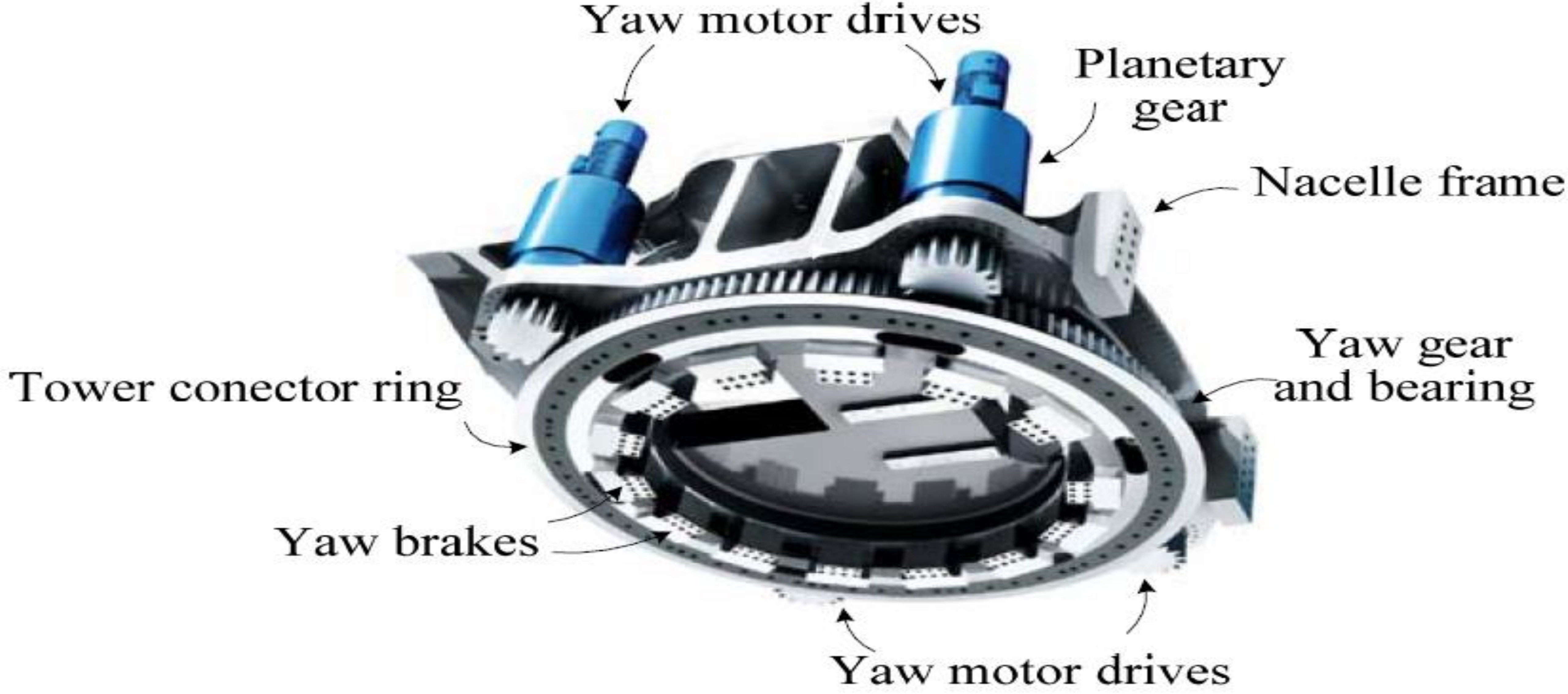
- Permanent magnet generators have higher efficiency & power density as compared to wound rotor generators.
- Recent trend indicates a move toward direct drive turbines with PMSG.
- Although most SG based turbines are direct driven, some manufacturers have developed SG turbines with gearbox drive train.

4-pole and 120-pole(High pole number) PMSGs

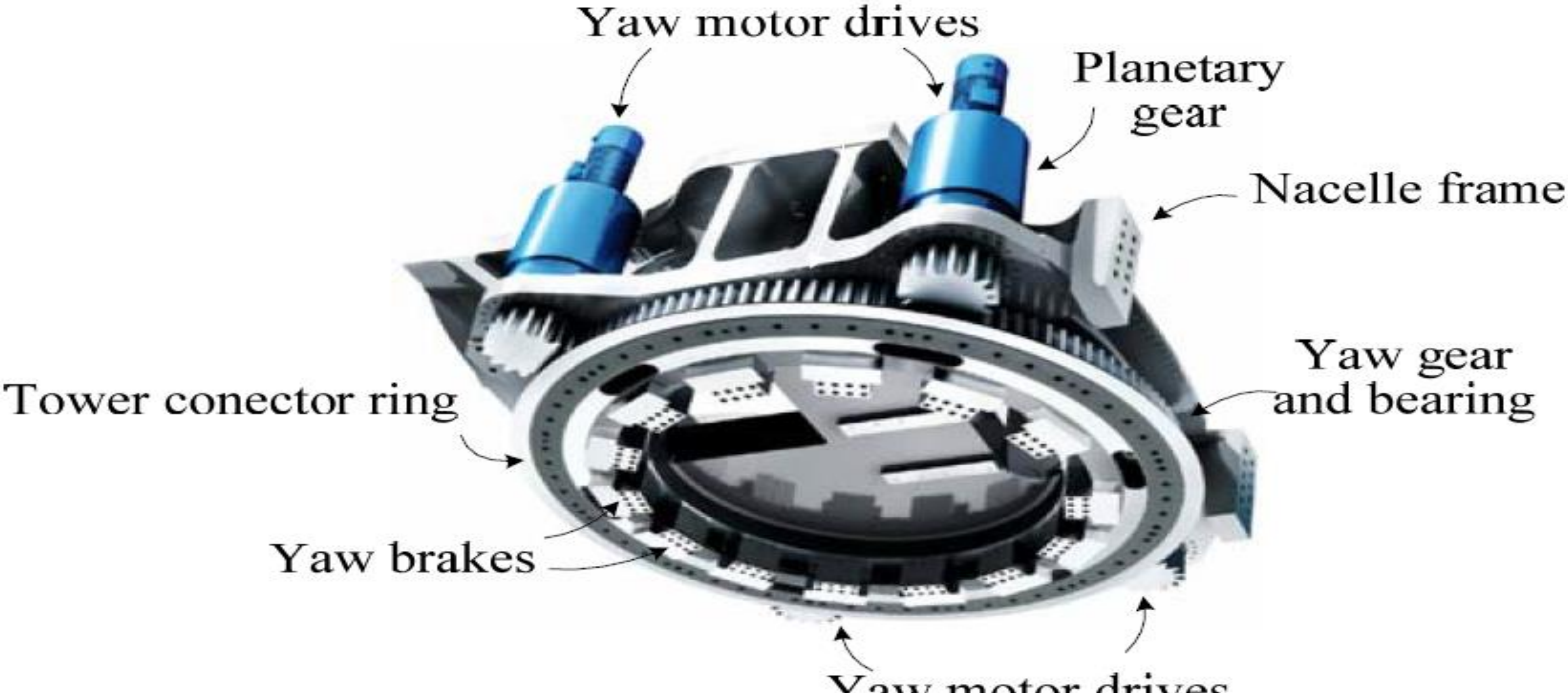
A multi-pole WRSG for direct drive WECS



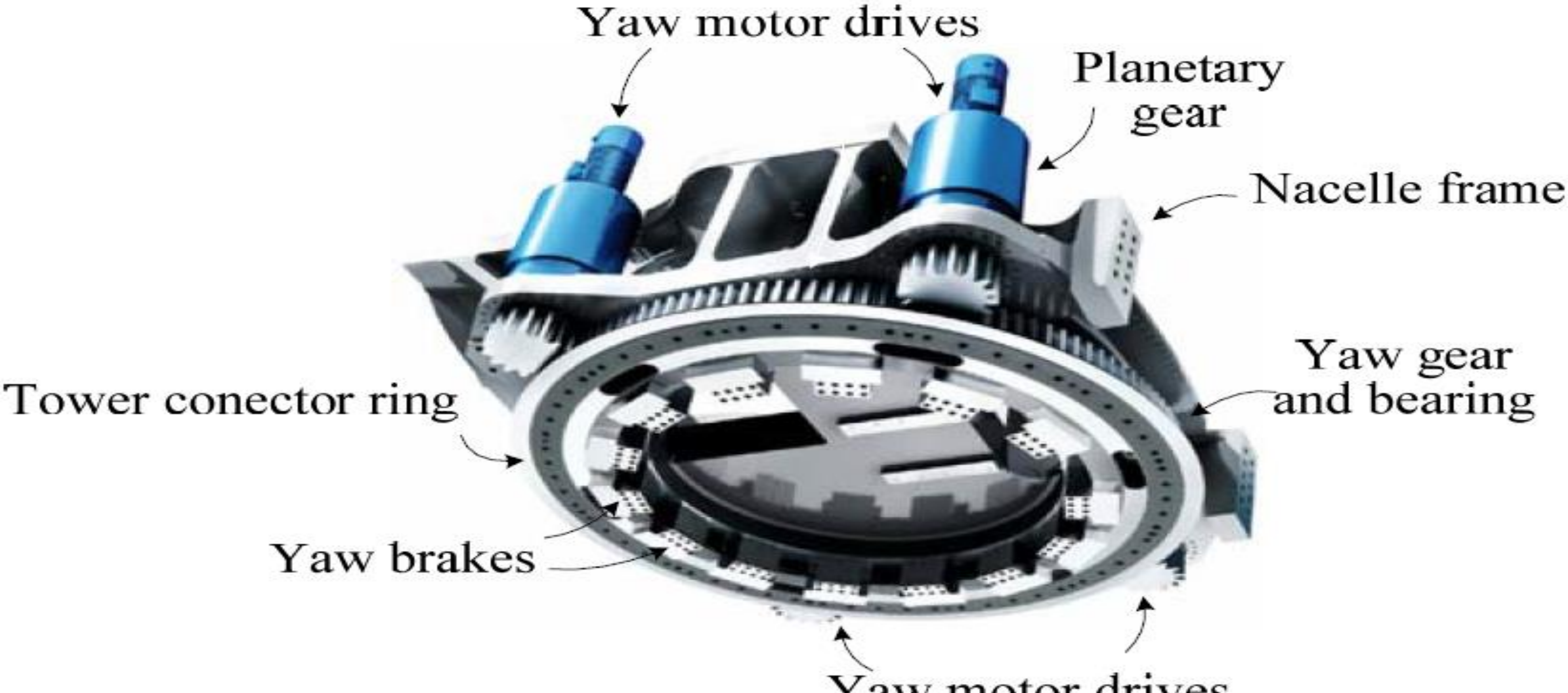
2.2.6 Yaw Drive



Main function of yaw drive is to maximize captured wind energy by keeping turbine facing into wind.

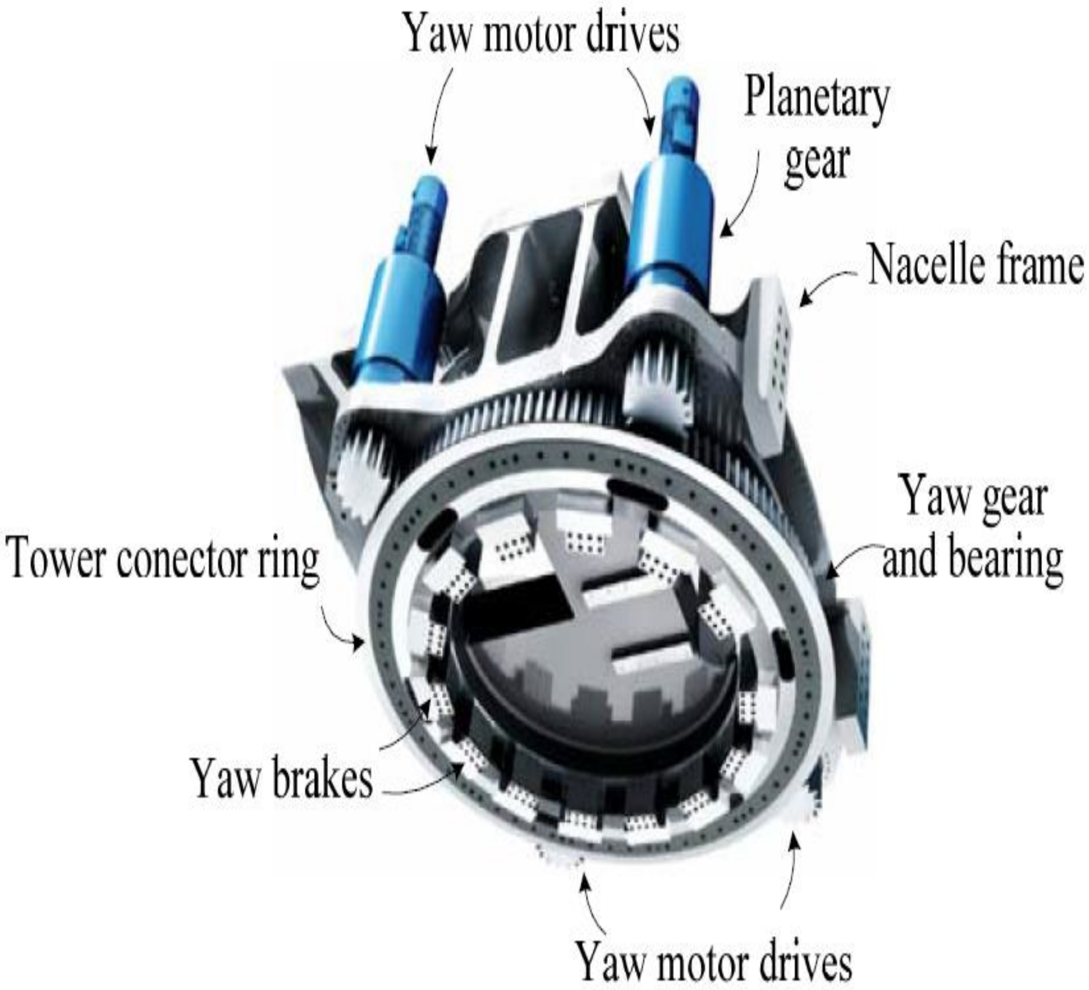


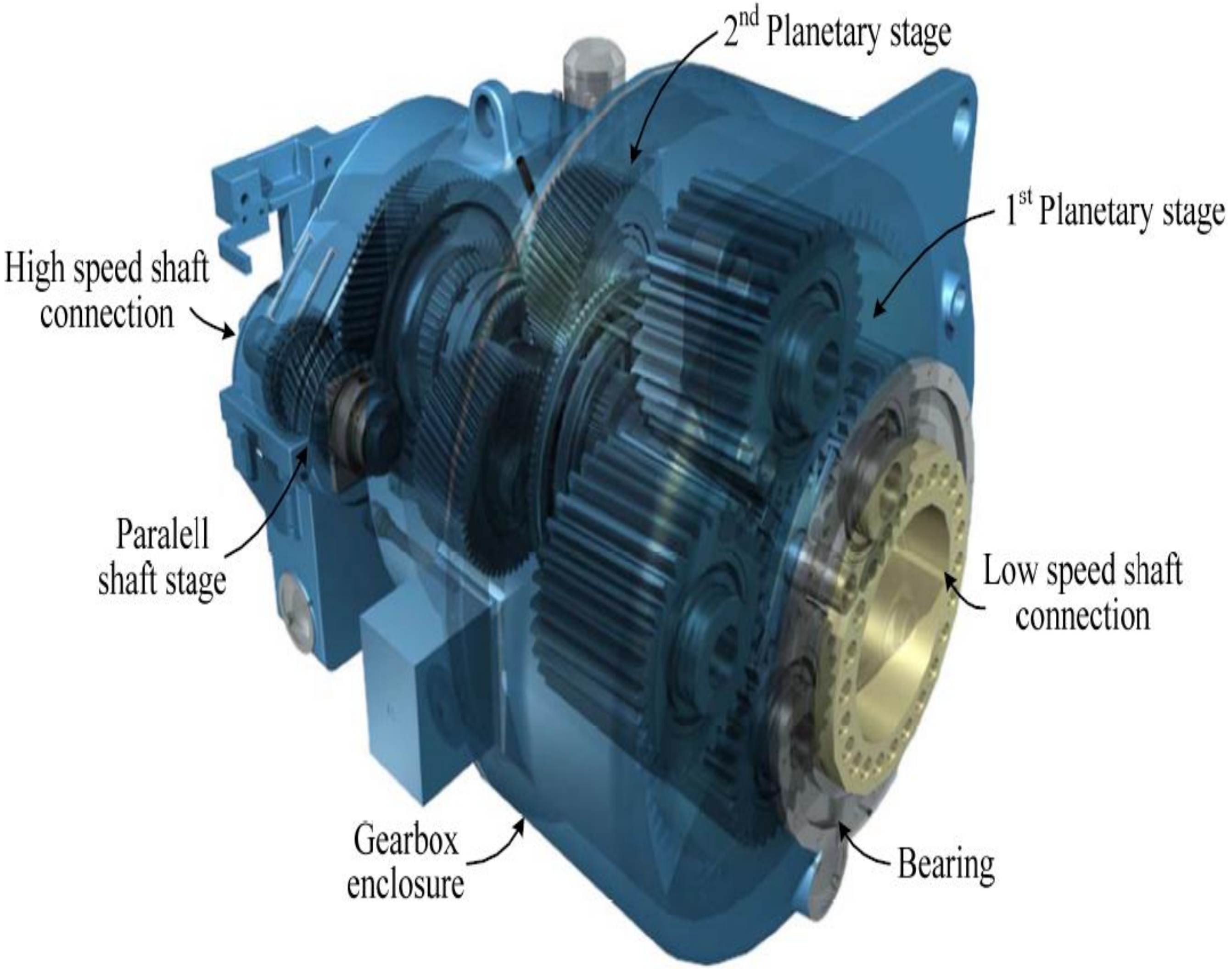
Yaw drive consists of more than one electric motor drives, yaw gear, gear rim & bearing



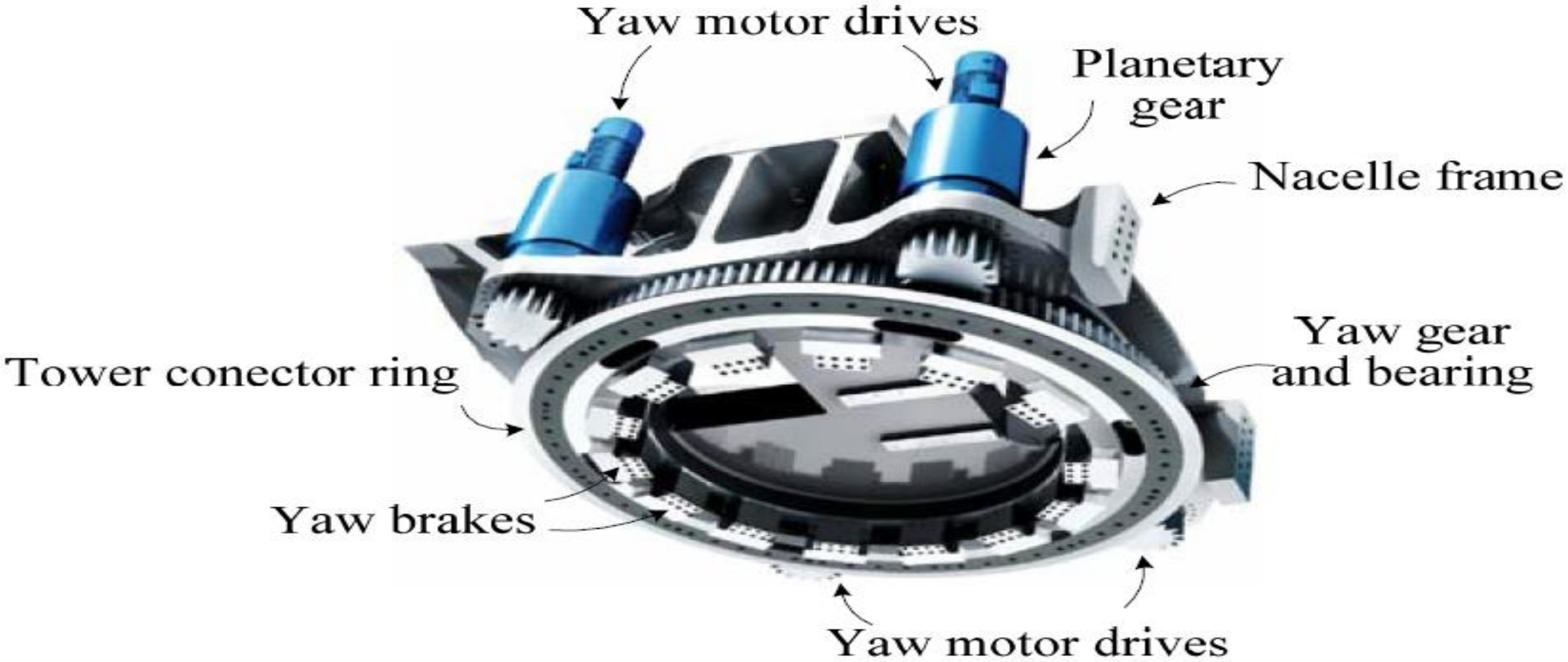
A set of yaw brakes are disposed around the yaw rim to lock position of turbine when facing wind or during maintenance.

Yaw drive uses a planetary gear to lower rotating speed of yaw gear.

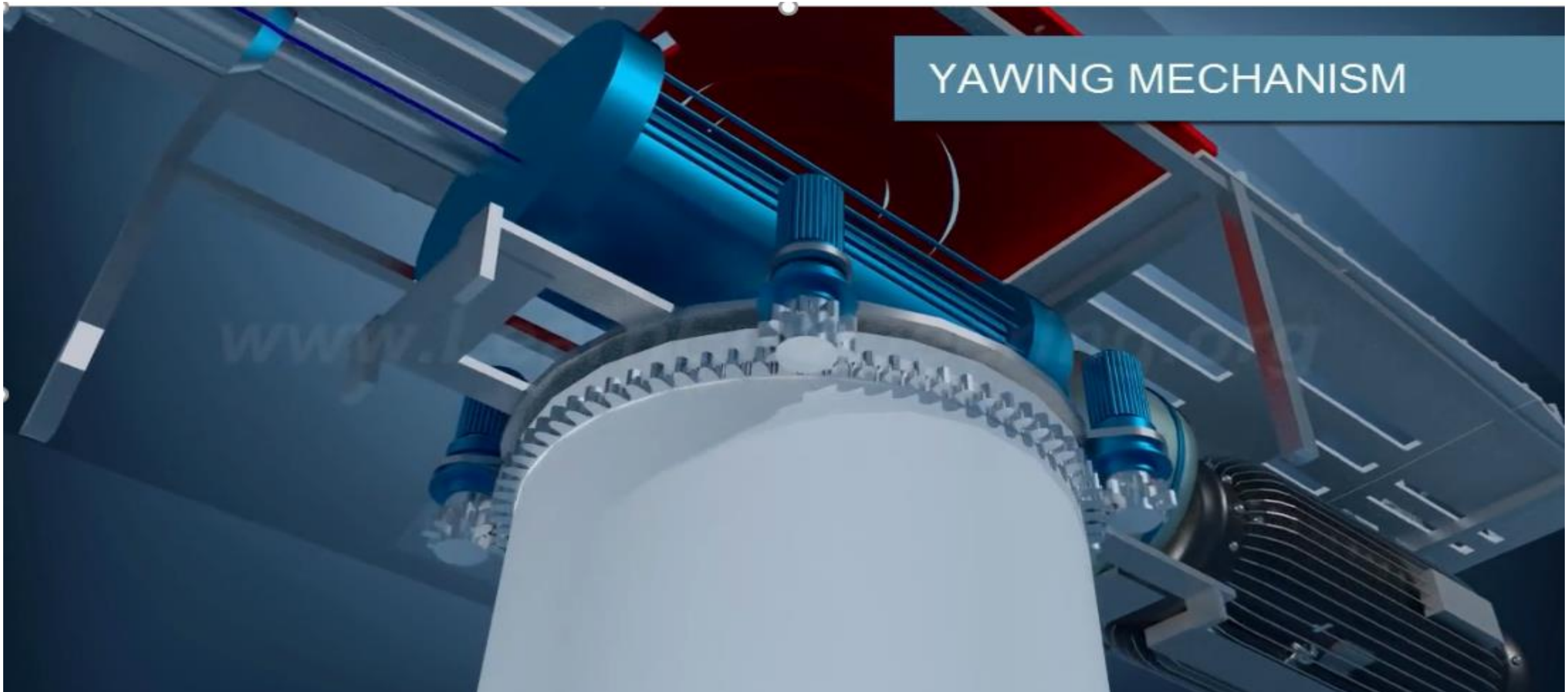




All motors are commanded by same signals, & lock after turning wind turbine into the desired position.



Yaw system typically needs to generate torque from 10-70 kNm to turn nacelle.

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In early wind turbines, yaw control is also used for power regulation.

- e.g, to limit power captured by turbine during high wind gusts, turbine can be horizontally turned out of wind
- However, this technology is no longer in use since power regulation by means of yaw control is very limited for 3 reasons.

1. Large moment of inertia of nacelle & turbine rotor along yaw axis reduces speed of response of yaw system.

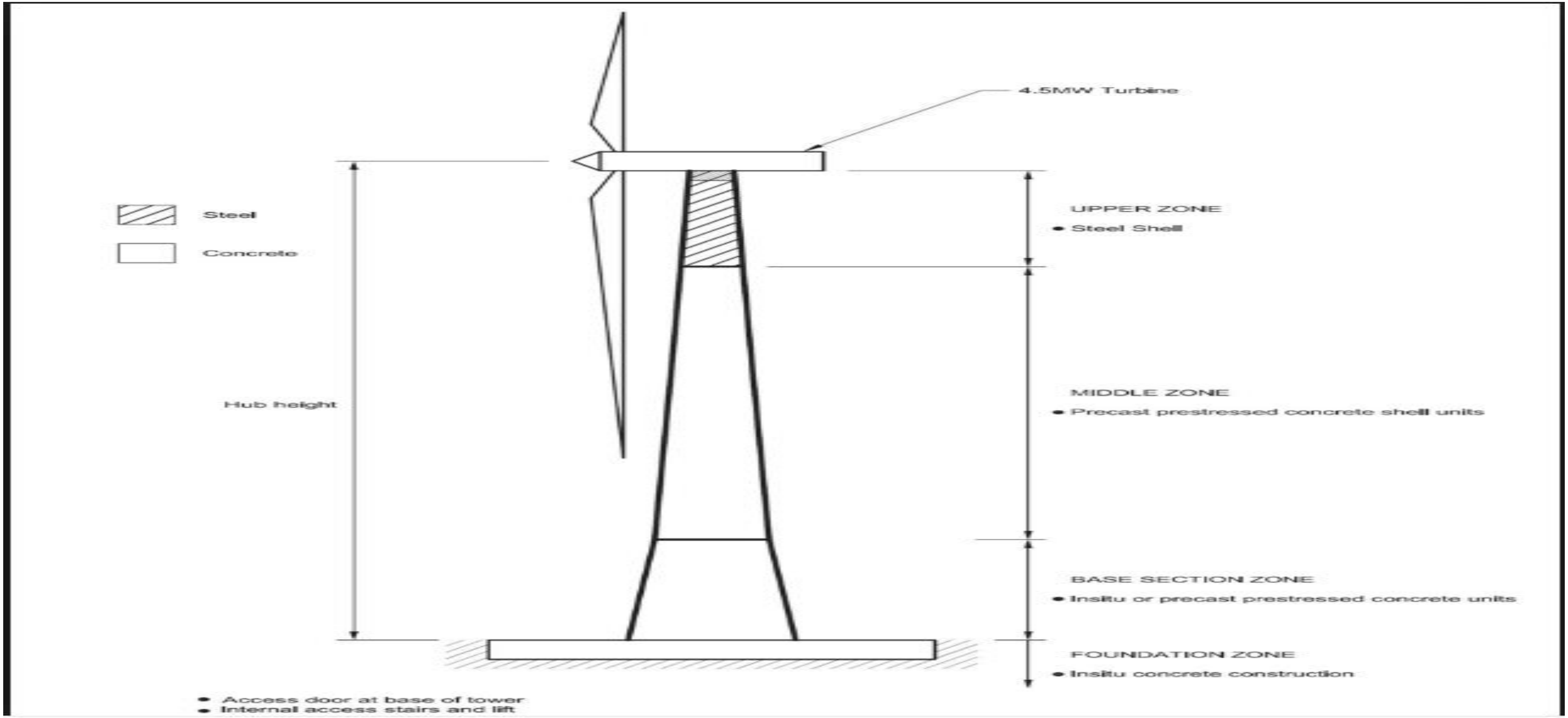
2. Cosine relationship between component of wind speed perpendicular to rotor disc &

- yaw angle makes power capture insensitive to yaw angle e.g.
- 15º of yaw change only bring power reduction of a few %.

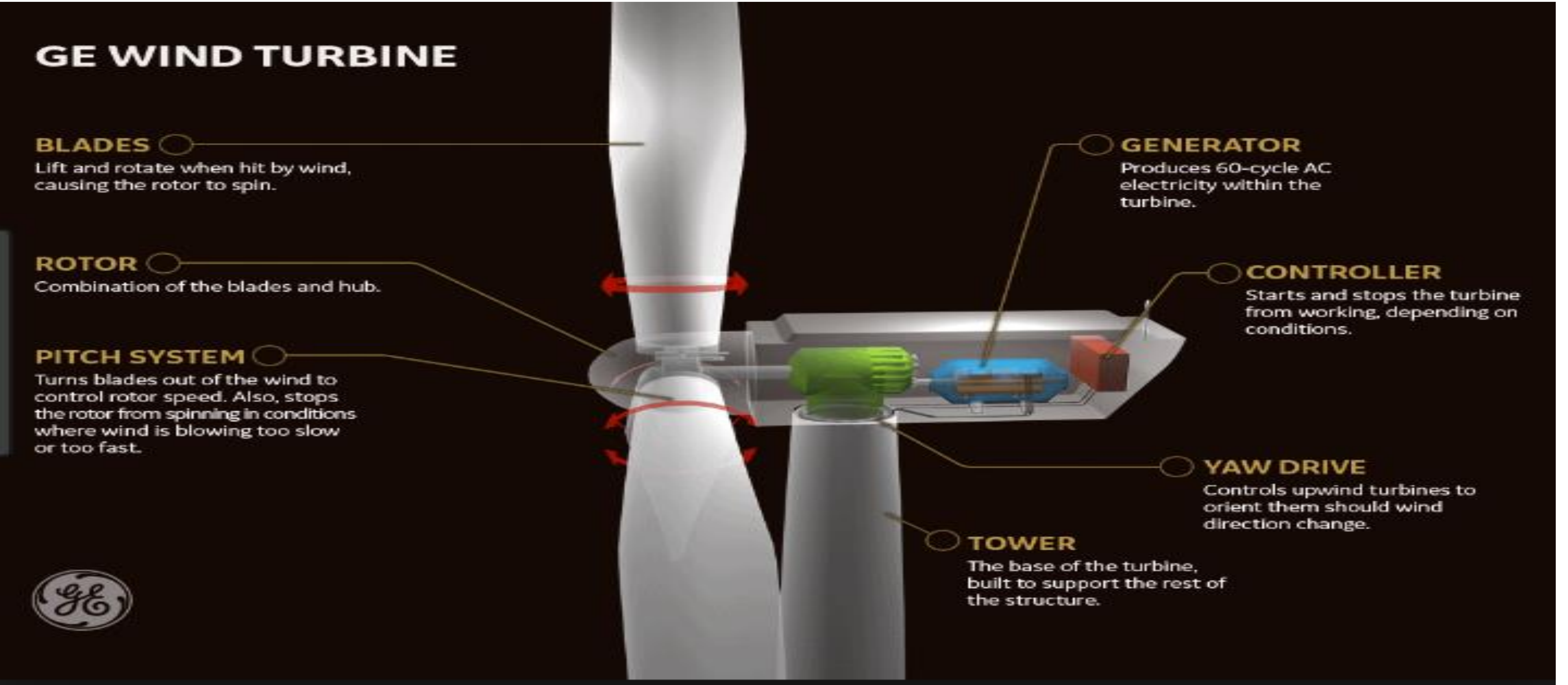
3. Yaw control imposes mechanical stress on different parts of turbine,

- Causing vibrations that could reduce life span of turbine.

2.2.7 Tower and Foundation



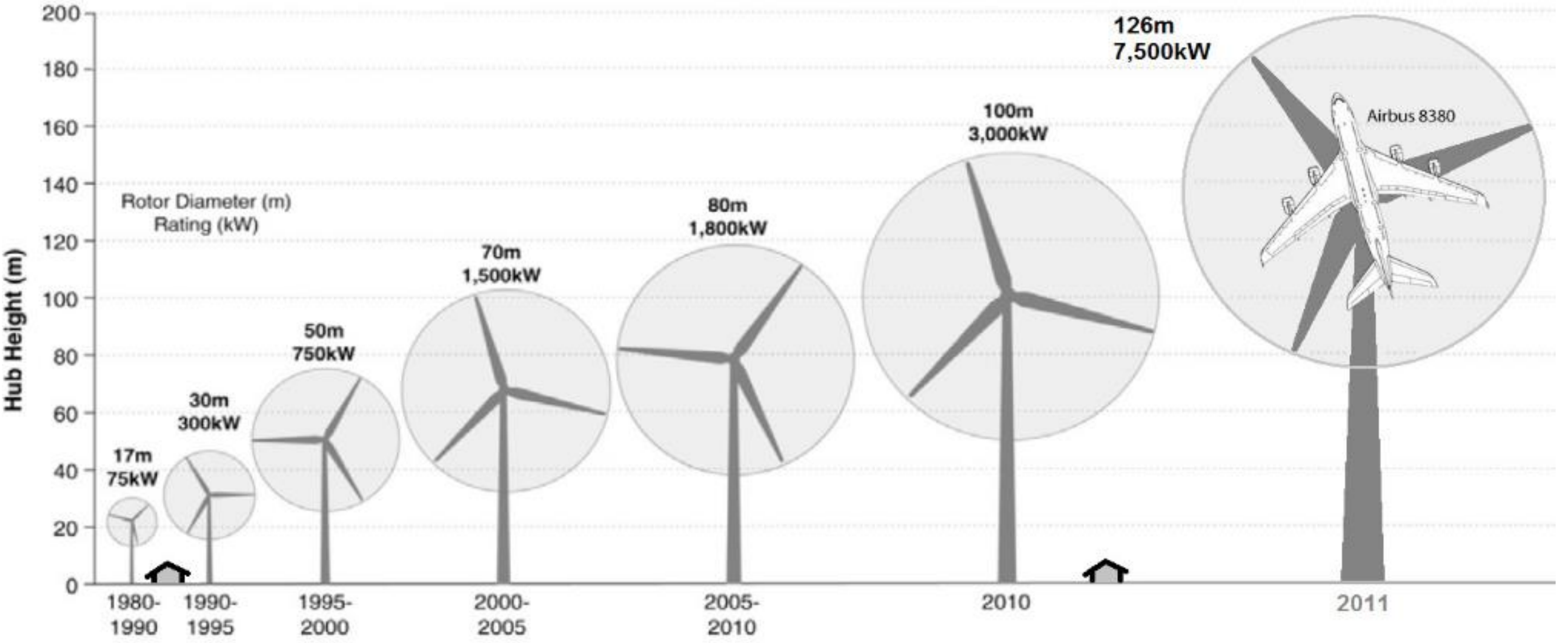
Main function of tower is to: support nacelle & turbine rotor



Most towers for wind turbines are made of steel.

Concrete towers, or towers with a concrete base & steel upper sections are sometimes used as well.

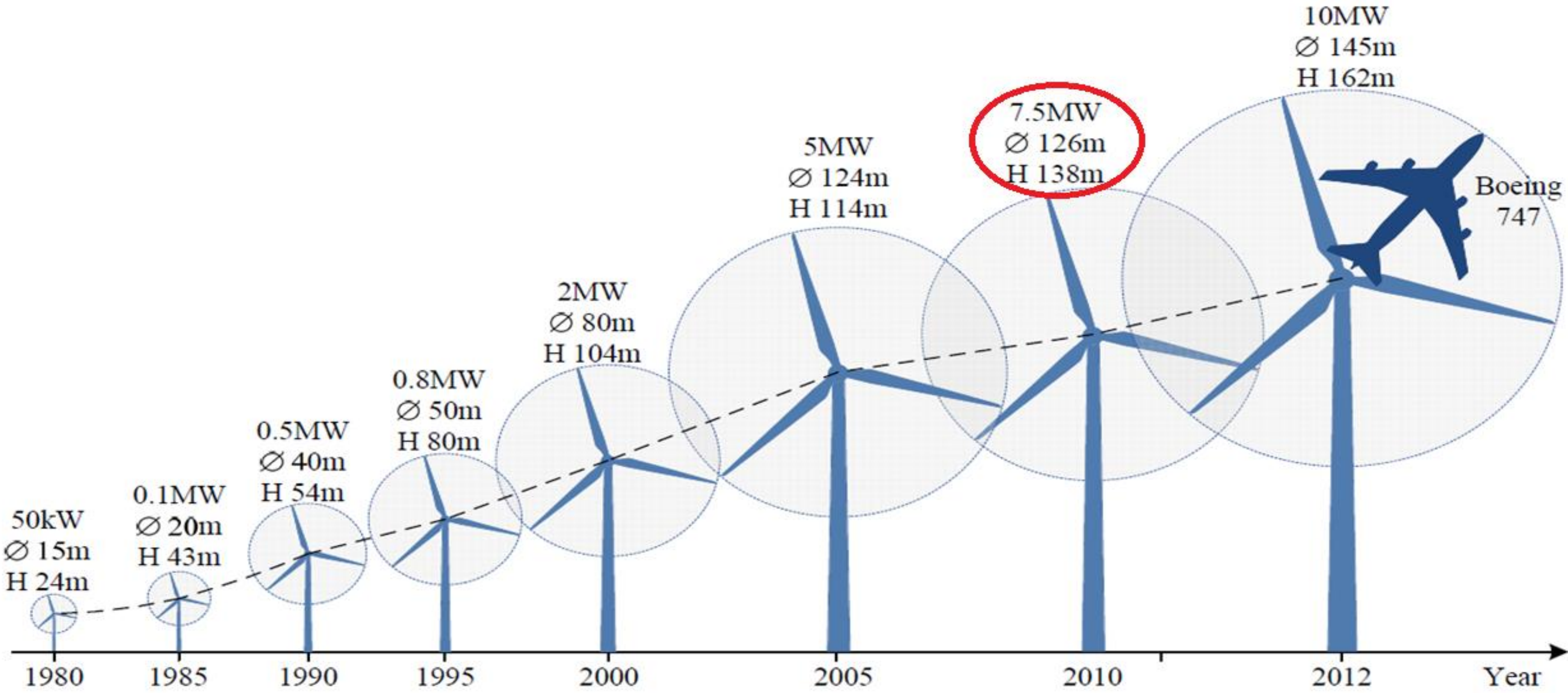
Height of tower increases with turbine power rating & rotor diameter.



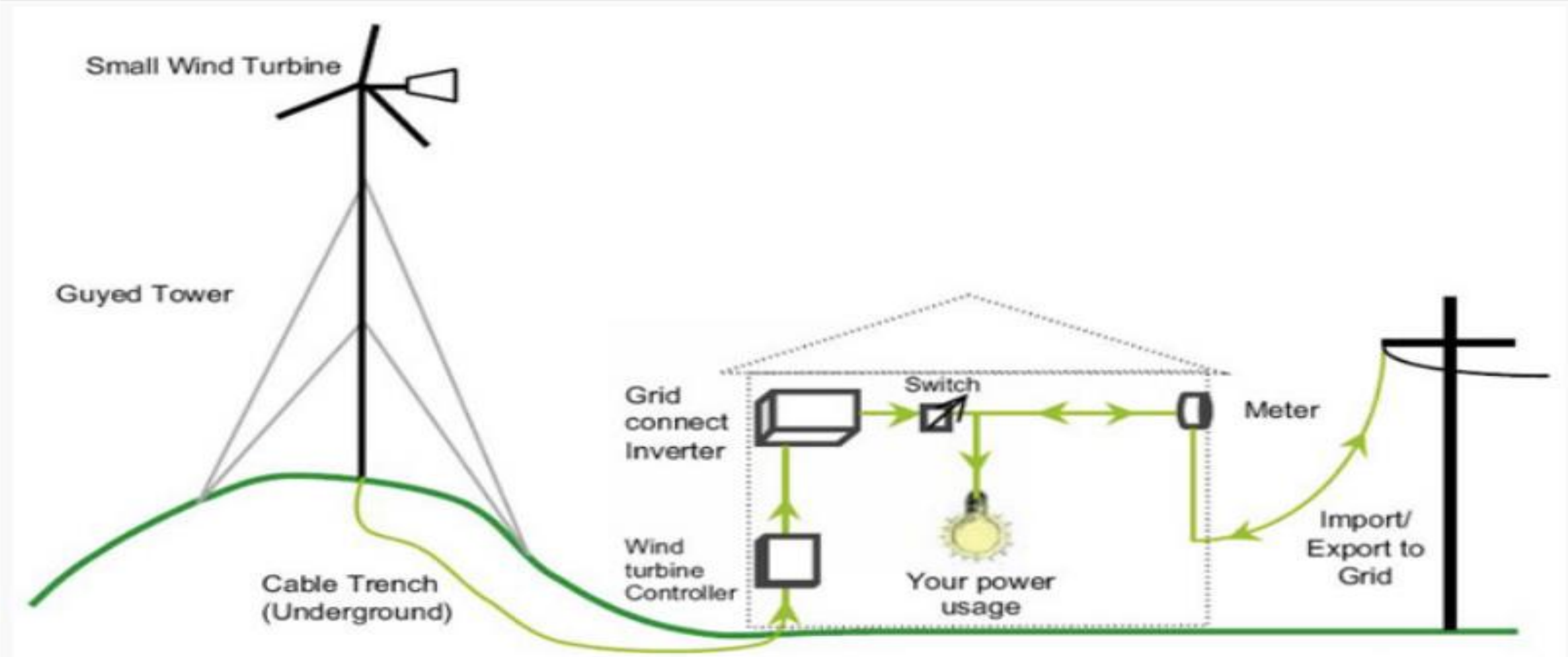
Small wind turbines have towers as high as a few blade rotor diameters.

- Towers of medium & large turbines are approximately equal to blade rotor diameter.
- Highest tower to date is a 160 m steel lattice tower for a 2.5 MW wind turbine.

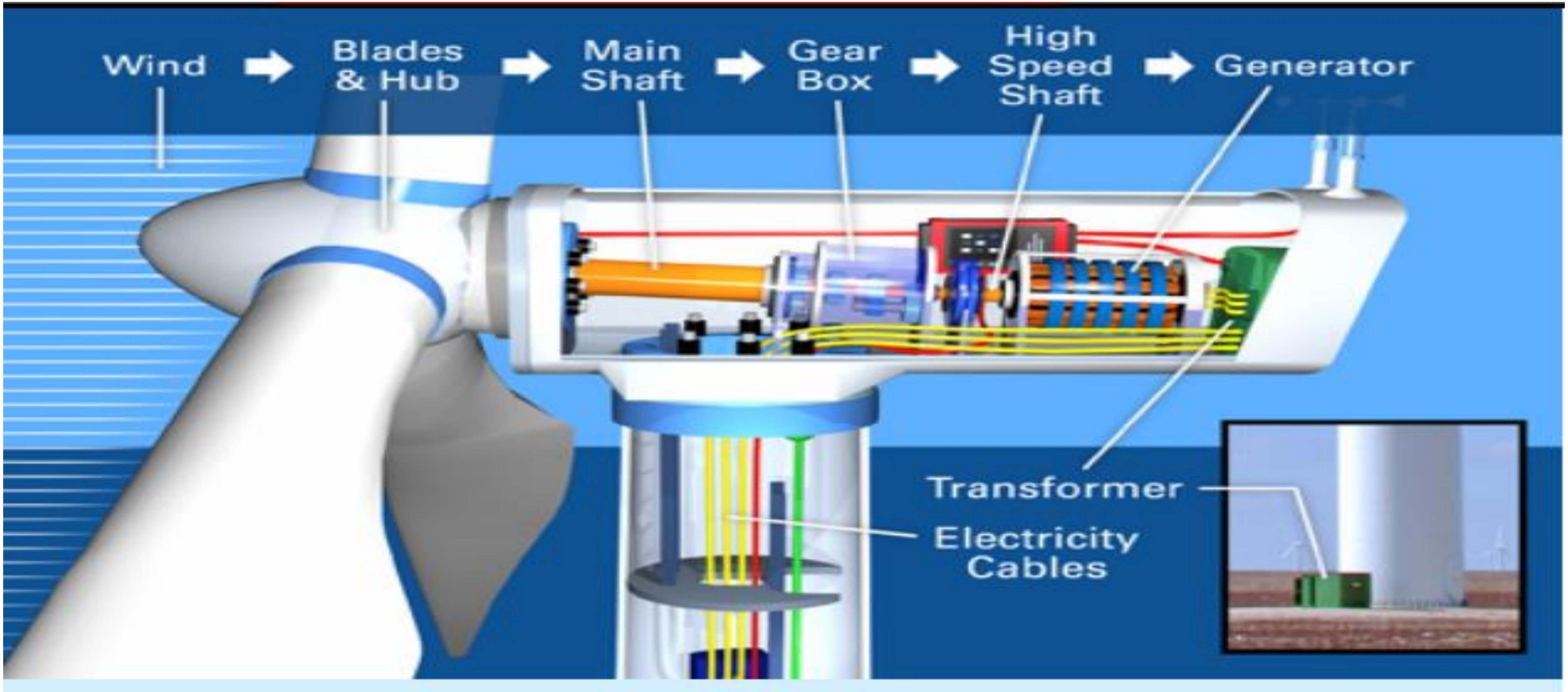
Wind turbine with a rotor diameter of 126 meters has a concrete tower of 138 meters.



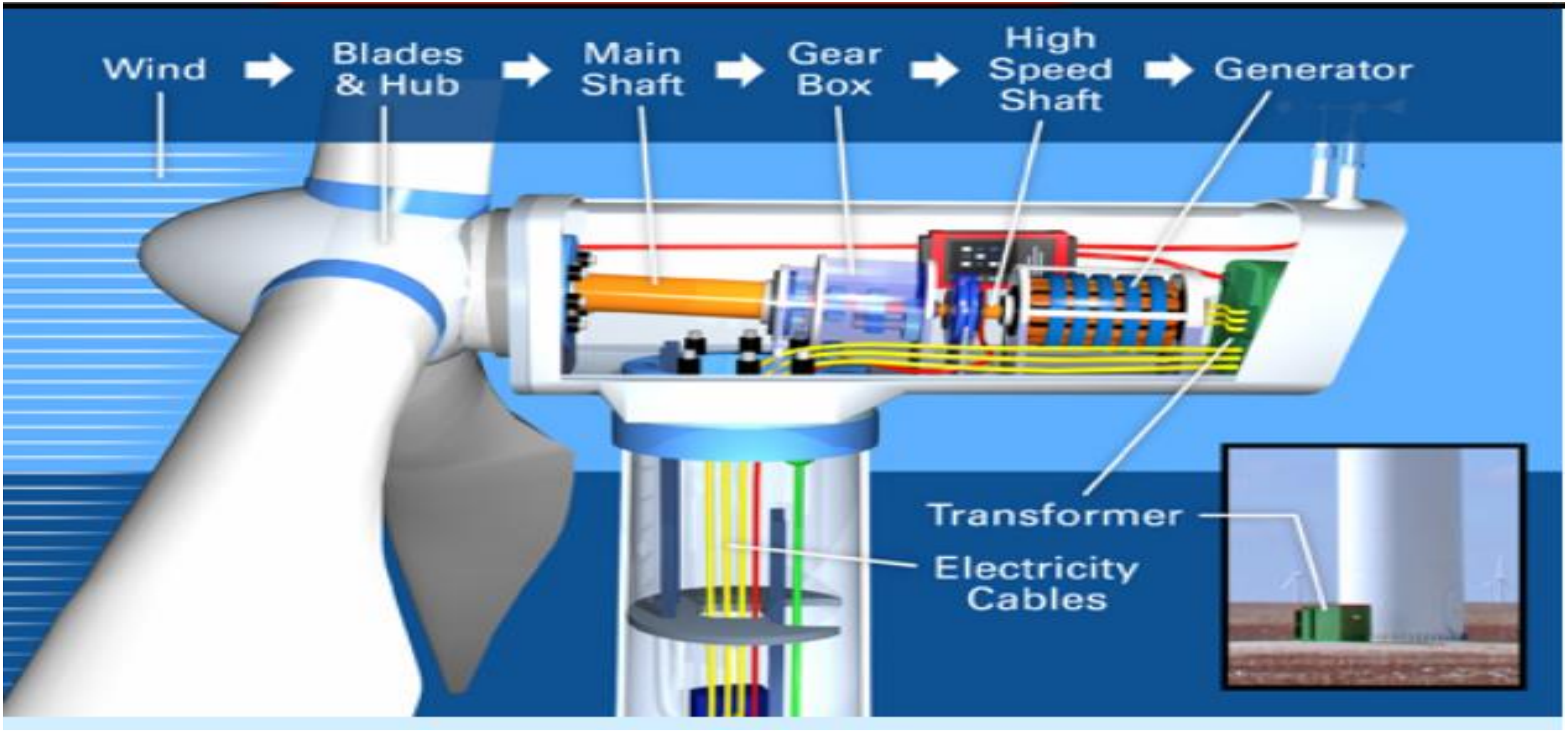
Tower also houses power cables connecting generator or power converters to transformer located at base of tower.



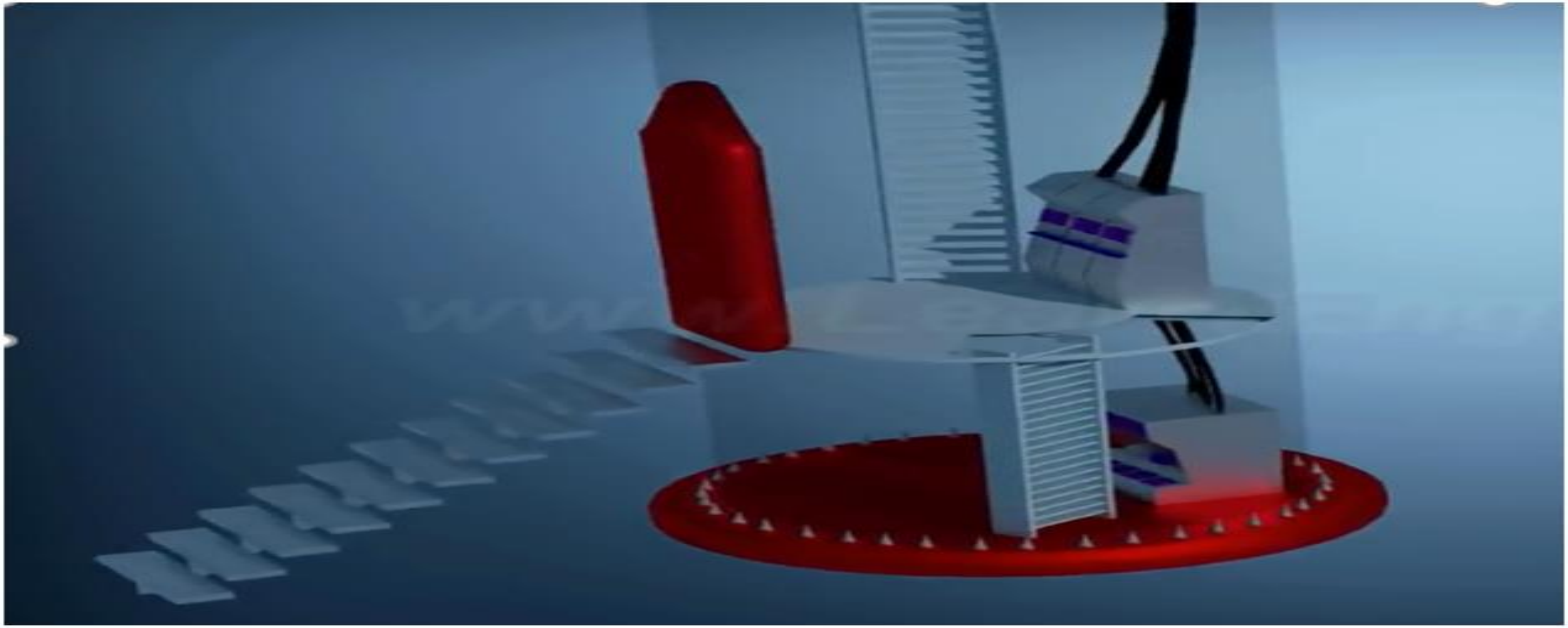
In some cases transformer is also included in nacelle, & cables connect transformer to wind farm substation.



In large multi-MW-turbines, power converters may be located at base of tower to reduce weight& size of nacelle.



Stairs to nacelle for maintenance are often attached along the inner wall of tower in large wind turbines.



Structural dynamics

- Special attention should be given to structural dynamics in order to avoid vibration caused by mechanical resonance modes of wind turbine.
- Top Head Mass (THM) of nacelle & turbine rotor has a significant bearing on dynamics of tower & foundation.
- In practice, low THM is generally a measure of design for reduction of manufacturing & installation costs.

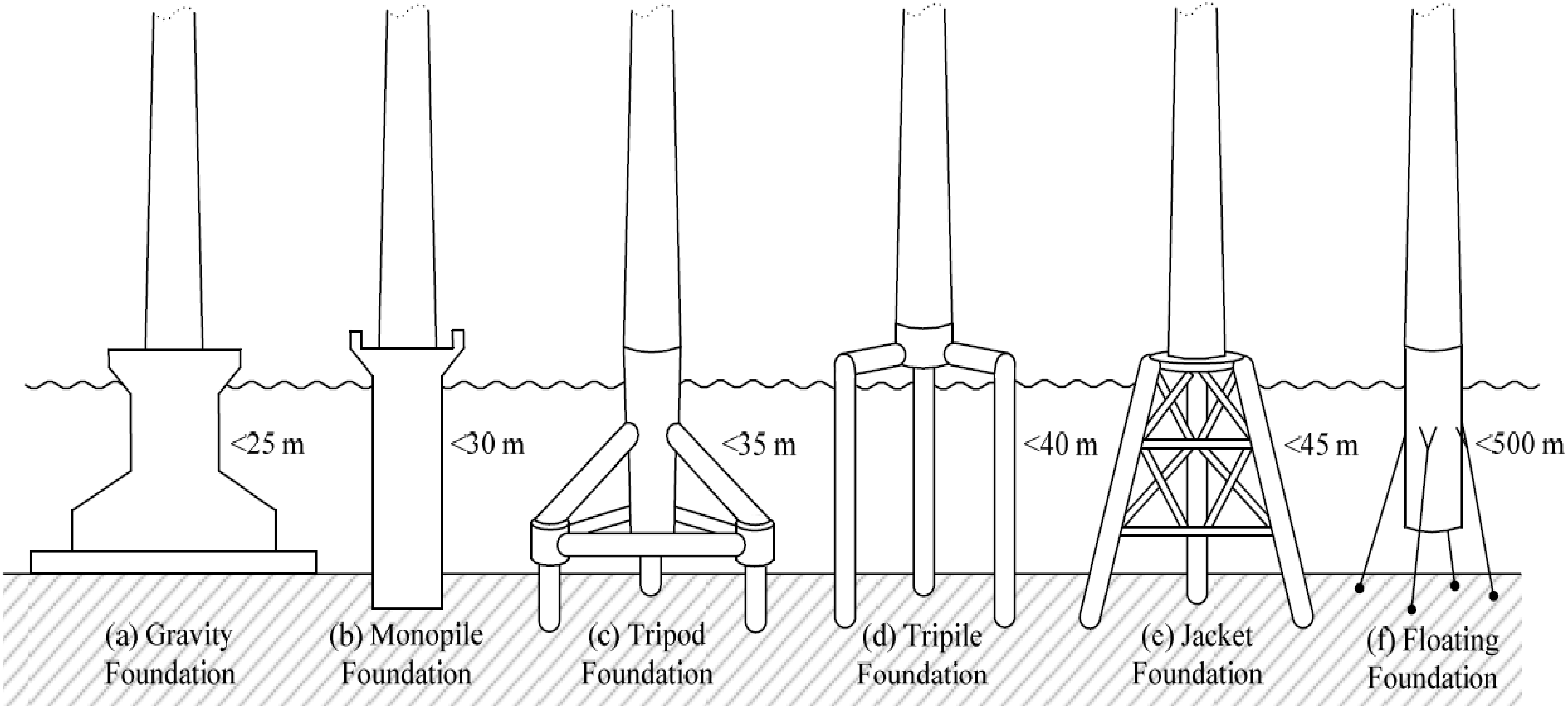
Wind-turbine foundation is also a major component in a wind energy system.

- Types of foundation commonly used for on land wind turbines include slab, multi-pile and mono-pile types.

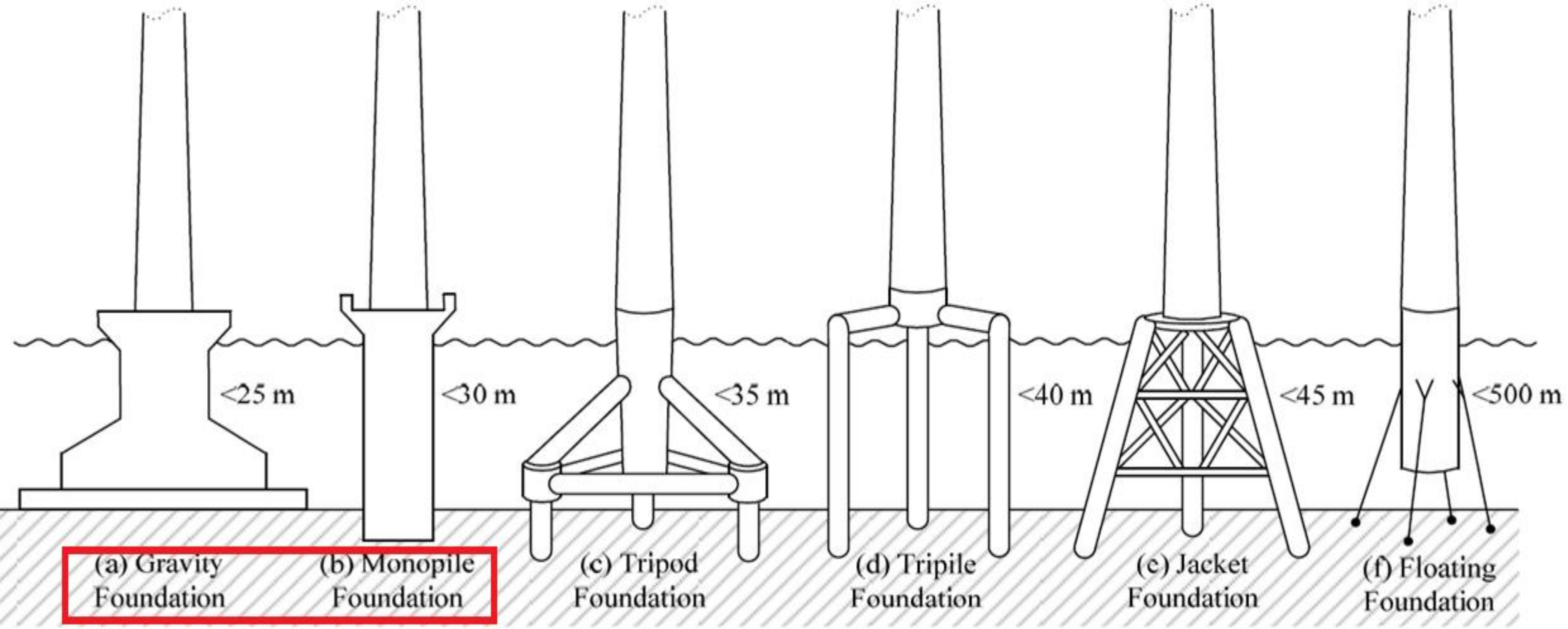
Foundations for offshore wind turbines are challenging

- Since they are located at variable water depths & different soil types.
- They have to withstand harsh conditions as well.
- This explains wide variety of foundations developed over the years for offshore turbines, some more proven than others.

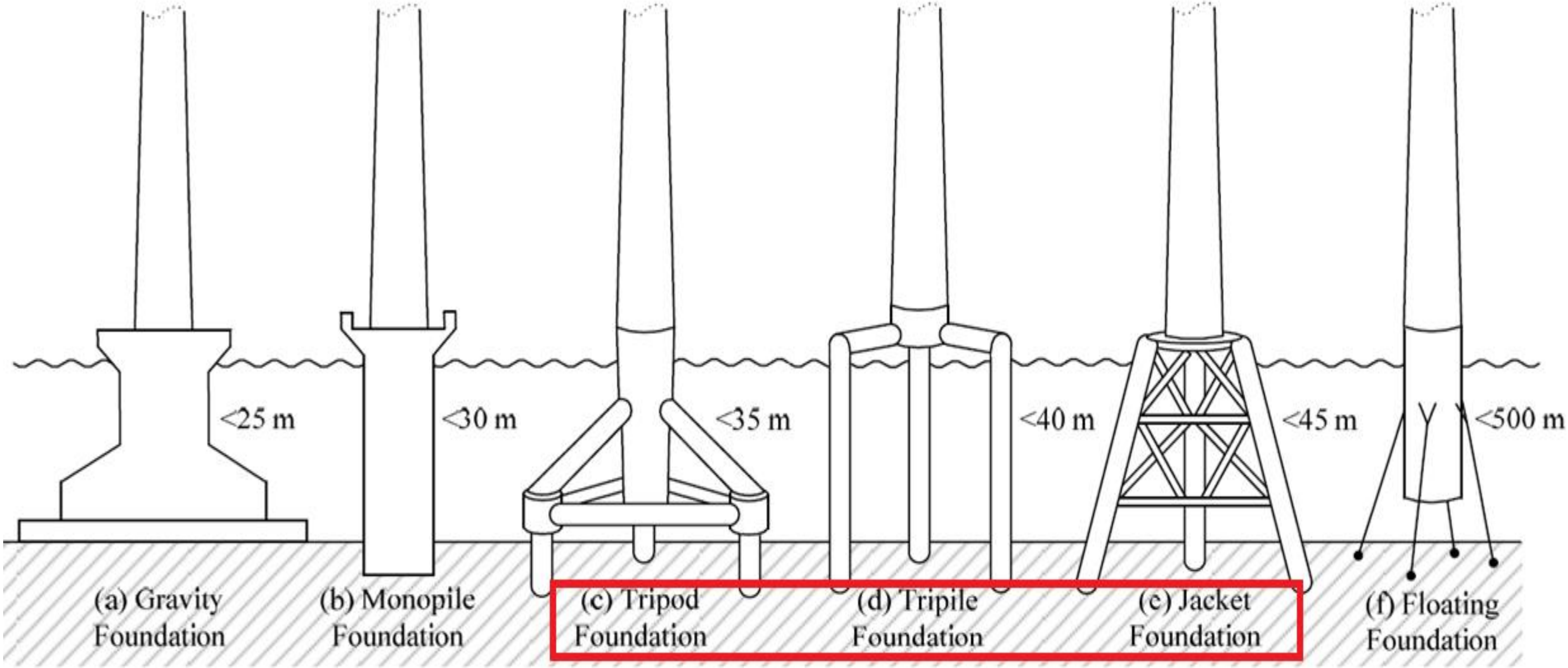
Foundations for offshore wind turbines.



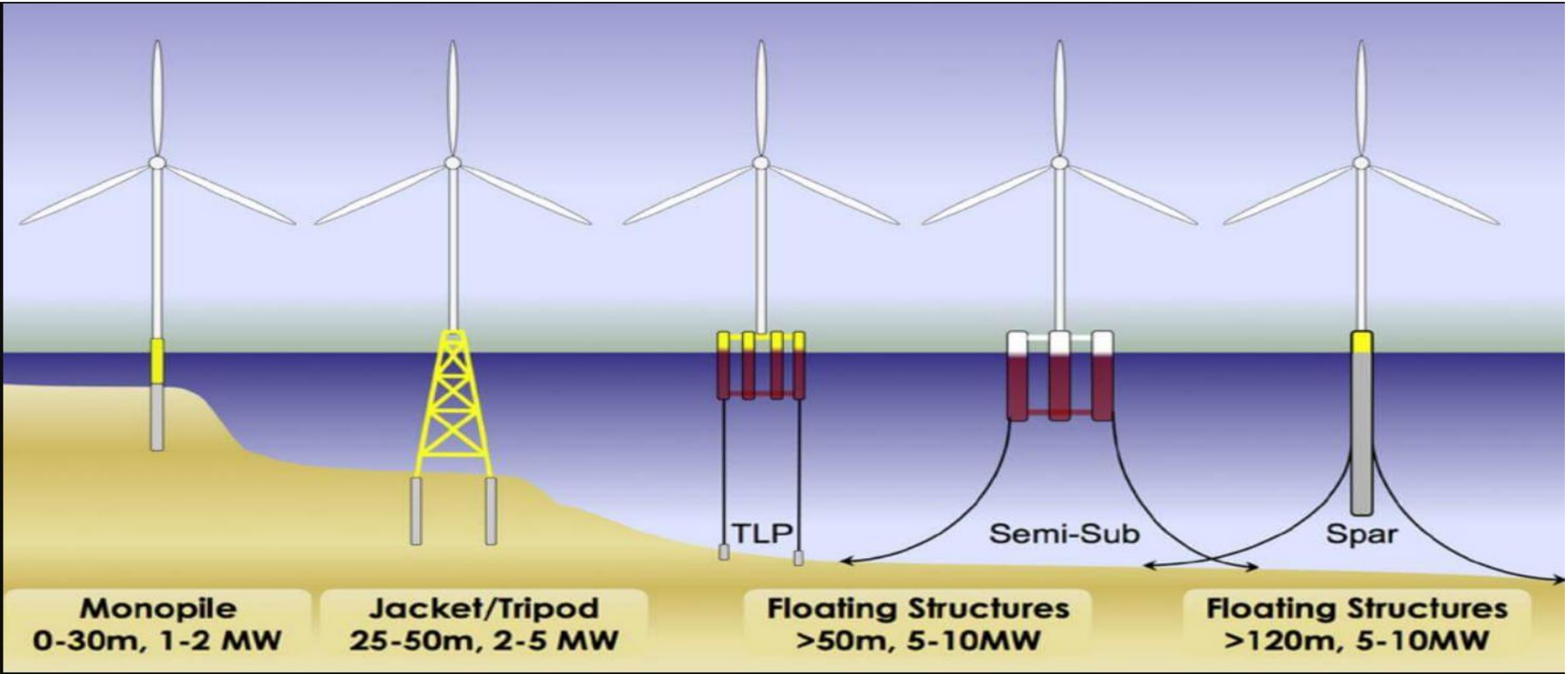
Gravity foundation & mono-pile foundation are more common in shallow waters.



Tripod, tri-pile & jacket foundation can reach greater depths, usually located farther away from coast line.

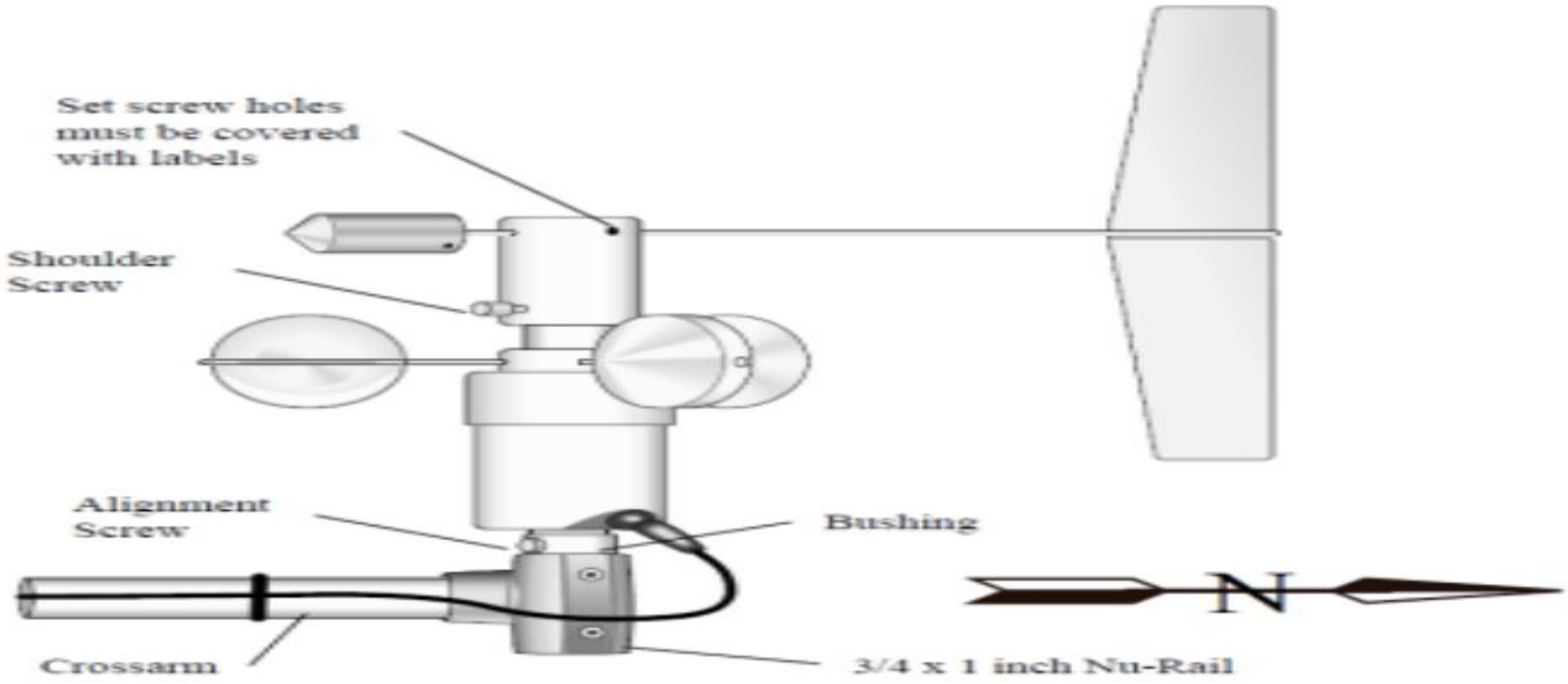


New technologies such as floating (anchored) foundation are currently under development for more challenging water depths.

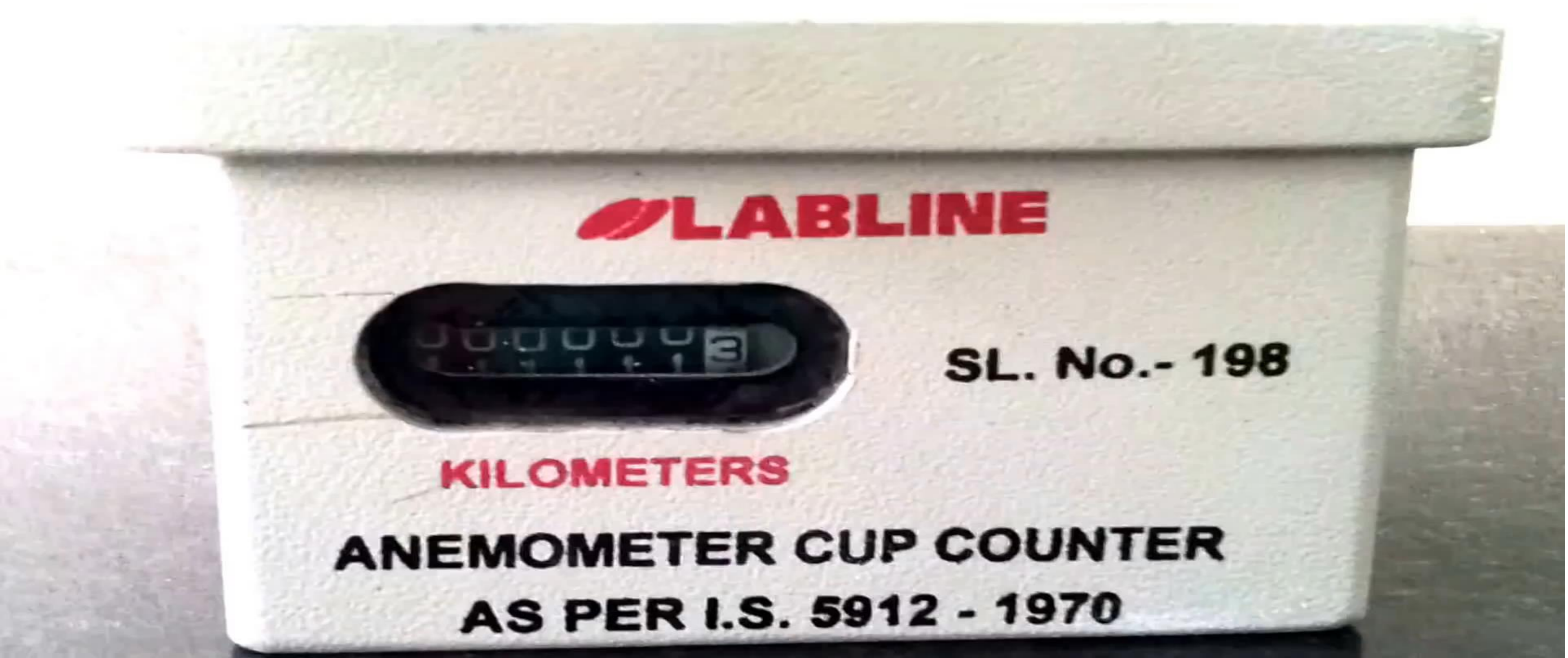


What are Anemometers?

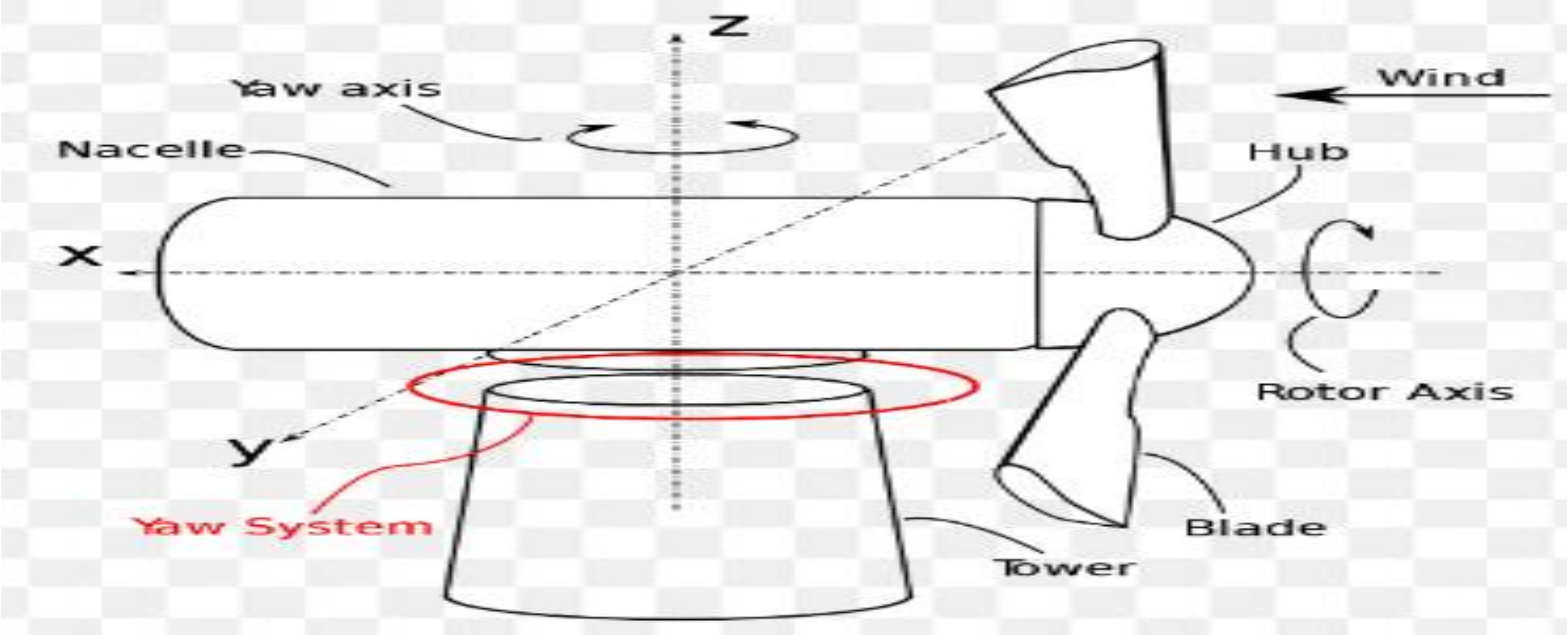
2.2.8 Wind Sensors (Anemometers)



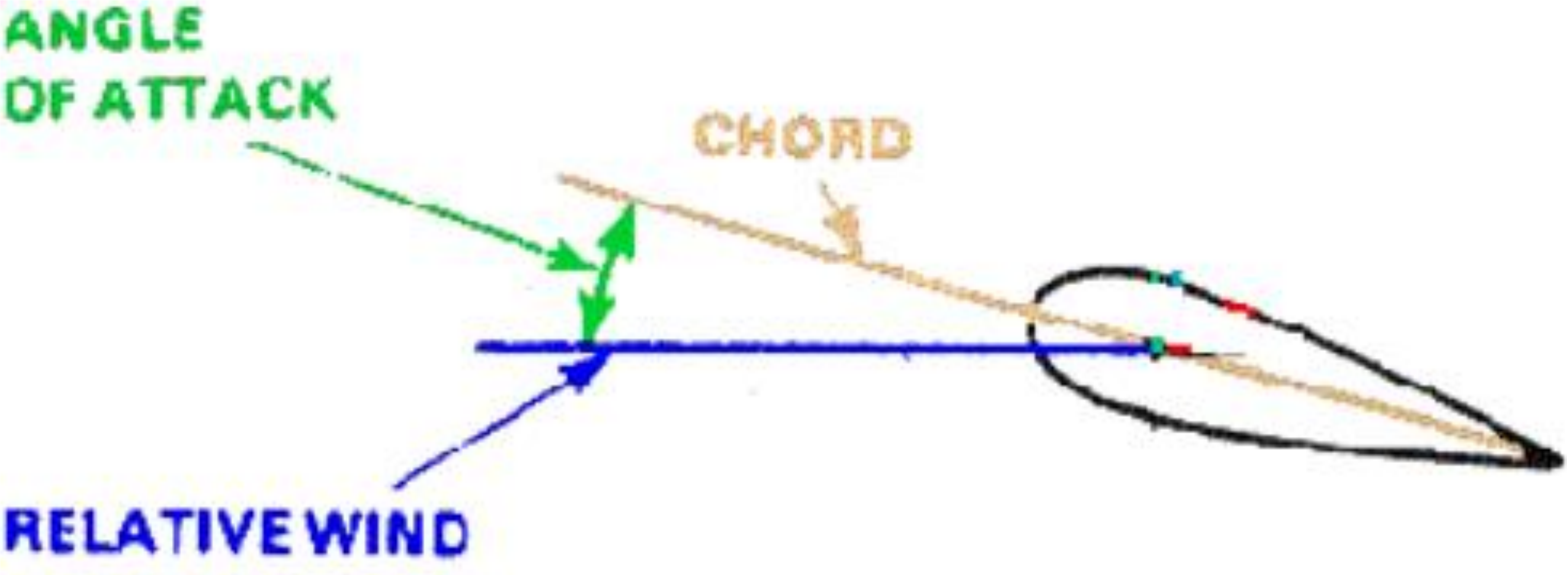
HOW ANEMOMETER WORKS..?



Pitch/stall & yaw control systems require wind speed & direction measurements, respectively.



Pitch/stall control needs wind speed to determine angle of attack of blade for optimal operation.

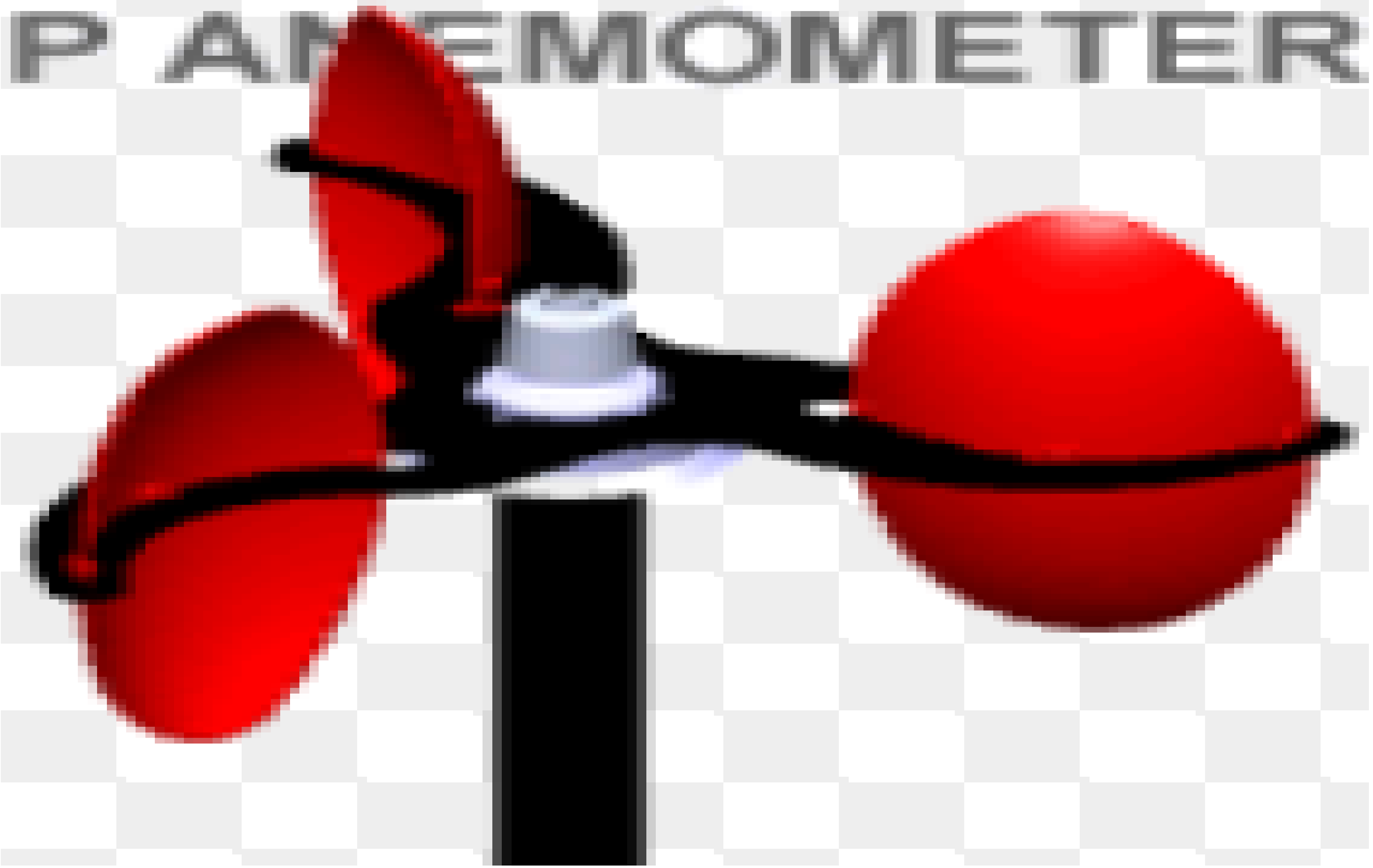


Yaw control

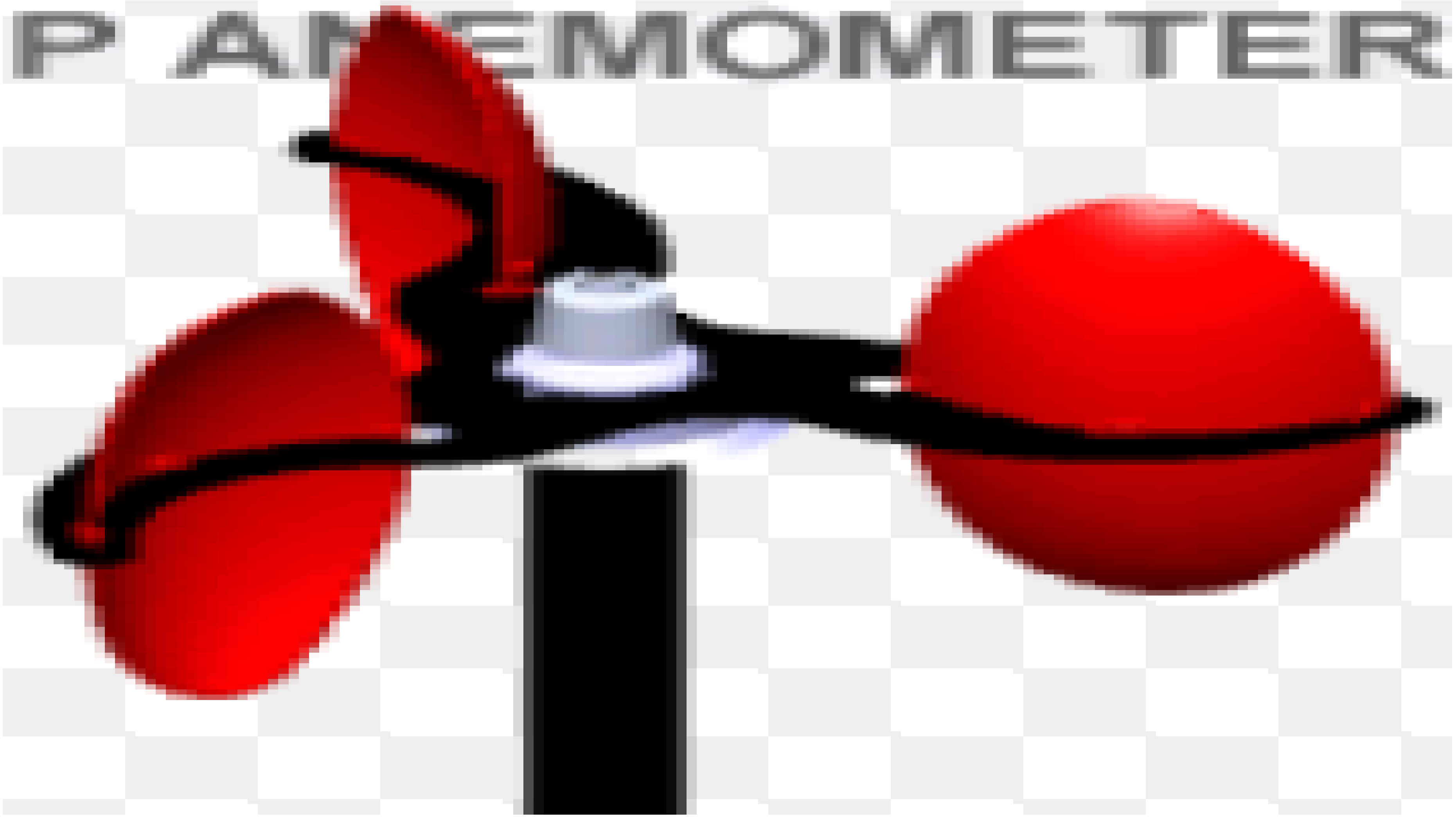
- Yaw control requires wind direction to face turbine into the wind for maximum wind power capture.
- In variable speed turbines, wind speed is needed to determine the generator speed for maximum power extraction.

Most large wind turbines are equipped with sensors, also referred to as anemometers, for wind data collecting and processing.

Wind speed sensor is usually made of 3-cup vertical-axis micro turbine driving an optoelectronic rotational speed transducer.



Wind direction is measured by a wind vane connected to an optoelectronic angle transducer.



Main components of a wind measurement system are located on top back part of nacelle.

More than one sensor system may be used in a wind turbine for more reliable and accurate measurements.

Ultrasonic anemometer

Ultrasonic anemometers are used in practical wind turbines.

- They measure wind speed by emitting & receiving acoustic signals through air & monitoring transmission time.

Several emitters and receptors are disposed in such a way that a 3-dimensional measurement can be made.

- Transmission time is affected by both wind speed & direction.

Wind speed & direction can be computed from propagation times.

- Ultrasonic anemometers are more accurate & reliable than mechanical ones with moving parts.
- However, they are more expensive.

Ultrasonic anemometer on top of nacelle of a modern wind turbine.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