جامعة الطفيلة التقنية
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EE 0113416
Wind Energy Systems

Chapter 2: Types

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Historical Development of Wind Energy

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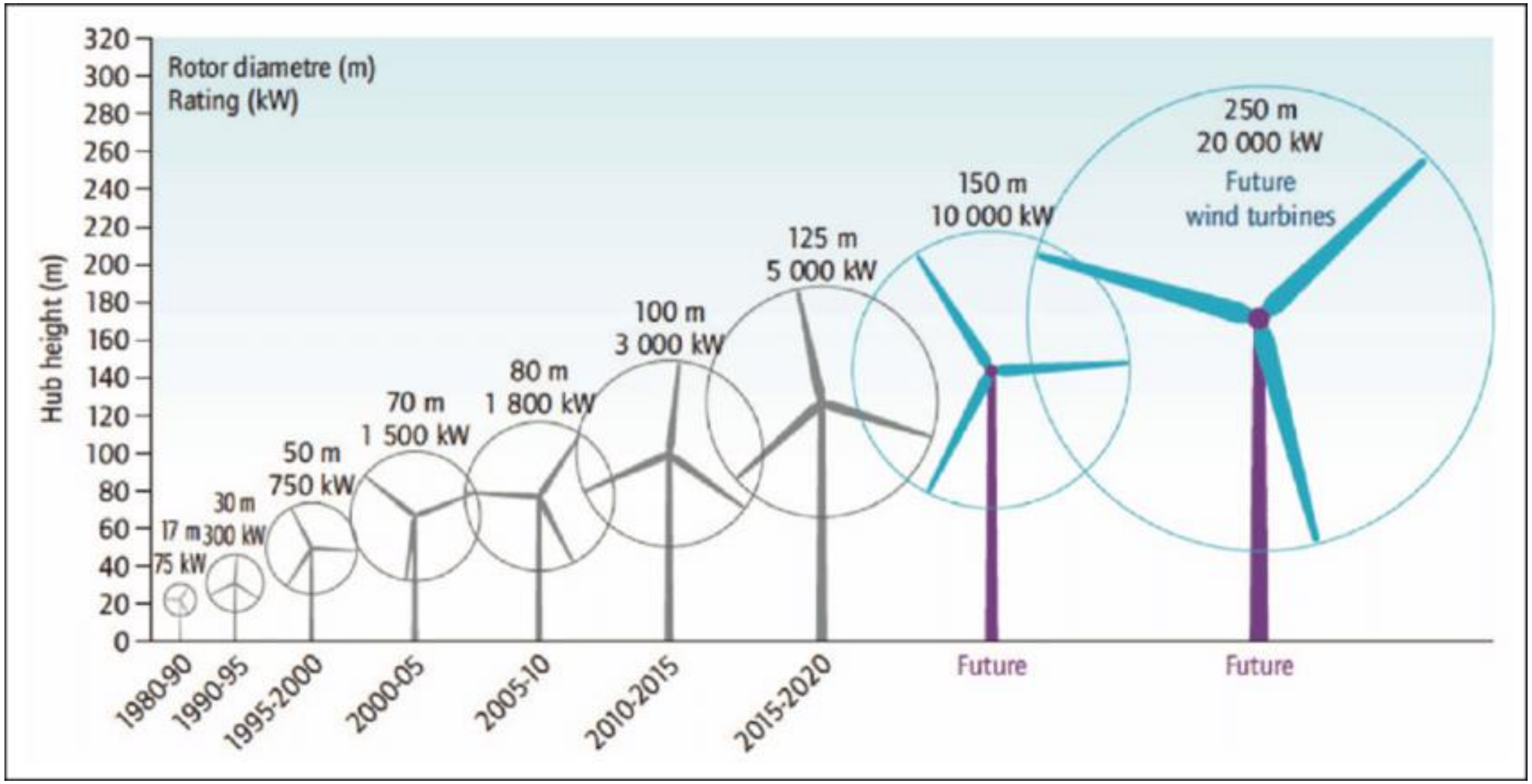
- Charles F. Brush is the first person to build wind turbine to produce electricity in Cleveland, Ohio in 1888
  - It was just 12 kW

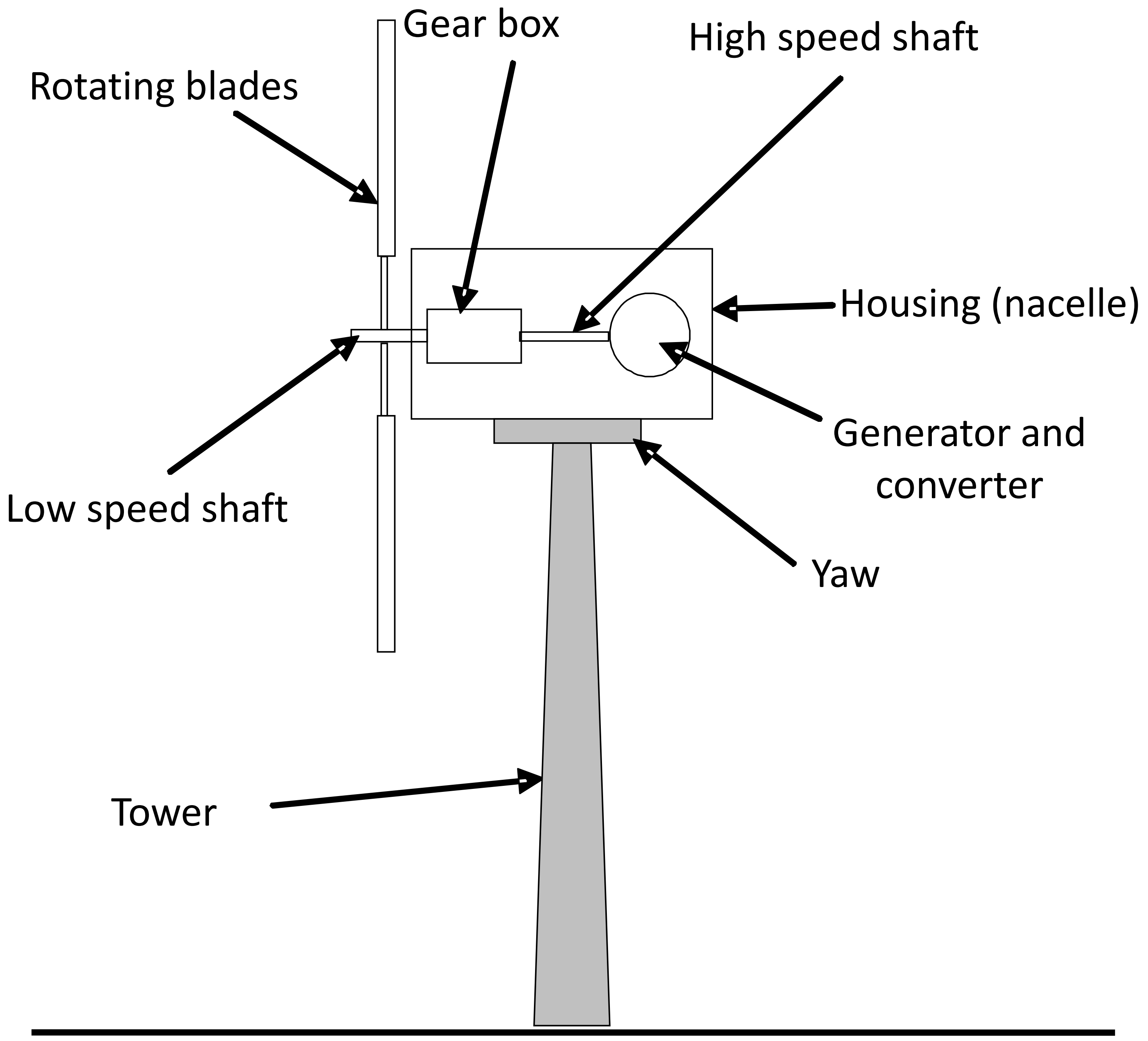
- Poul la Cour of Denmark built the first wind turbine outside of the US to generate electricity in 1891

Historical Development of Wind Energy

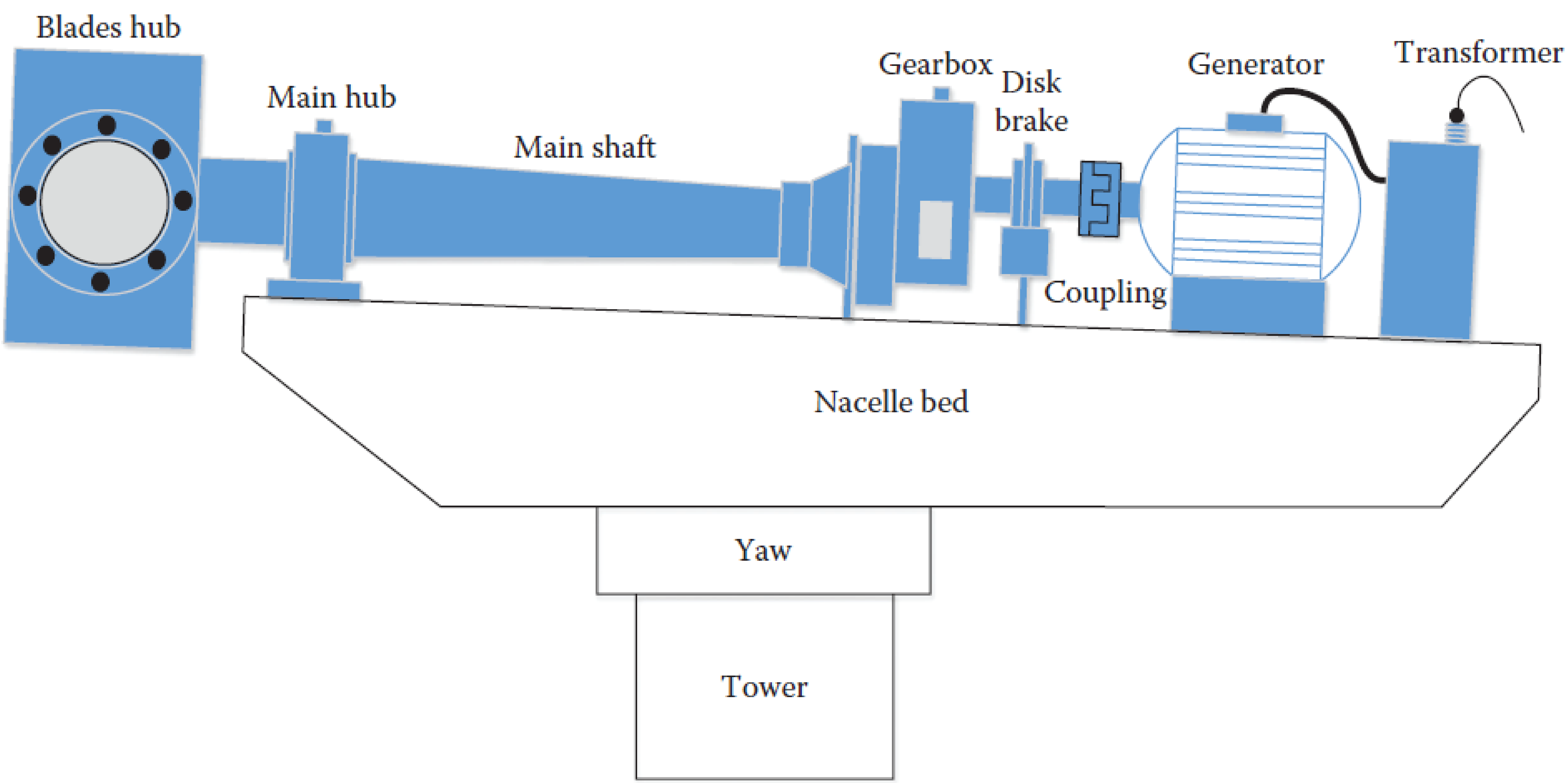
- 1930-1940: Thousands of wind turbines were used in rural areas not yet served by the power grid
- Interest in wind power declined as the utility grid expanded
- Oil crisis in 1970s created a renewed interest in wind until US government stopped giving tax credits
- In 1990s, interest is renewed



Key Parts of Horizontal Axis Wind Turbine (HAWT)



Structure

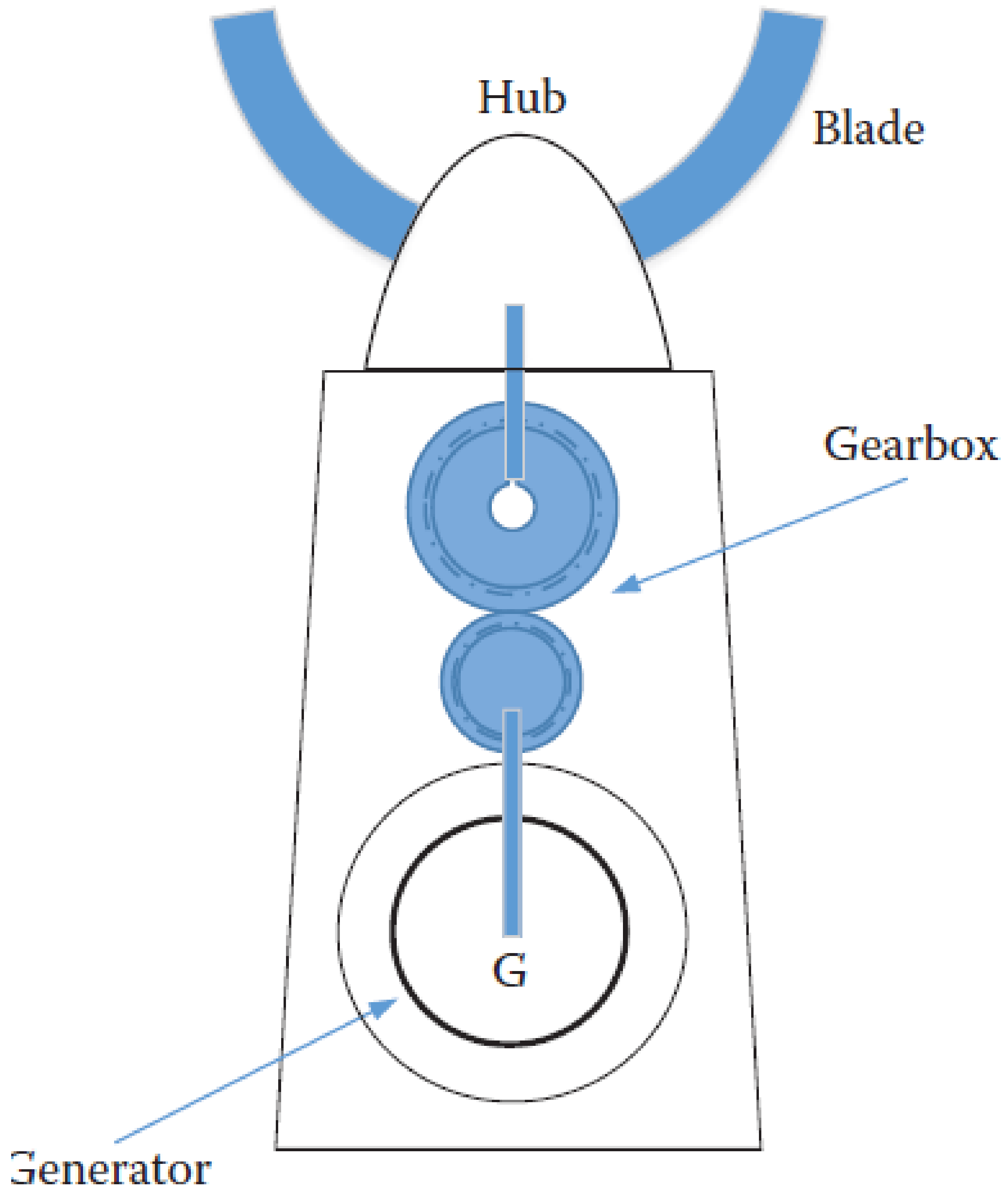

Blades hub
Main hub
Main shaft
Gearbox
Disk brake
Generator
Transformer
Coupling
Nacelle bed
Yaw
Tower

Advantages of the HAWT

- The tall tower allows the turbine to access strong wind
- It is a high efficiency turbine as its blades continuously receive power from wind during the entire rotation.
- The speed of the blade is fairly constant during a single rotation. Thus rapid fluctuations in electrical variables such as voltage and reactive power is insignificant.

Disadvantages of HAWT

- It requires massive tower construction to support the heavy nacelle
- The heavy generator, gearbox and transformer inside the nacelle have to be lifted during construction and maintenance
- It requires an additional yaw control system to turn the blades toward wind
- They are more obtrusive and can cause local opposition



Vertical Axis Wind Turbines (VAWT)

Advantages of VAWT

- There is no need for a yaw mechanism to direct the blade into wind. This is an advantage for sites with variable wind directions.
- The generator, gearbox and transformers are all located at the ground level, making it easier to install and maintain than the HAWT
- The cut-in speed of the VAWT is generally lower than that for the HAWT

Disadvantages of VAWT

- The wind speed is slower near ground; hence the available wind power is lower.
- Air flow near the ground and other objects can create turbulent flow. This can introduce vibration that eventually shorten the service life of the turbine
- Because of its massive inertia, they may require external power source to startup the turbine
- The bearing at the base carry the heavy load of the blades. Their failure rate is high.

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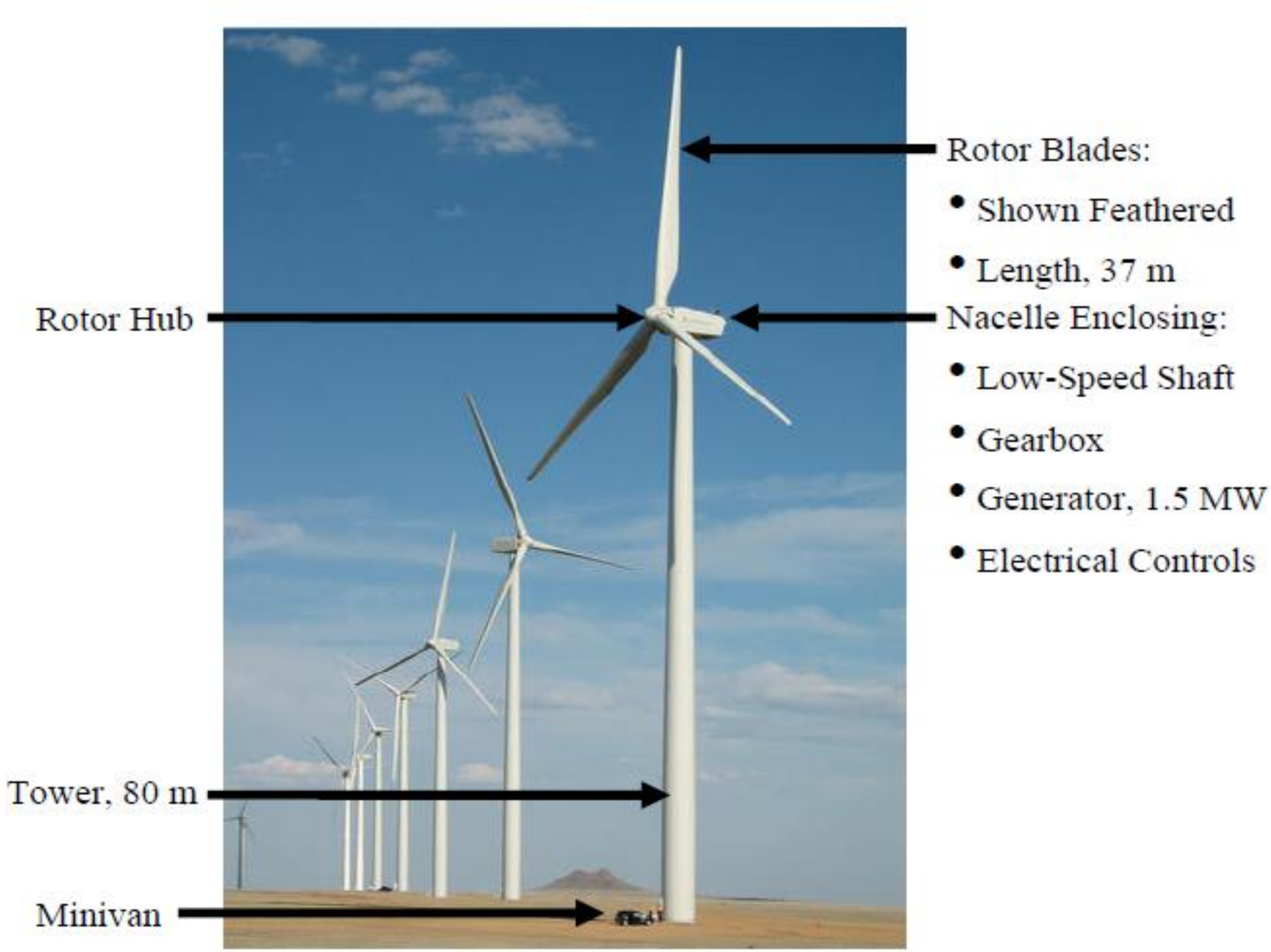
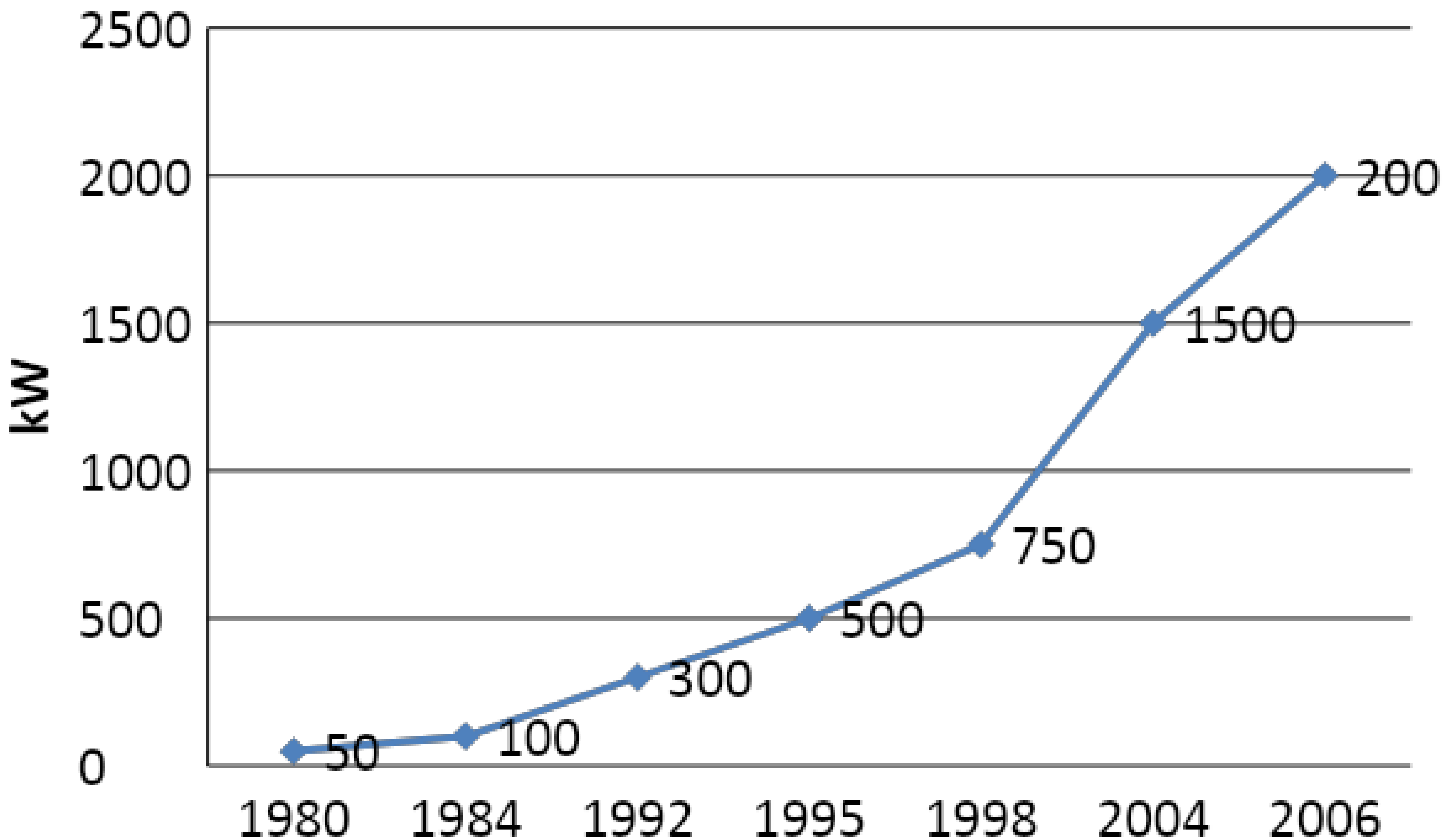
Wind Turbine Gearboxes

- A significant amount of the weight in the nacelle is due to the gearbox
  - Gearboxes common source of turbine failures
  - They require periodic maintenance (e.g., change the oil)
- A newer type of wind turbines do not use gearboxes
  - Directly coupled to the grid through a converter
  - The electrical generator has a large number of poles

1.5 MW Turbine



Rapid Growth of Wind Turbine Size



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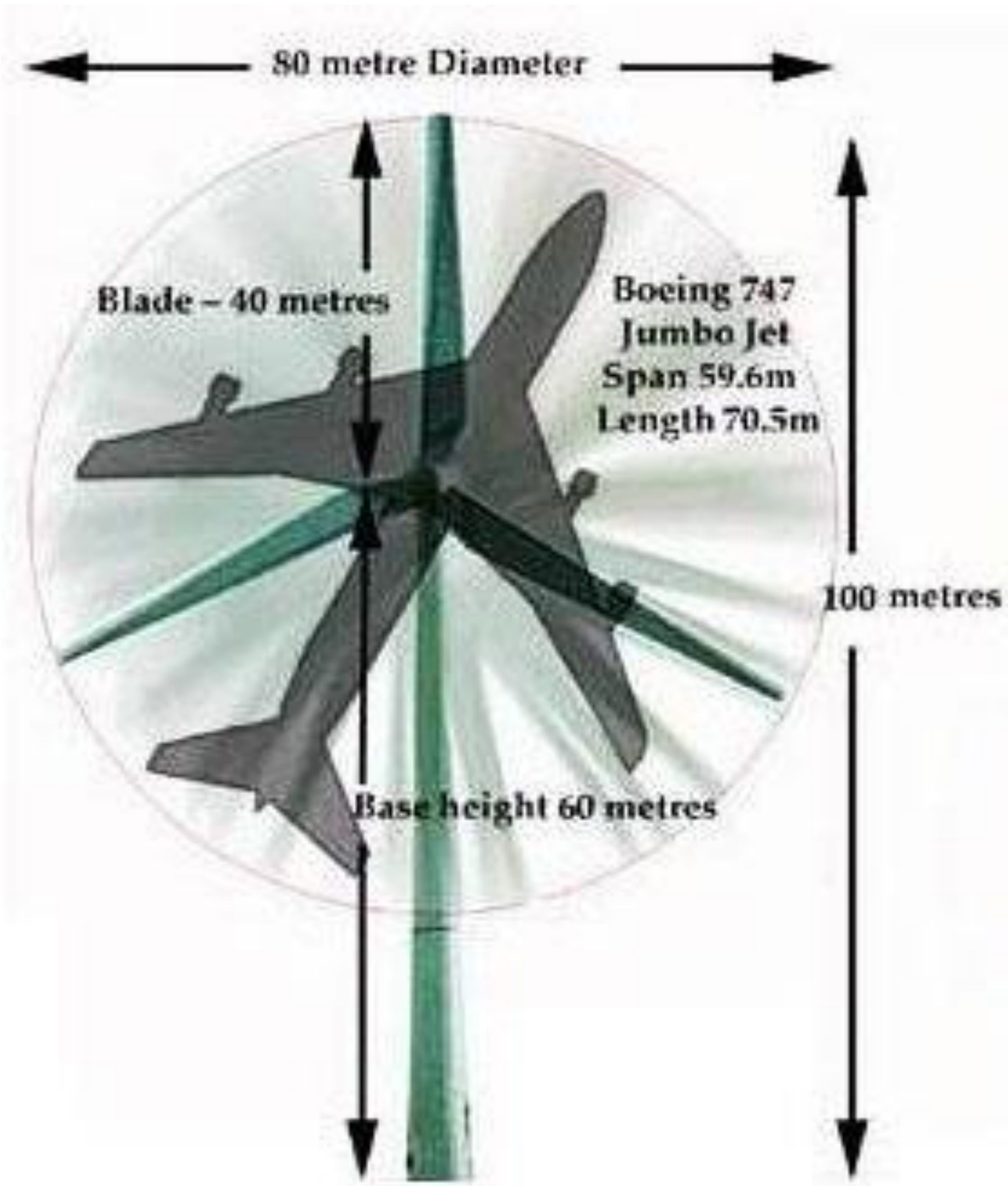
Basic Wind Turbine Specifications (2MW)



Rotor Diameter = 80 meters

Swept Area = 5,026 m^2

Blade Rotation = 15.5-16.5 rpm

Generator Voltage = 690 Volts

Capacity = 1,800-2,000 kW

Nacelle (housing) Weight = 77 tons

Rotor Weight = 41 tons

Tower Weight = 105 tons

Total Weight = 223 tons

GE 3.6MW

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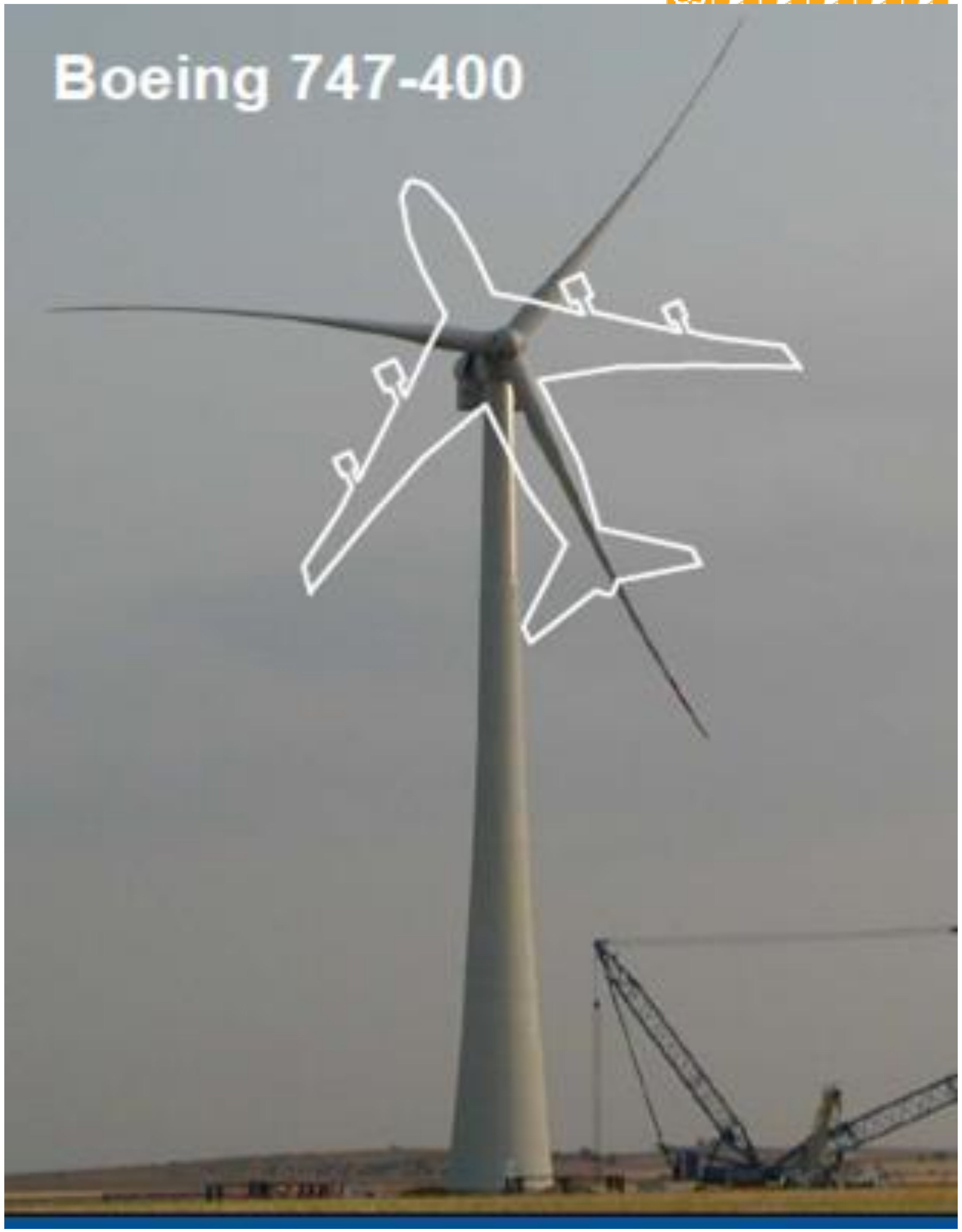
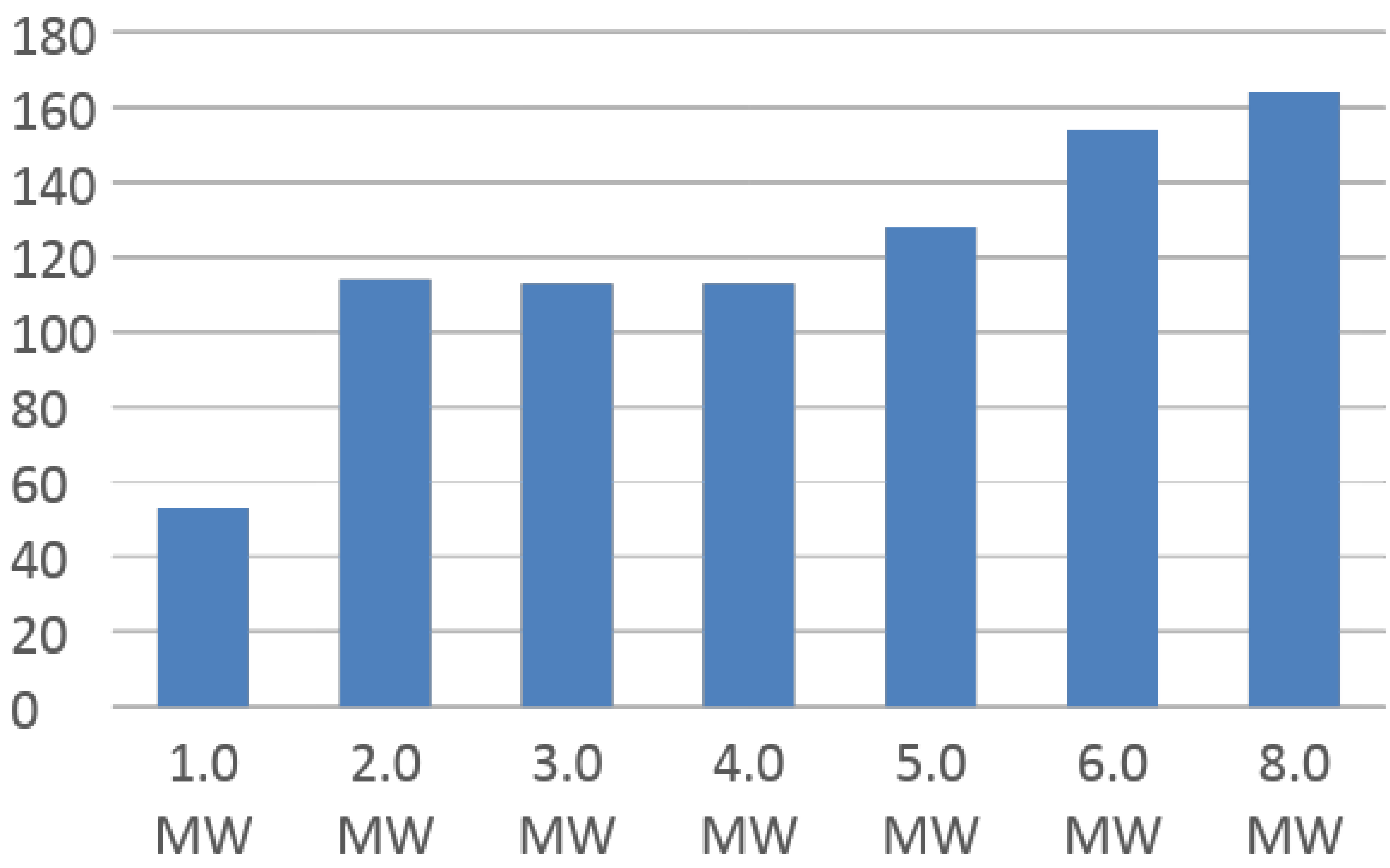


Maximum rotor diameter (m)



Average height of wind turbines

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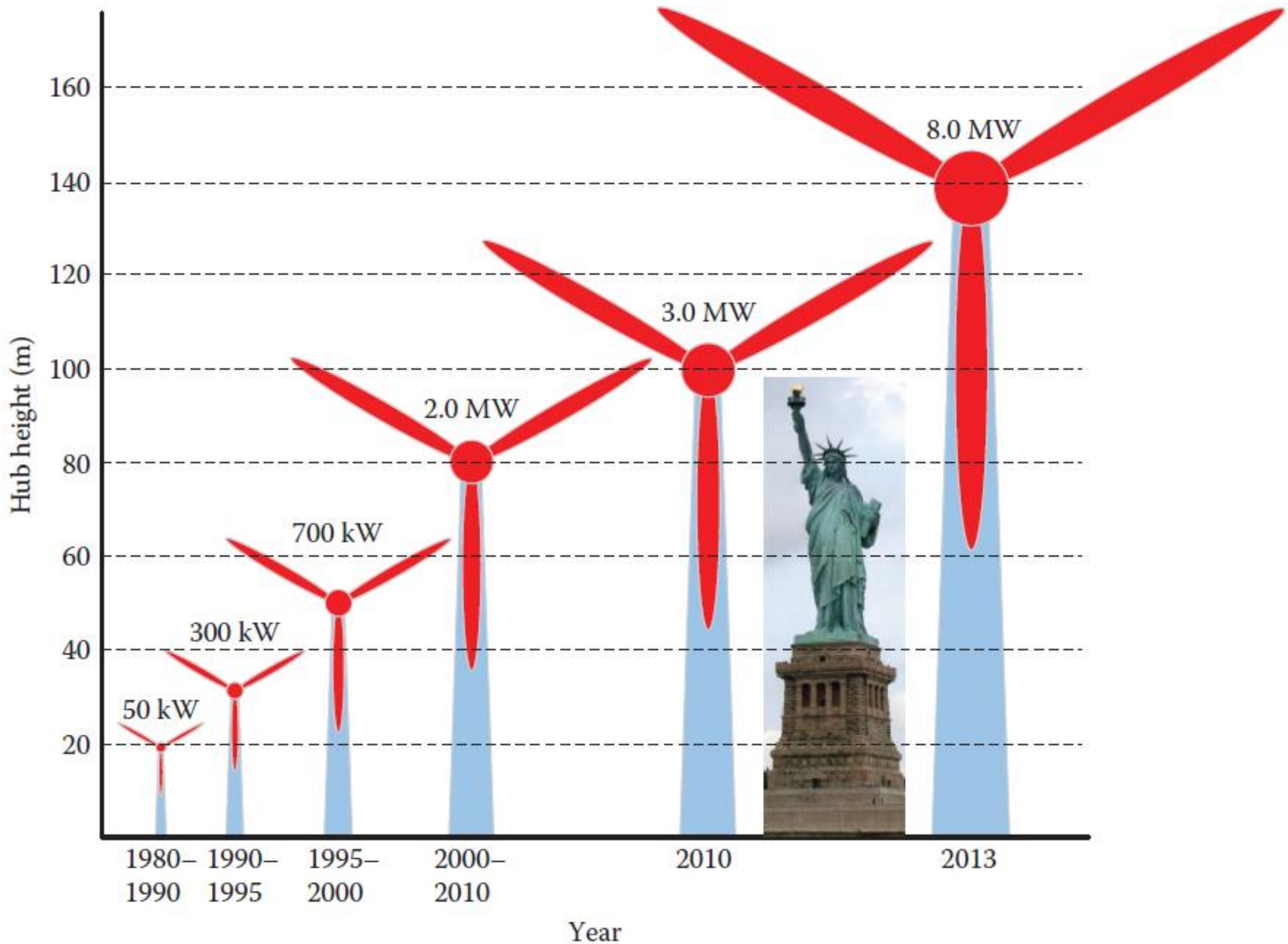


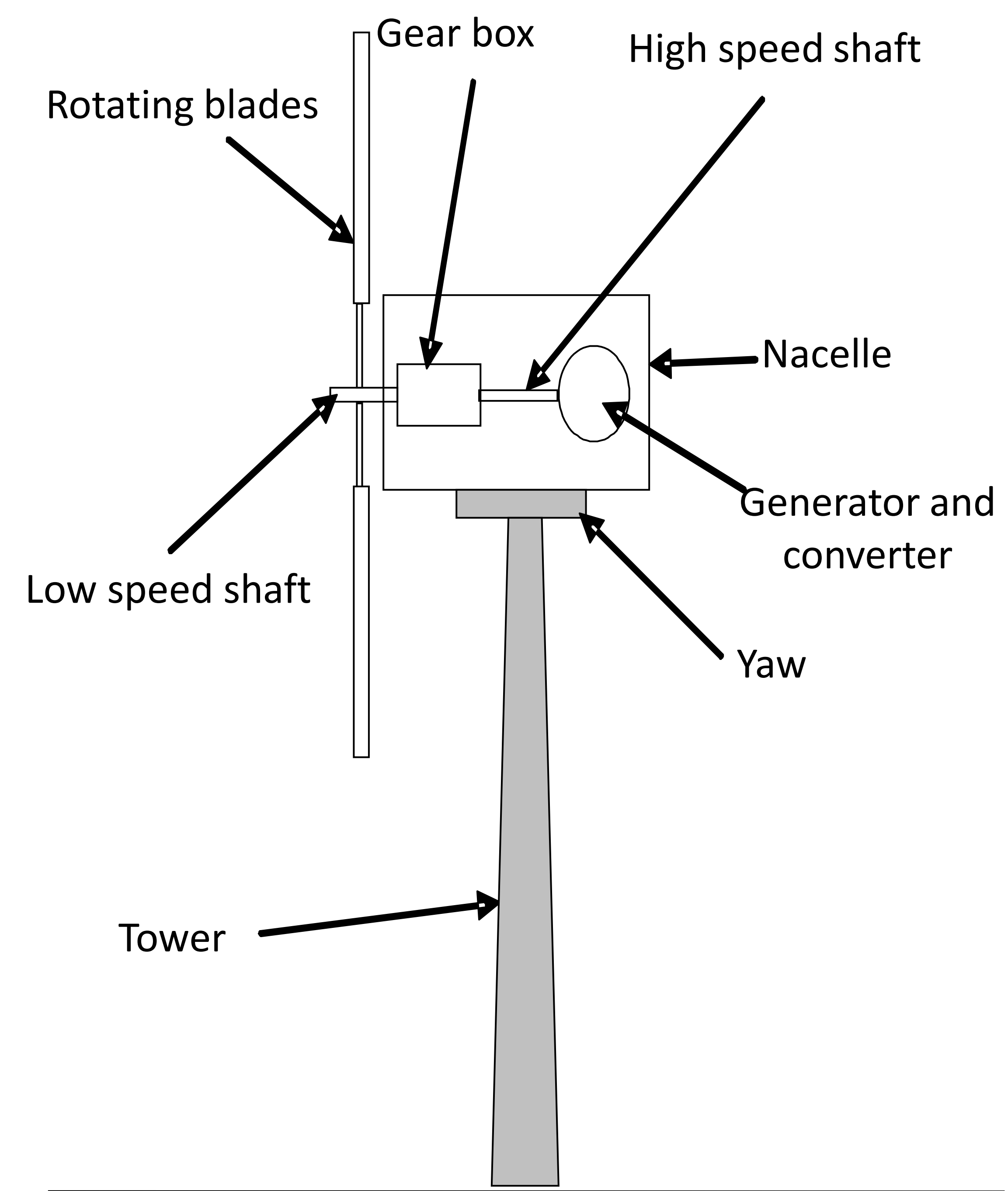
VESTAS 1.8MW

Controllable Mechanical Variables

- Operating wind speed of modern turbines

  4 m/s > W < 30 m/s

  ~9 mph > W < ~67 mph
- **Pitch Control**
  - To maximize C_p
  - Reduce C_p when wind speed produces power higher than the rating of the turbine
  - Regulate the output power of the turbine as part of grid control action
- **Yaw Control**
  - To align the rotor to face wind
- **Feathering**
  - To lock the blades at high wind speeds (>50mph)



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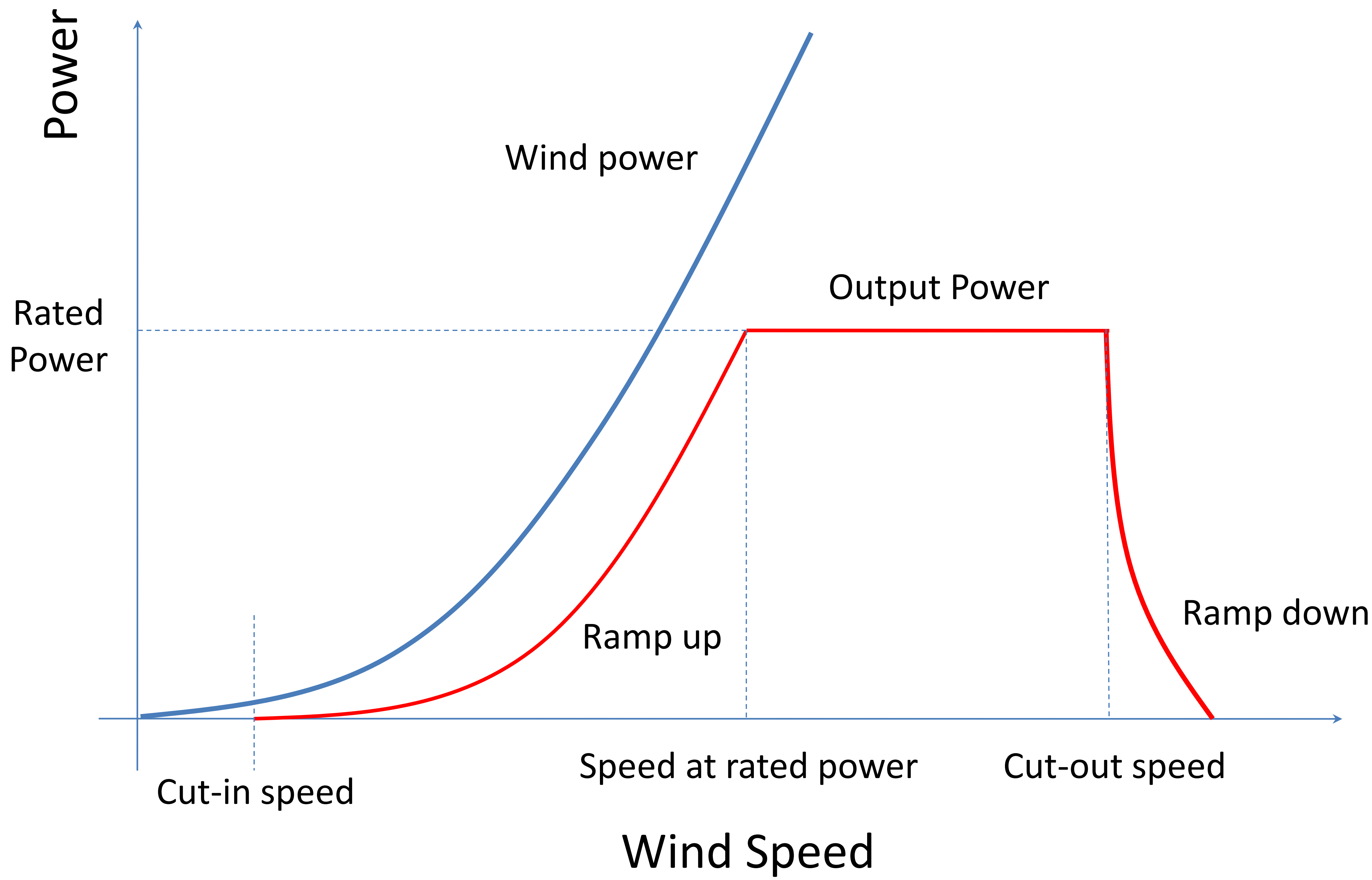
Typical Power-Speed Characteristics



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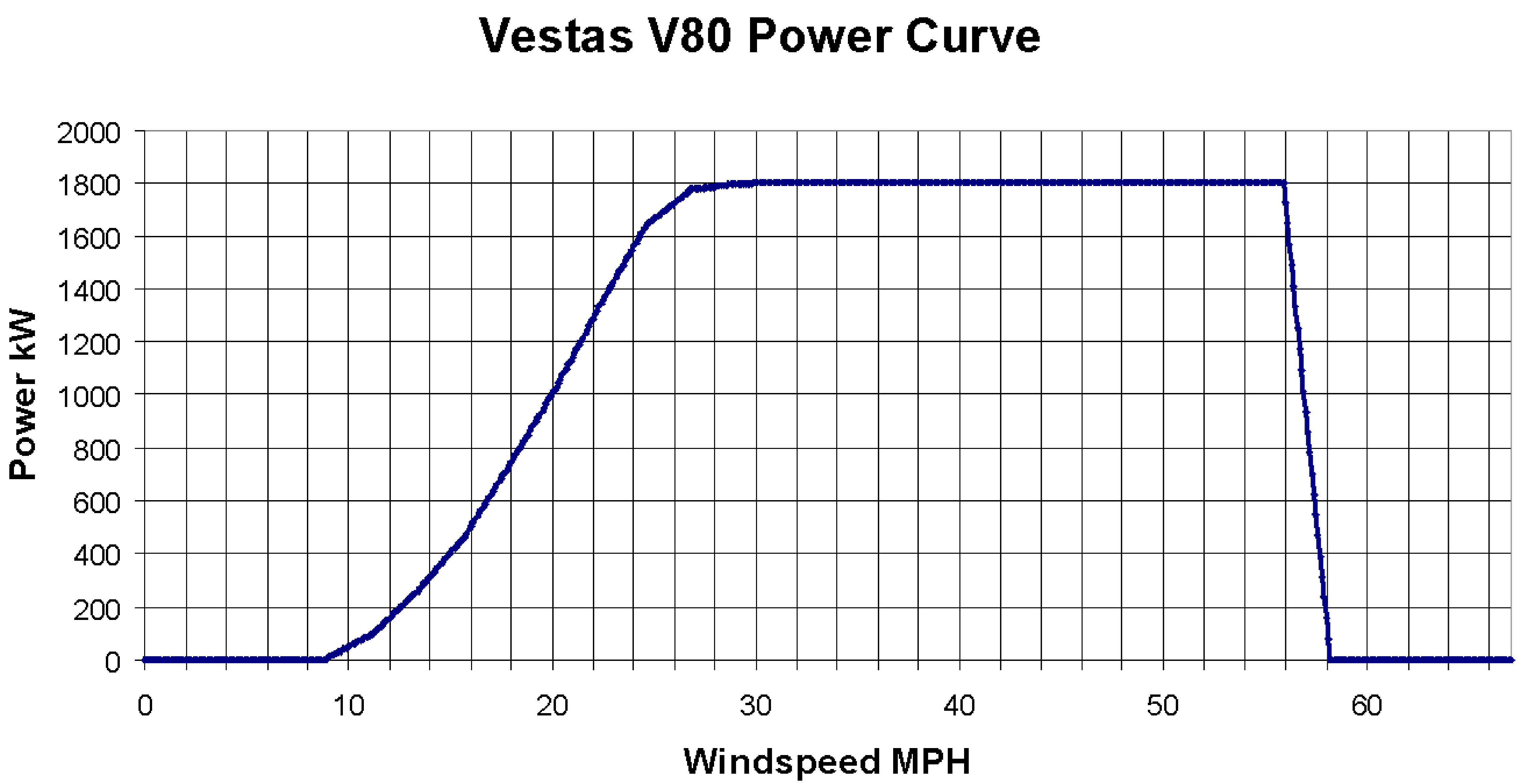
Wind Turbine Performance



Types of Wind Turbine Generators (WTG)

- Asynchronous Generator (Induction Machine)
  - Squirrel Cage Induction Generator (SCIG)
  - Wound Rotor Induction generator (WRIG)
- Synchronous Generator (SG)

Fixed and Variable Speed IG

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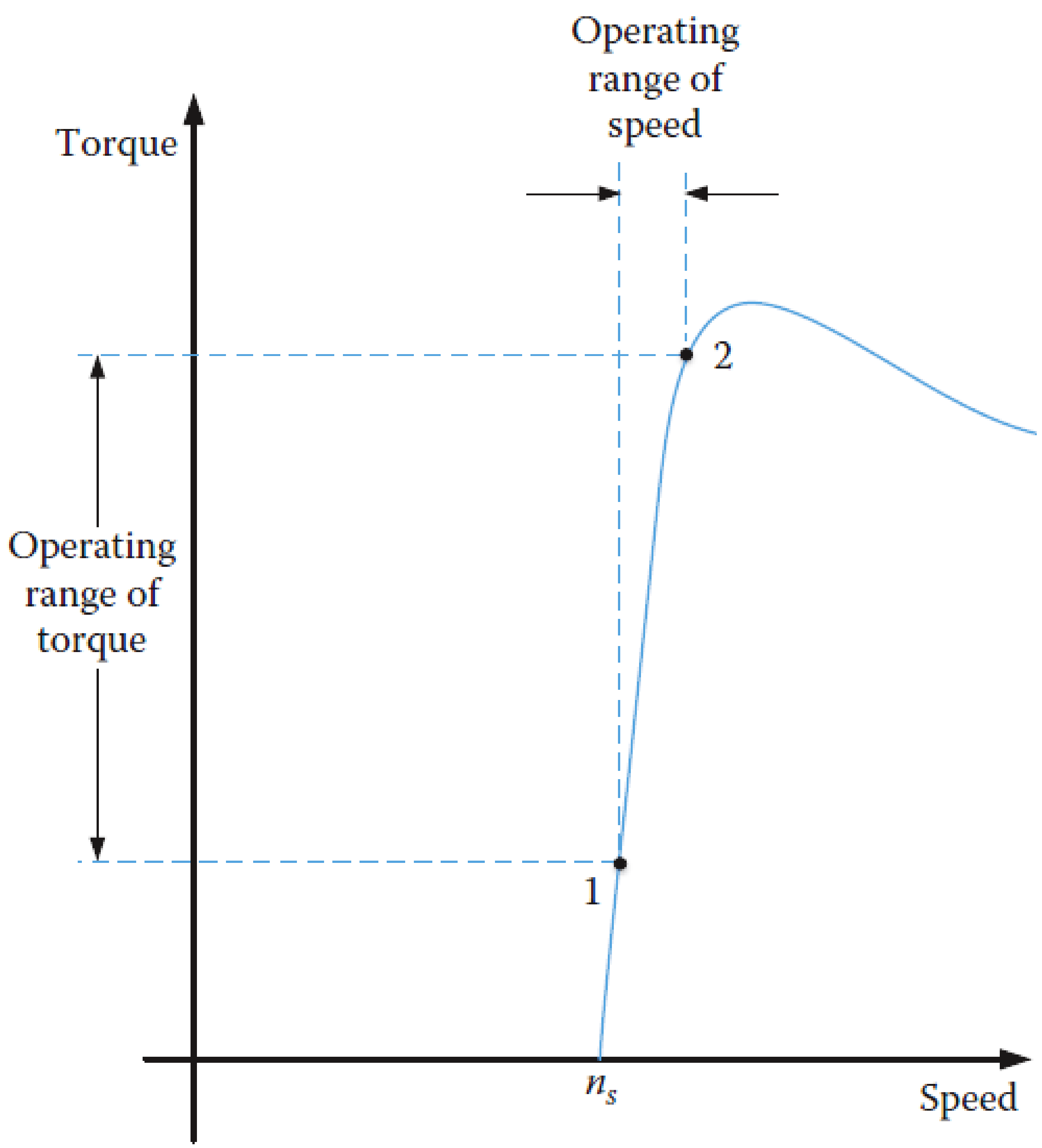
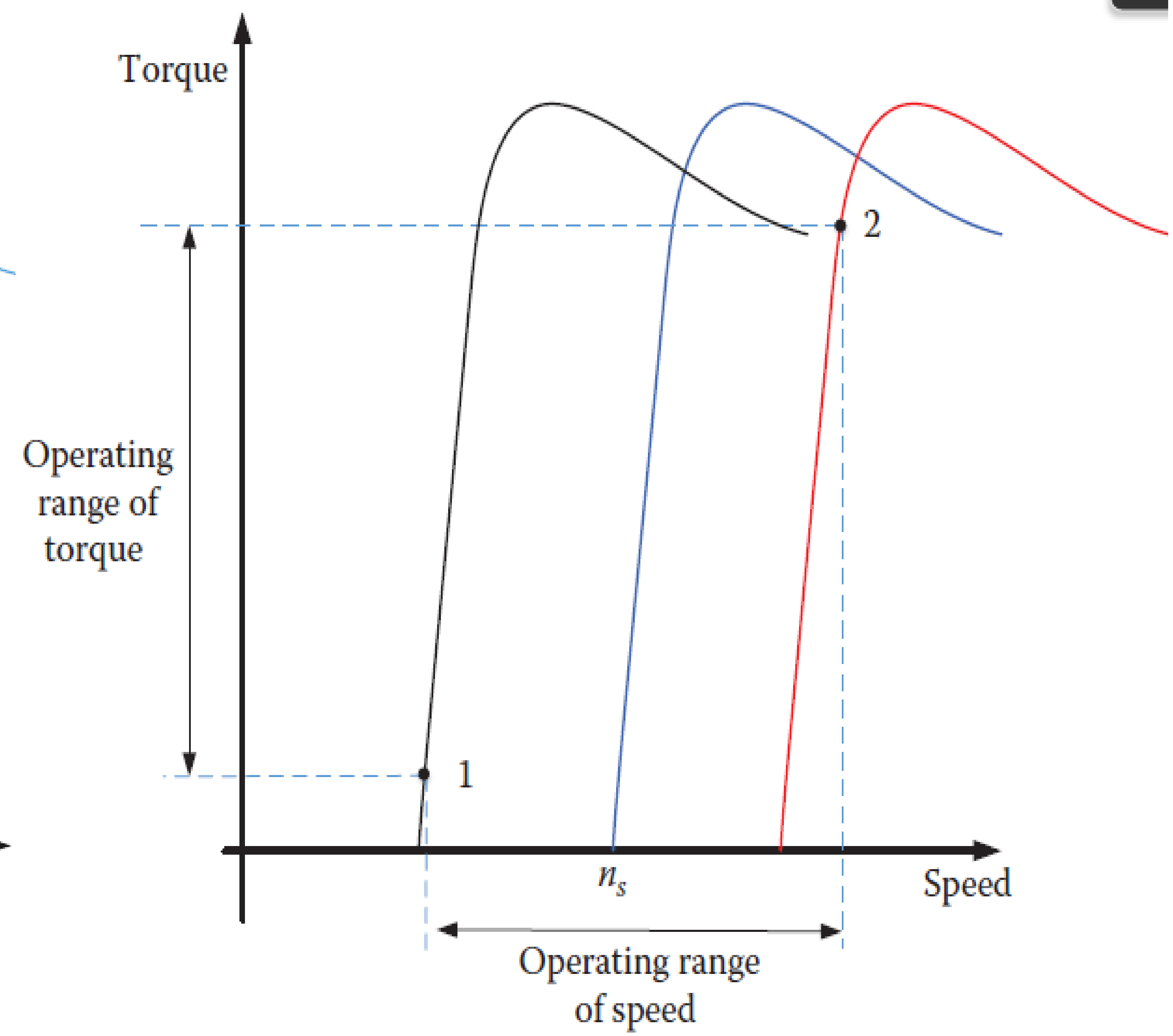
Fixed and Variable Speed WT

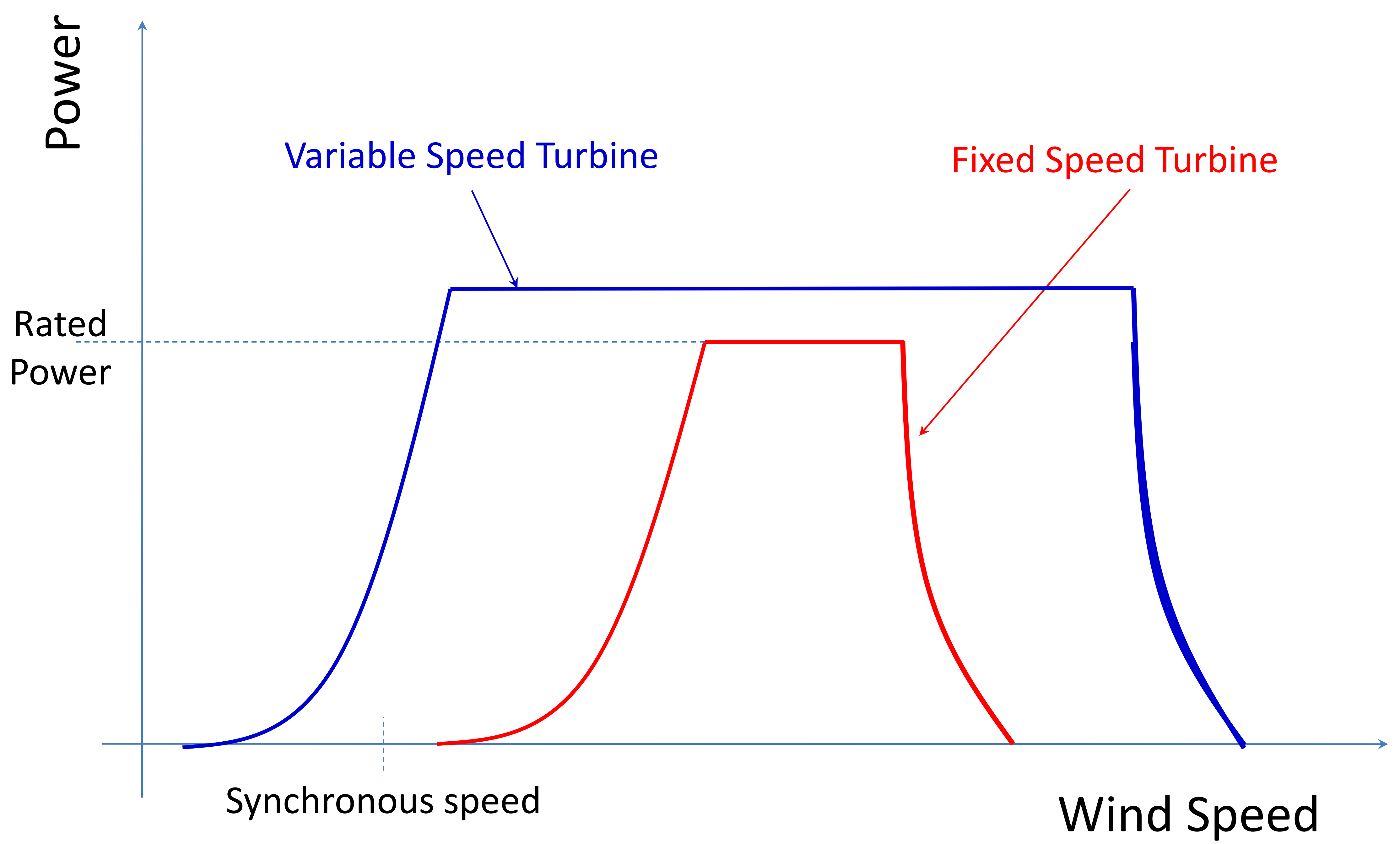


Fixed speed



Variable speed

Fixed vs Variable Speed Turbines



Fixed Speed Wind Turbine (FSWT) System

- Mainly squirrel cage induction generator
- The rotor speed variations are very small,
  - approximately 1-2% of the rated speed.
- Advantages of FSWT are
  - Does not require brushes
  - Rugged construction
  - Low cost
  - Low maintenance
  - Simple to operate

Fixed Speed Wind Turbine (FSWT) System

- Drawbacks of FSWT are
  - Because the rotor speed cannot vary, fluctuations in wind speed translate directly into drive train torque fluctuations. This causes more stress on the mechanical system
  - The speed of the FSWT is very high (above the synchronous speed)
    - Higher structural loads
    - More noise
    - More bird collisions

Variable Speed Wind Turbine (VSWT) System

- **Advantages**
  - The power can be regulated even when the speed of the turbine changes widely
  - The system can produce power at low speeds (lower than the synchronous speed)
  - The speed of the generator can be adjusted to achieve higher aerodynamic efficiency (maximize the coefficient of performance)
  - Lower mechanical stress due to the reduction of the drive train torque variations.
  - Noise problems are reduced because the turbine runs at low speed.
- **Drawback**
  - More expensive

Main Types of Wind Turbines

Main Types of WTG

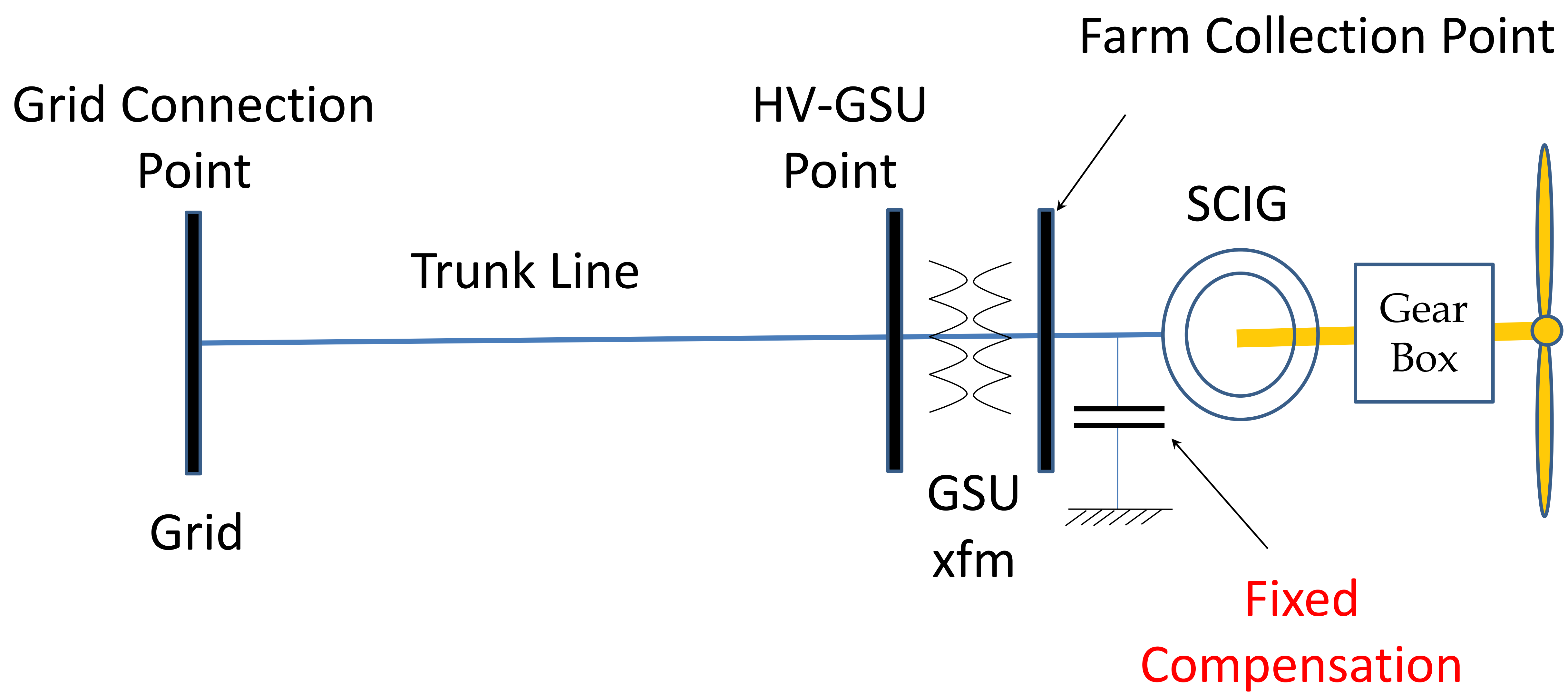
Fixed Speed Types

- ***Type 1:*** Squirrel cage induction generator directly coupled to the grid. May have pitch control

Variable Speed Types

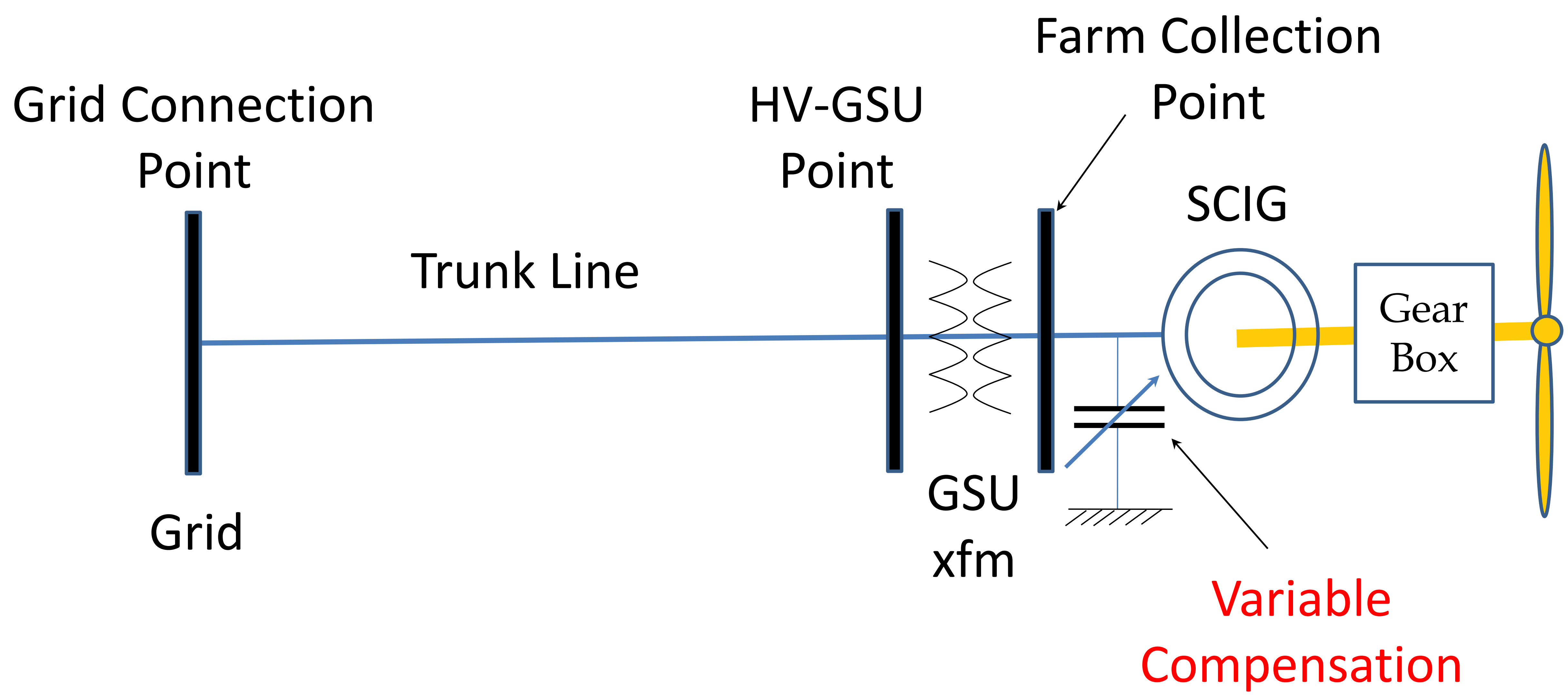
- ***Type 2:*** Wound rotor induction machine with external rotor resistance control
- ***Type 3:*** Wound rotor Doubly-fed induction generator (Voltage injected in the rotor winding)
- ***Type 4:*** Synchronous generator, the stator is connected to the grid via power converter (Full converter)

Type1: SCIG with Fixed Compensation



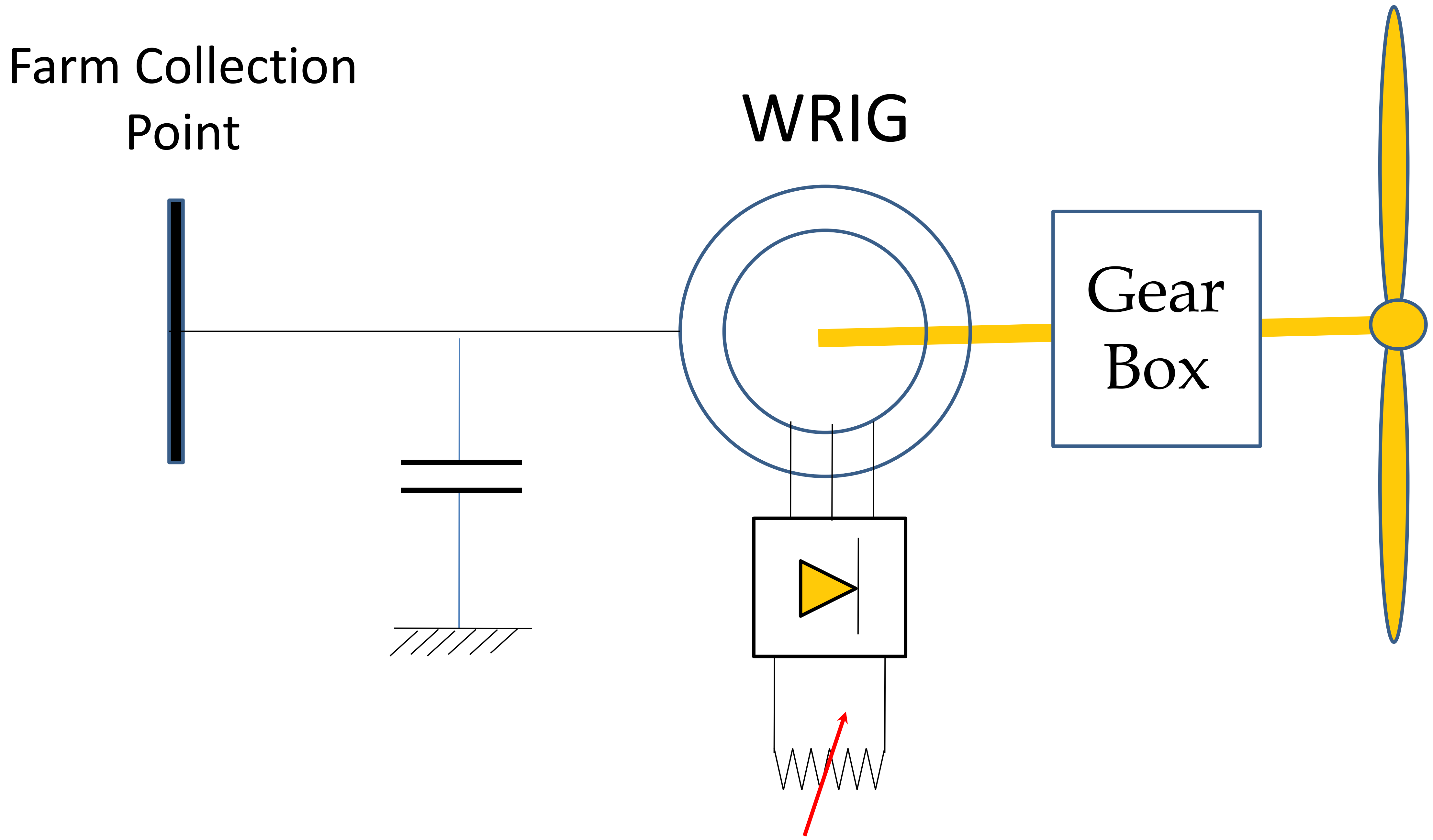
HV-GSU: High Voltage side of Generation Step-Up transformer

Type1: SCIG with Variable Compensation

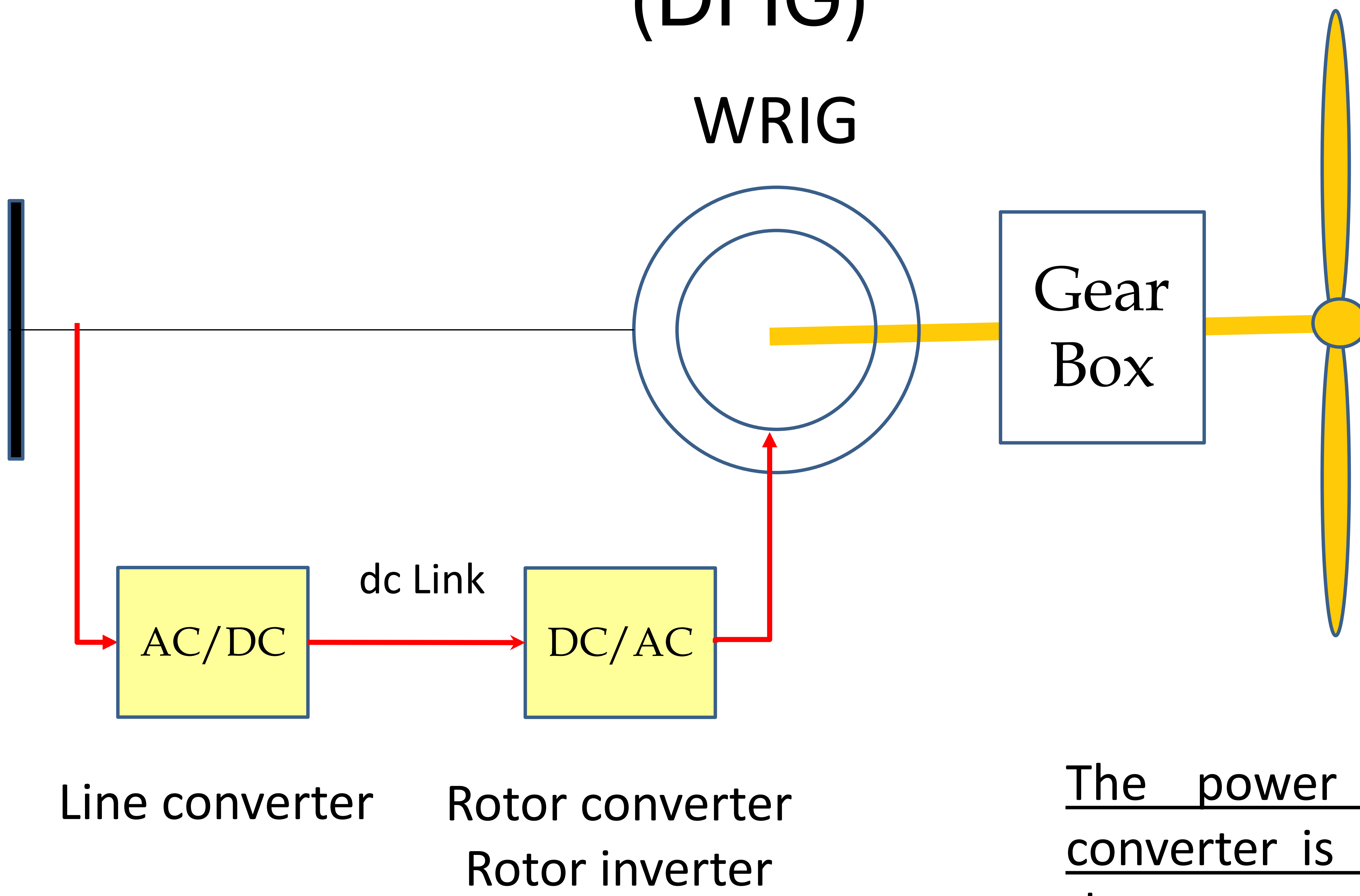


HV-GSU: High Voltage side of Generation Step-Up transformer

Type 2: Wound Rotor IG

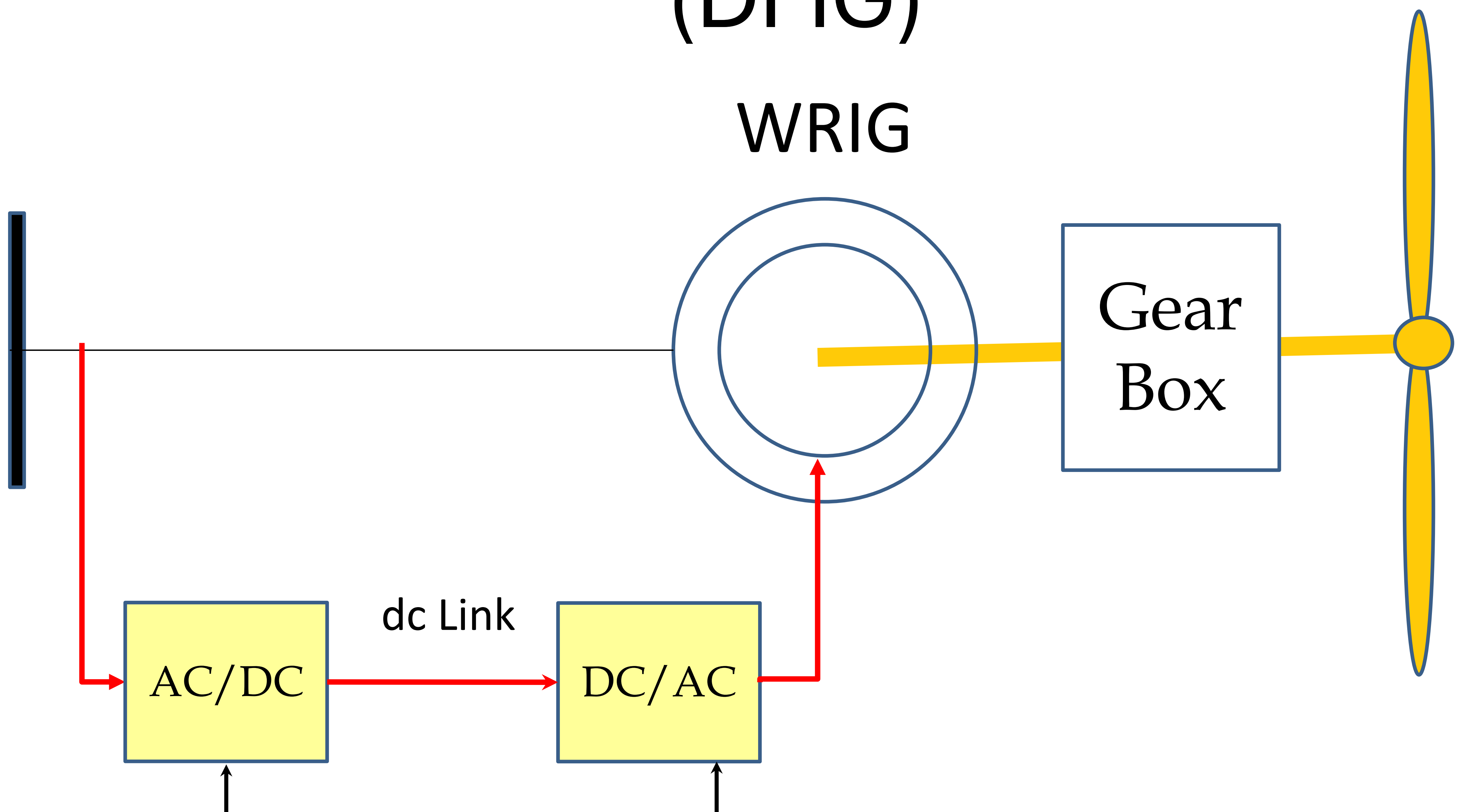


Type 3: Doubly Fed Induction Generator (DFIG)



The power rating of the converter is often about 1/3 the generator rating

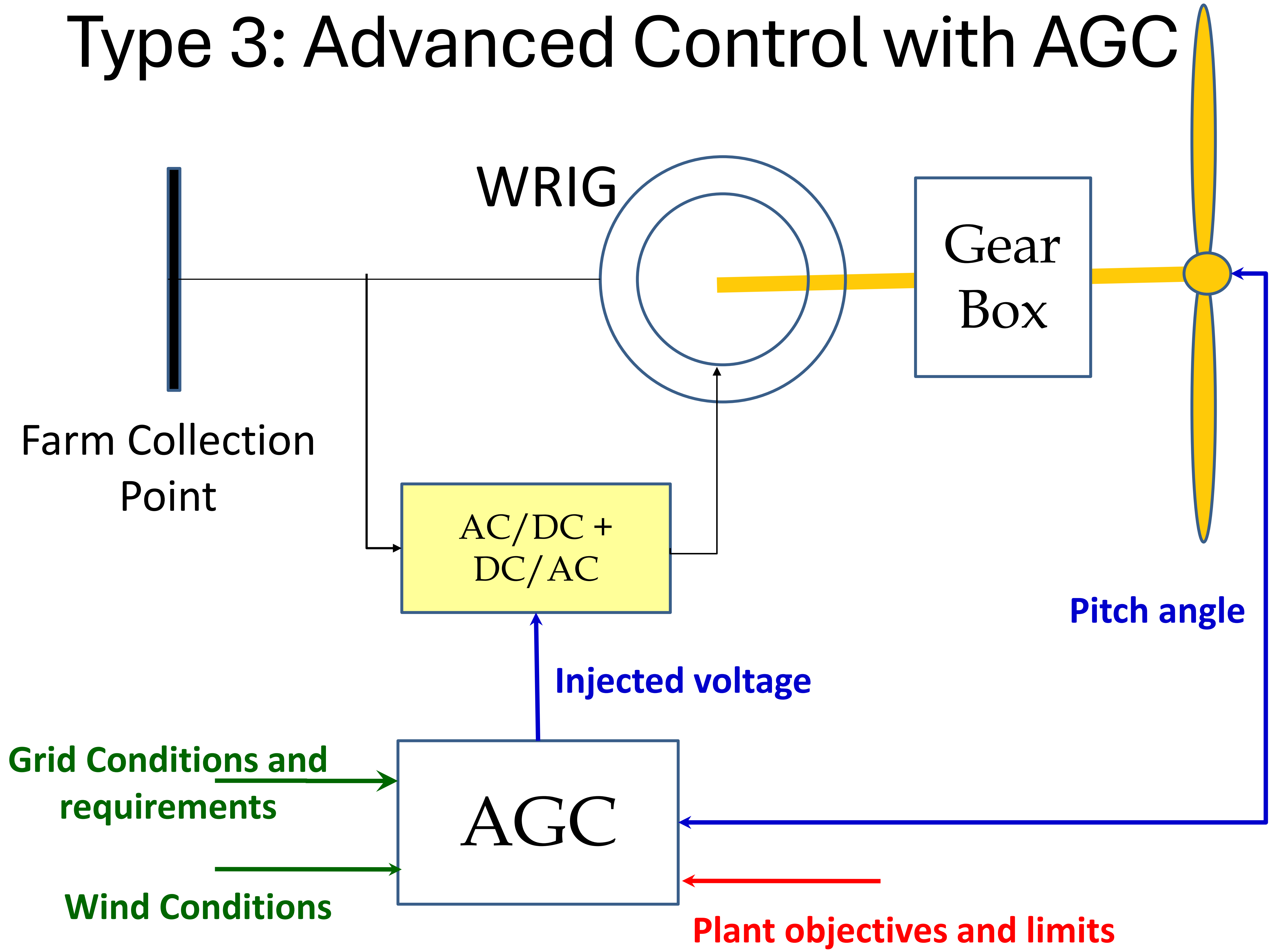
Type 3: Doubly Fed Induction Generator (DFIG)



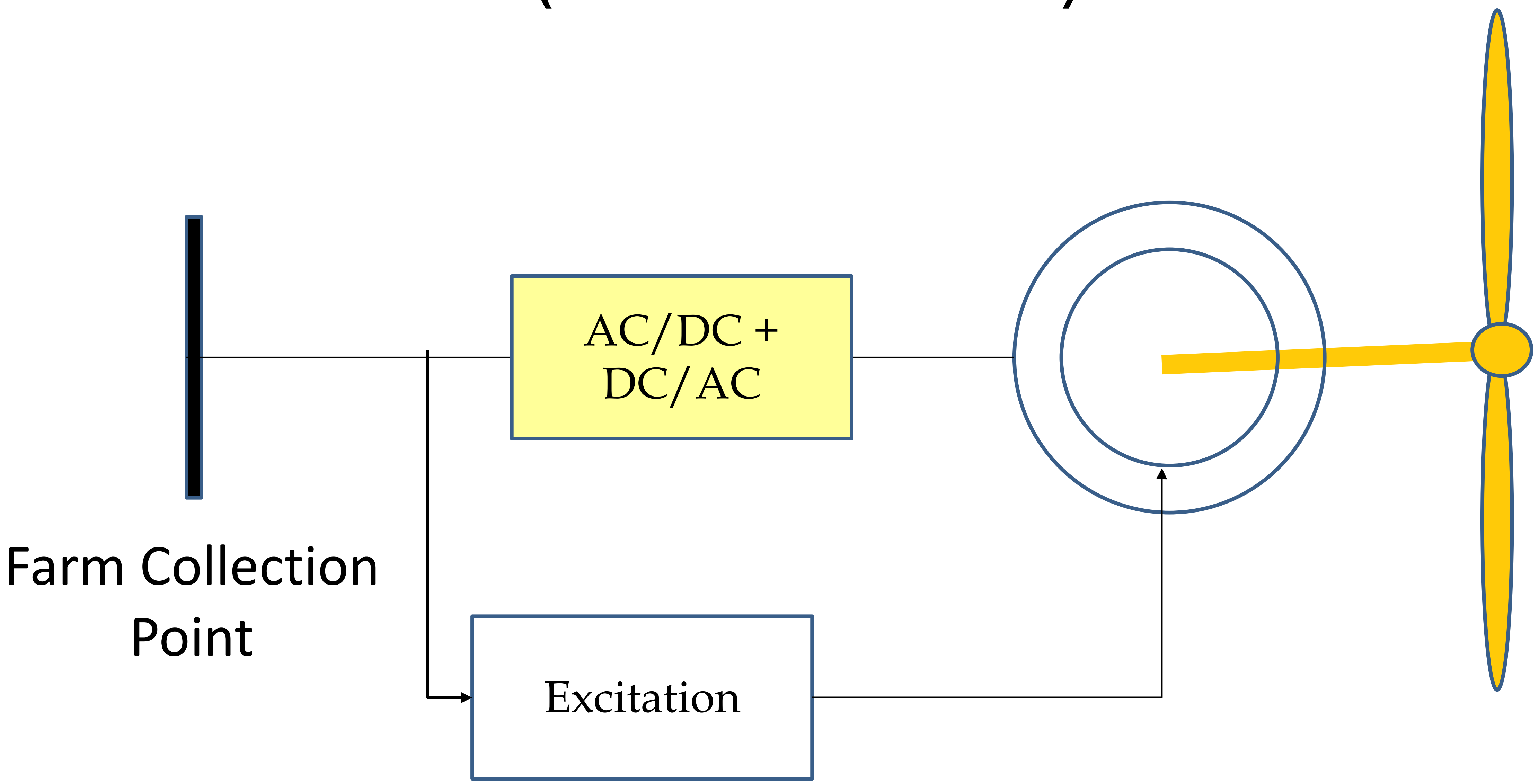
Controls
- DC link voltage
- Reactive power

Controls
- Electromagnetic torque (extracted power)
- Speed
- Terminal voltage of generator
- Reactive power

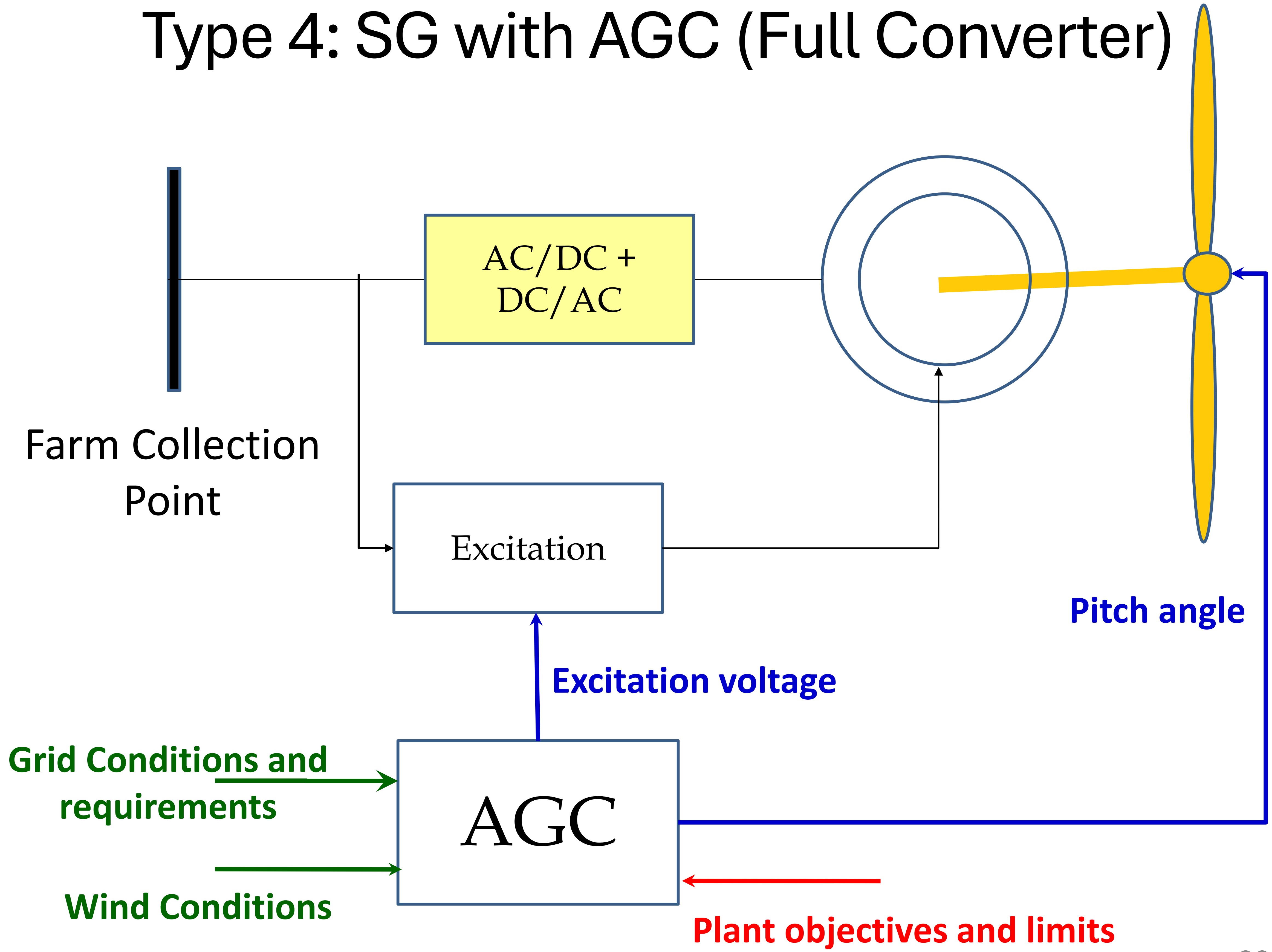
Type 3: Advanced Control with AGC



Type 4: SG with Excitation Control (Full Converter)



Type 4: SG with AGC (Full Converter)



Two Blades Turbines

Runs at fast speed to improve C_p

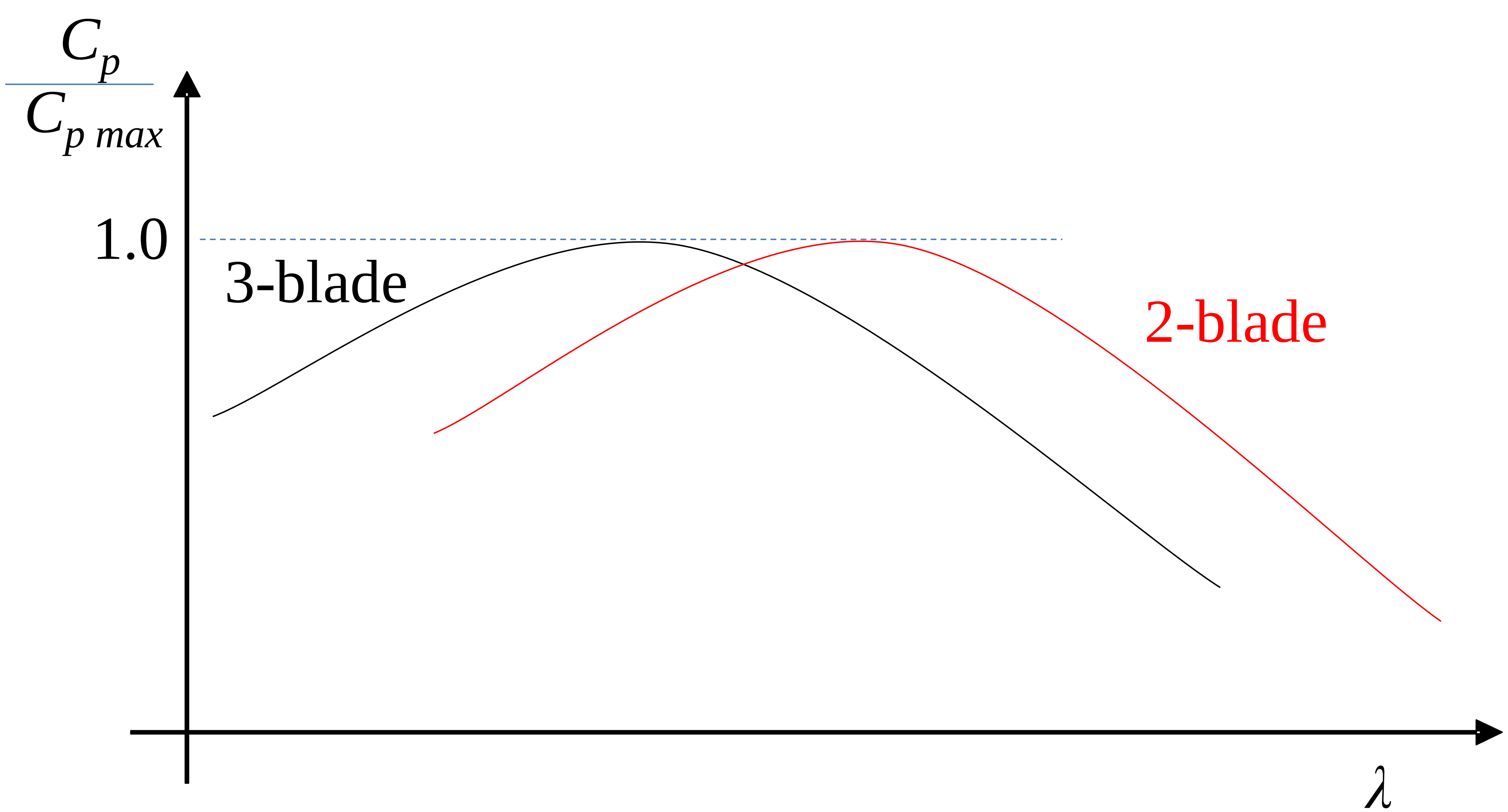
Advantages:

- Gearbox ratio is reduced

Disadvantages:

- For the same wind speed, the two-blade system captures less power than the three-blade system
- Creates gyroscopic imbalances (bending moment due to wind obstruction by tower)
- Higher speed means more noise
- Higher rate of bird collisions

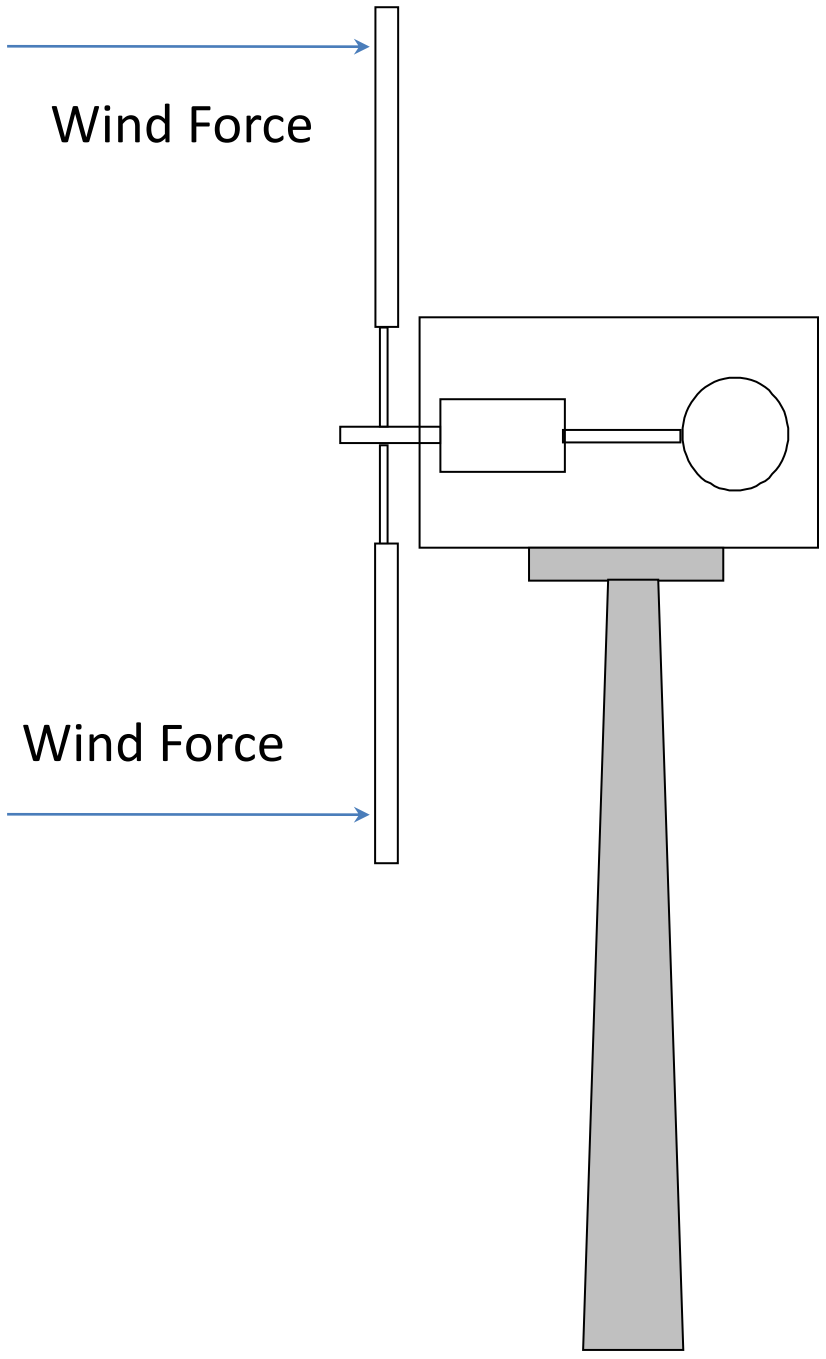
Effect of Number of Blades



2-blade turbine rotates at higher speed to achieve the same C_p as the 3-blade turbine

Bending Moments (2-blade)

- When one blade is at the top, it is receiving the **maximum force** from wind
- The bottom blade is receiving **less force**
- The forces are not balanced at hub
  - Torque on the hub is pulsating, thus stressing the hub gears



Force of Wind

$$F = A\,Pr\,C_d$$

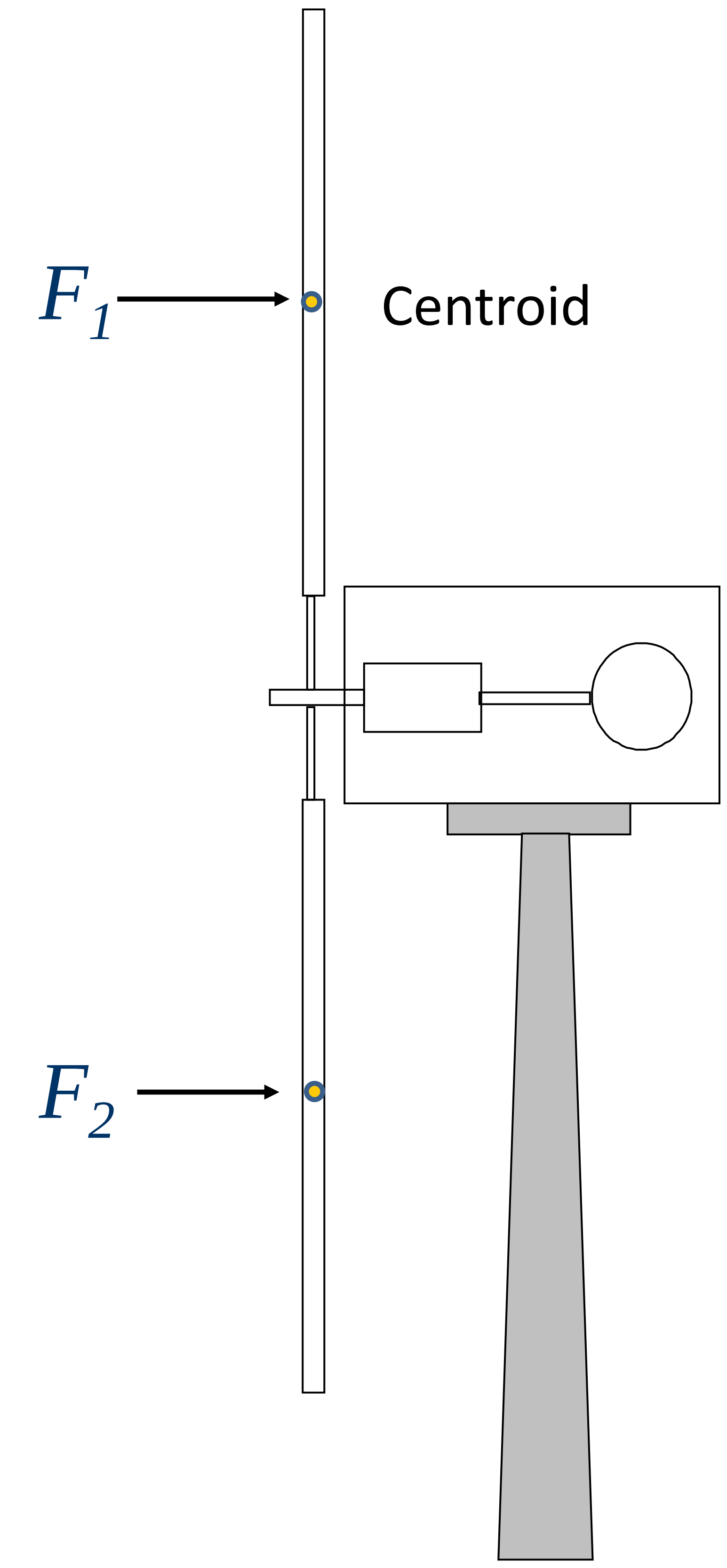
$$Pr \sim w^2$$

A: The area of the blade facing wind
Pr: Wind pressure
C_d : Drag coefficient of the blade

$$F = K\,w^2$$

$$\frac{w_1}{w_2} = \left(\frac{h_1}{h_2}\right)^{\alpha}$$

$$\frac{F_1}{F_2} = \left(\frac{h_1}{h_2}\right)^{2\alpha}$$



Bending Moment

- Find the ratio between the max and min power on the blades, assume α=0.2

$$\frac{F_{80}}{F_{40}} = \left(\frac{80}{40}\right)^{0.4} = 1.3195$$

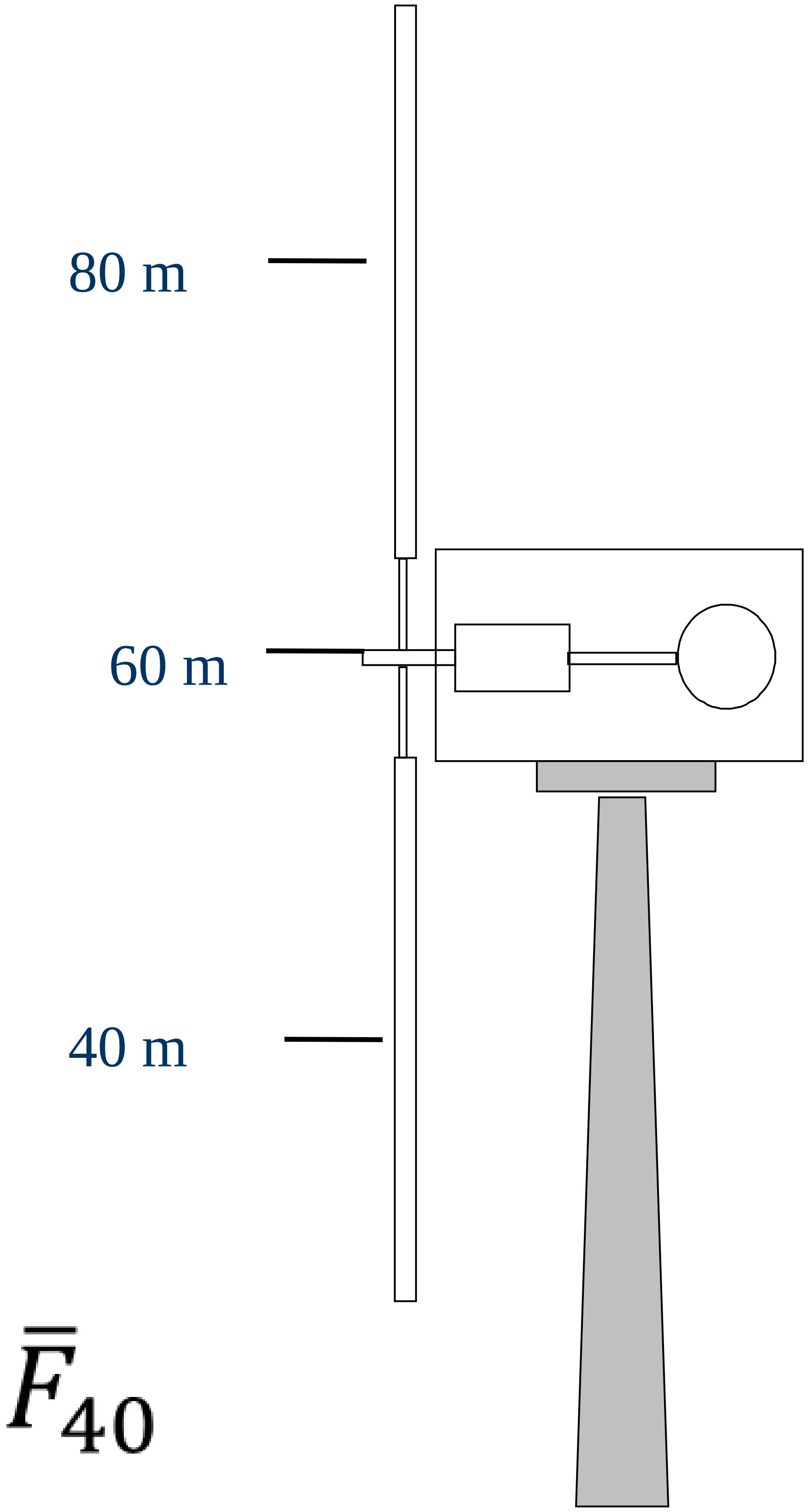
$$\bar{T}_{hub-v} = r\,\bar{F}_{80} + r\,\bar{F}_{40} = 2.3195\,r\,\bar{F}_{40}$$

- When the blades are in the horizontal position

$$\bar{T}_{hub-h} = r\,\bar{F}_{60} + r\,\bar{F}_{60} = 2.0\,r\bar{F}_{60}$$

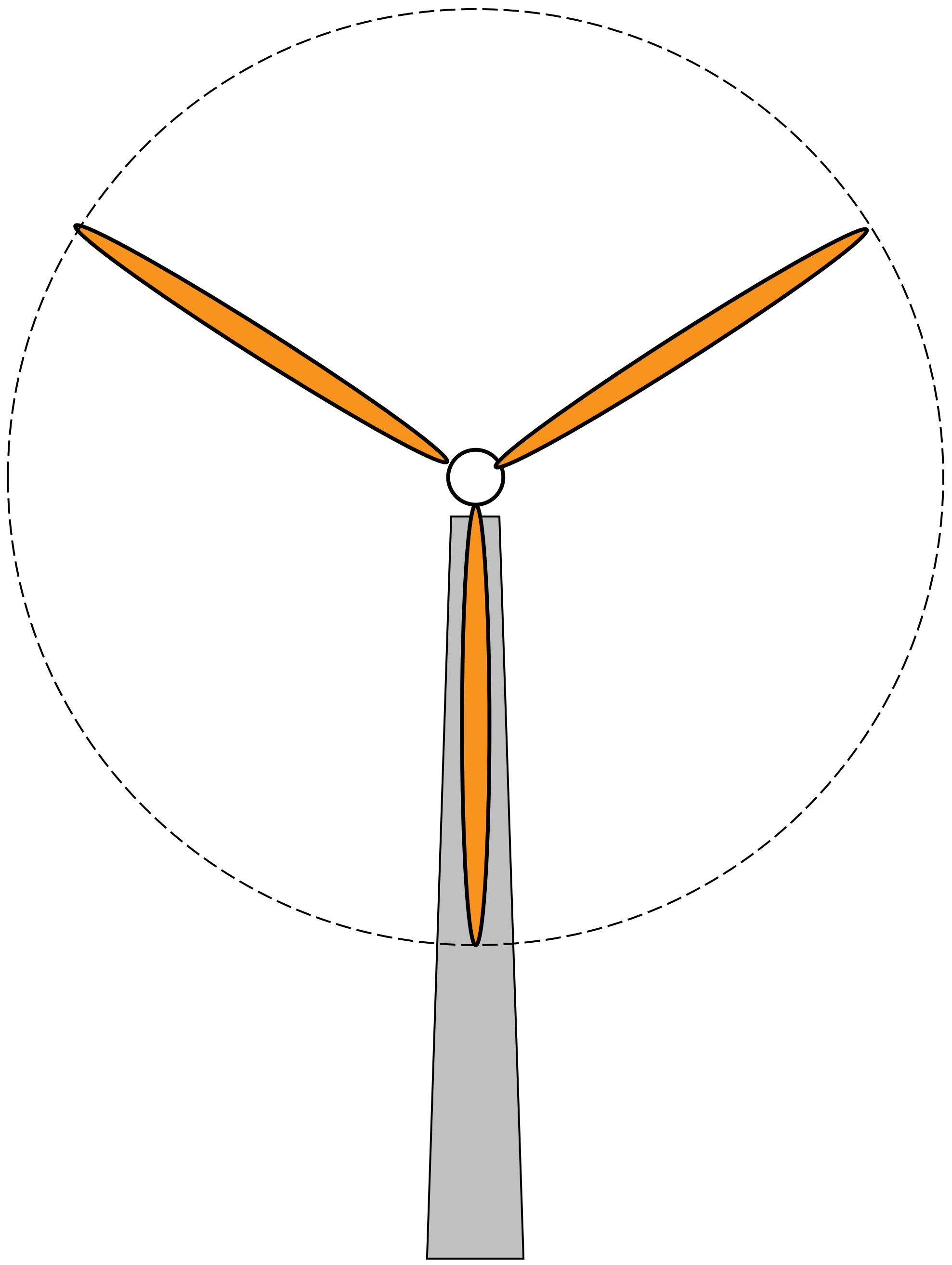
$$\bar{T}_{hub-h} = 2.0 \,*\, 1.176\,\bar{F}_{40} = 2.352\,r\,\bar{F}_{40}$$

$$\Delta\bar{T}_{hub} = \bar{T}_{hub-h} - \bar{T}_{hub-v} = 0.0335\,r\,\bar{F}_{40}$$



Bending Moments (3-blade)

- The bottom blade in the shadow of the tower receives **less than the maximum force**
- The other two blades are not in the vertical position, so they also receive **less than the maximum force**
- The forces are better distributed at the hub



Three-Blade Turbine

Advantages:

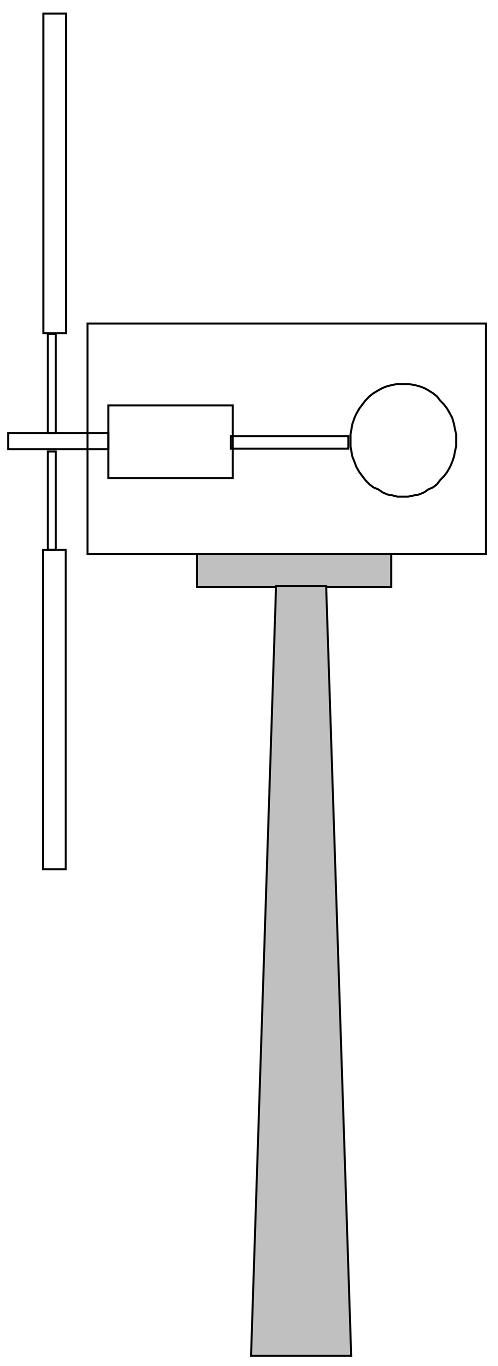
- Slow rotation
- three blades capture more energy than two blades for the same wind speed
- Gyroscopic forces are better balanced
- More aesthetic, less noise, fewer bird collisions

Disadvantages:

- Slower rotation increases gearbox costs
- Rotor assembled on the ground is more difficult

Why not 5 or 7 Blades?

- More expensive
- Increase wind wall effect
  - Reduction of wind speed through the blades, thus reducing the amount of energy that can be captured by the blade
  - Turbulent wind due to one blade may not die down before the other blades reach the area



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	To get the homework and project assignments

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