Wind Energy Conversion Systems

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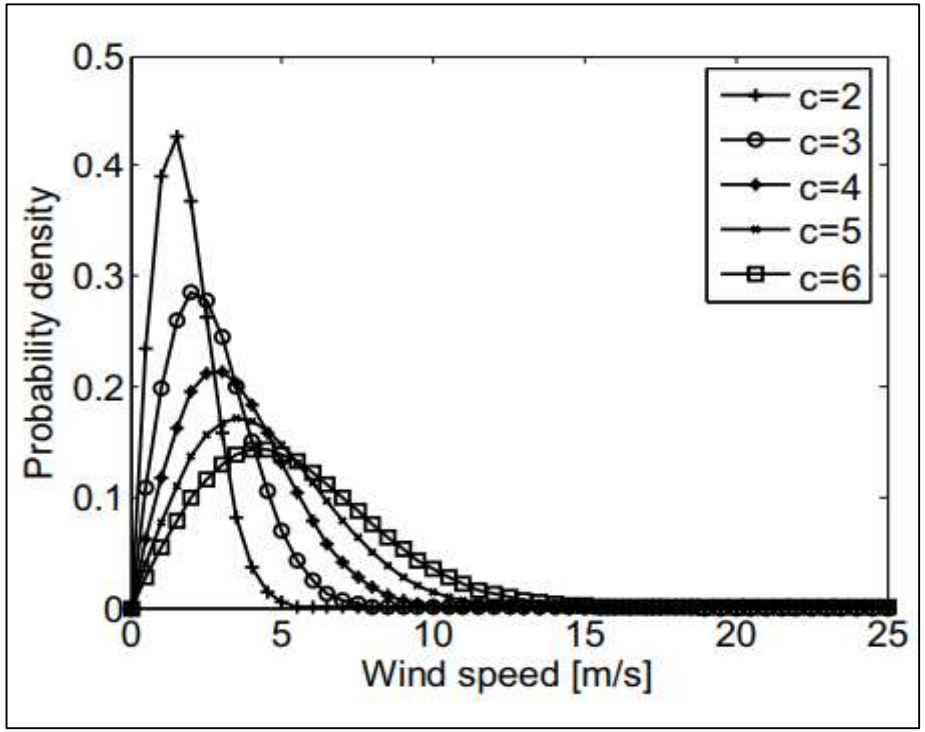
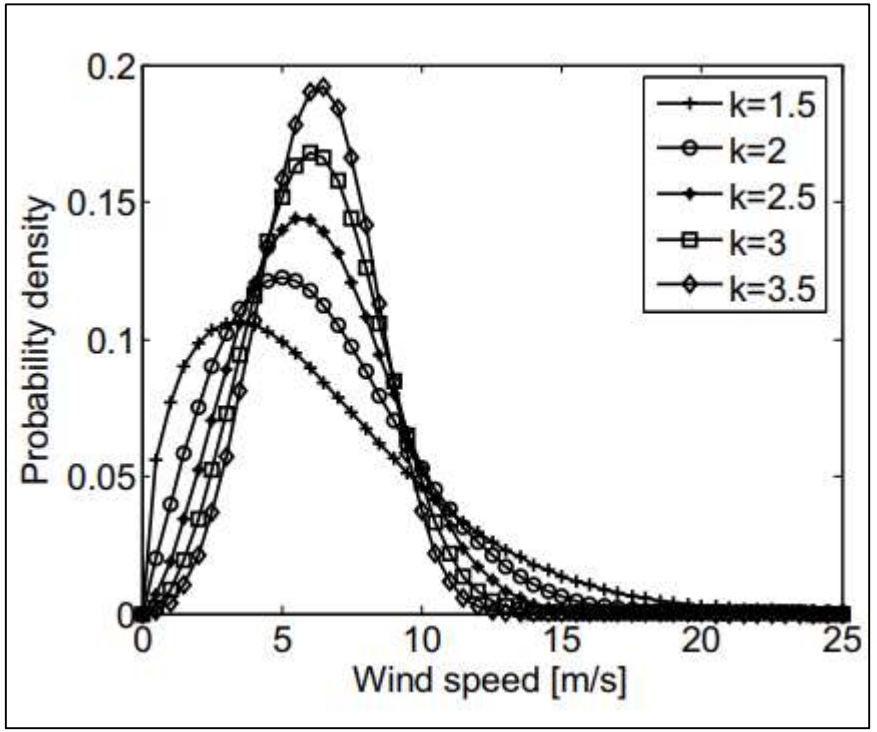
2018-MS-EE-4

Wind Energy Resource

The Site Wind Speed can be modeled by Weibull distribution. The Average Wind Speed v_{avg} increases with the Weibull distribution Scale Factor c and Shape Factor k.

$$v_{avg} = c.\Gamma(1 + \frac{1}{k})$$





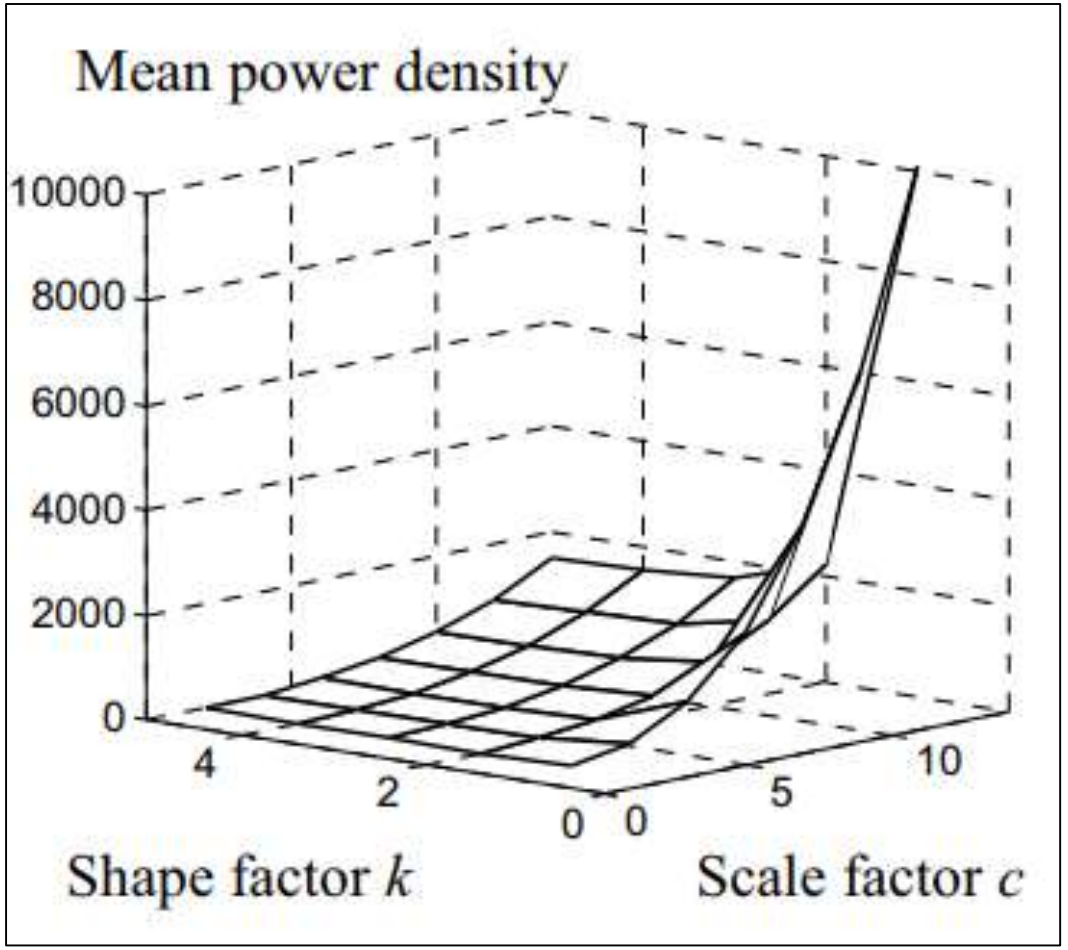
Wind Energy Resource

The Mean Wind Power Density and The Most Optimal Wind Speed increase with the Scale Factor c, but they decrease with the Shape Factor k.

$$P_{tmean} = \frac{1}{2}\rho.A.< v^3 >$$

$$\frac{d}{dv}[v^3 p(v)] = 0 \Rightarrow v_{opt} = c.(1+\frac{2}{k})^{\frac{1}{k}}$$

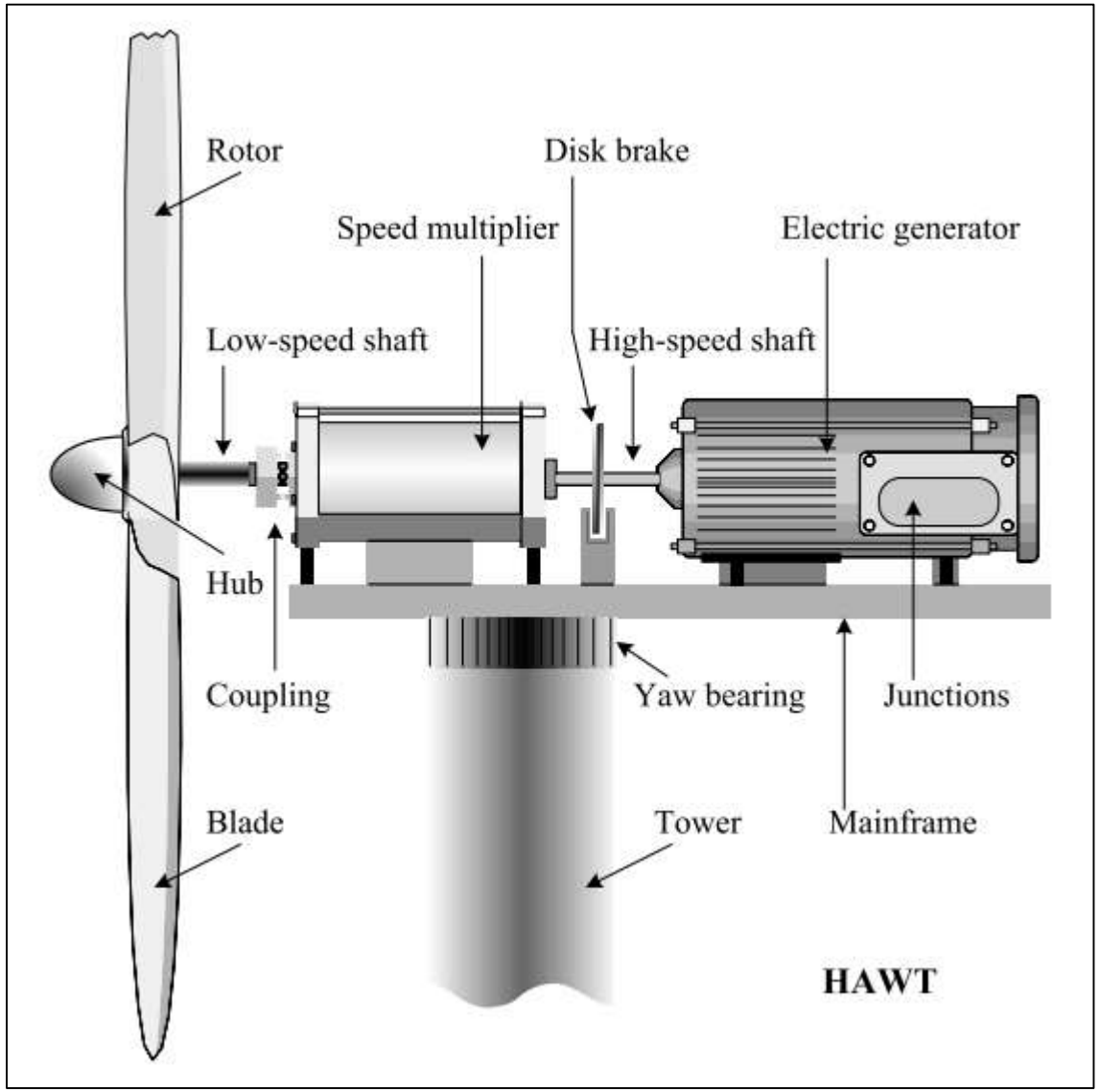
$$\frac{d}{dv}[v.p(v)] = 0 \Rightarrow v_{mean} = c.(1-\frac{1}{k})^{\frac{1}{k}}$$



WECS Technology

Horizontal Axis Wind Turbine Energy Conversion Chain consists of:

1. Aerodynamic Subsystem (Turbine Rotor and Turbine Hub)
2. Drive Train (Low-speed shaft, Speed Multiplier and High-speed shaft)
3. Electromagnetic Subsystem (Electric Generator)
4. Electric Subsystem (Elements for Grid Connection)



Wind Turbine Aerodynamics

The Power extracted from air mass $\rho A v_o \Delta t$ by Energy Extracting Actuator Disc is:

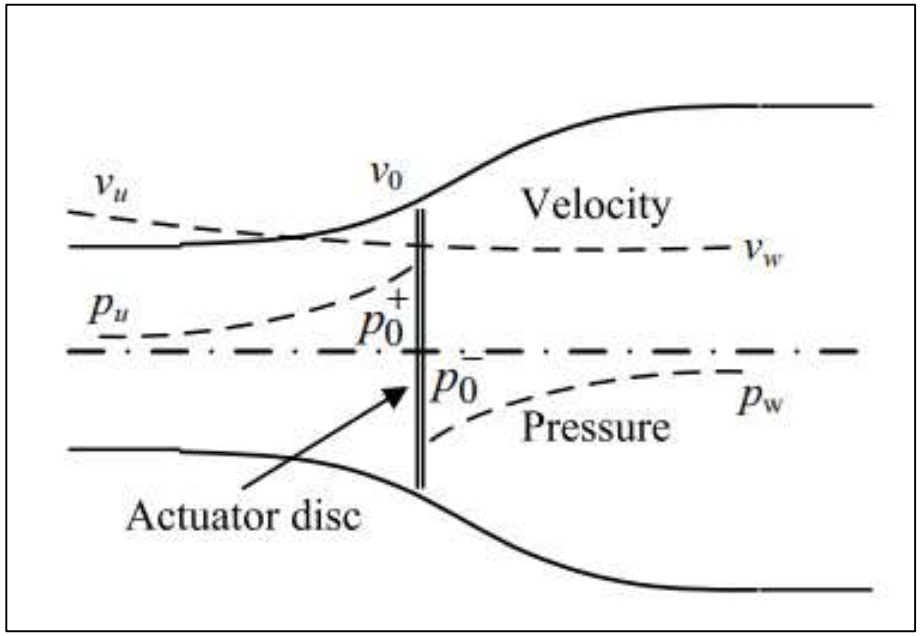
$$P_{extracted} = \frac{1}{2}\rho A v_o (v_{head}^2 - v_{tail}^2)$$

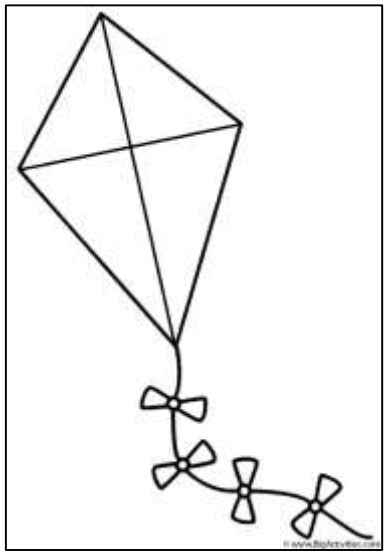
$$P_{extracted} = \frac{1}{2}\rho A v^3 C_p$$

Where Power Coefficient Cp is:

$$C_p = 4(1 - \frac{v_o}{v_{head}})(\frac{v_o^2}{v_{head}^2})$$

Example: Kite.



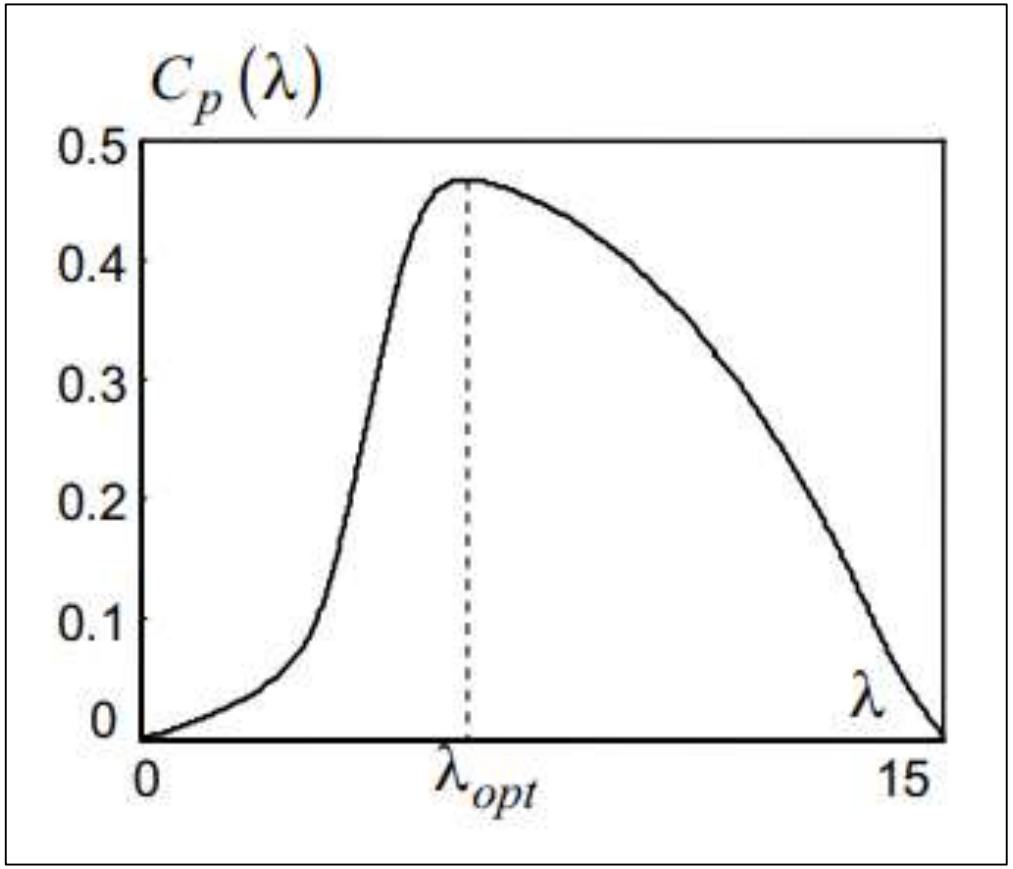


Wind Turbine Aerodynamics

Tip Speed Ratio λ is:

$$\lambda = \frac{Blade\ Length.Rotor\ Speed}{Wind\ Speed}$$

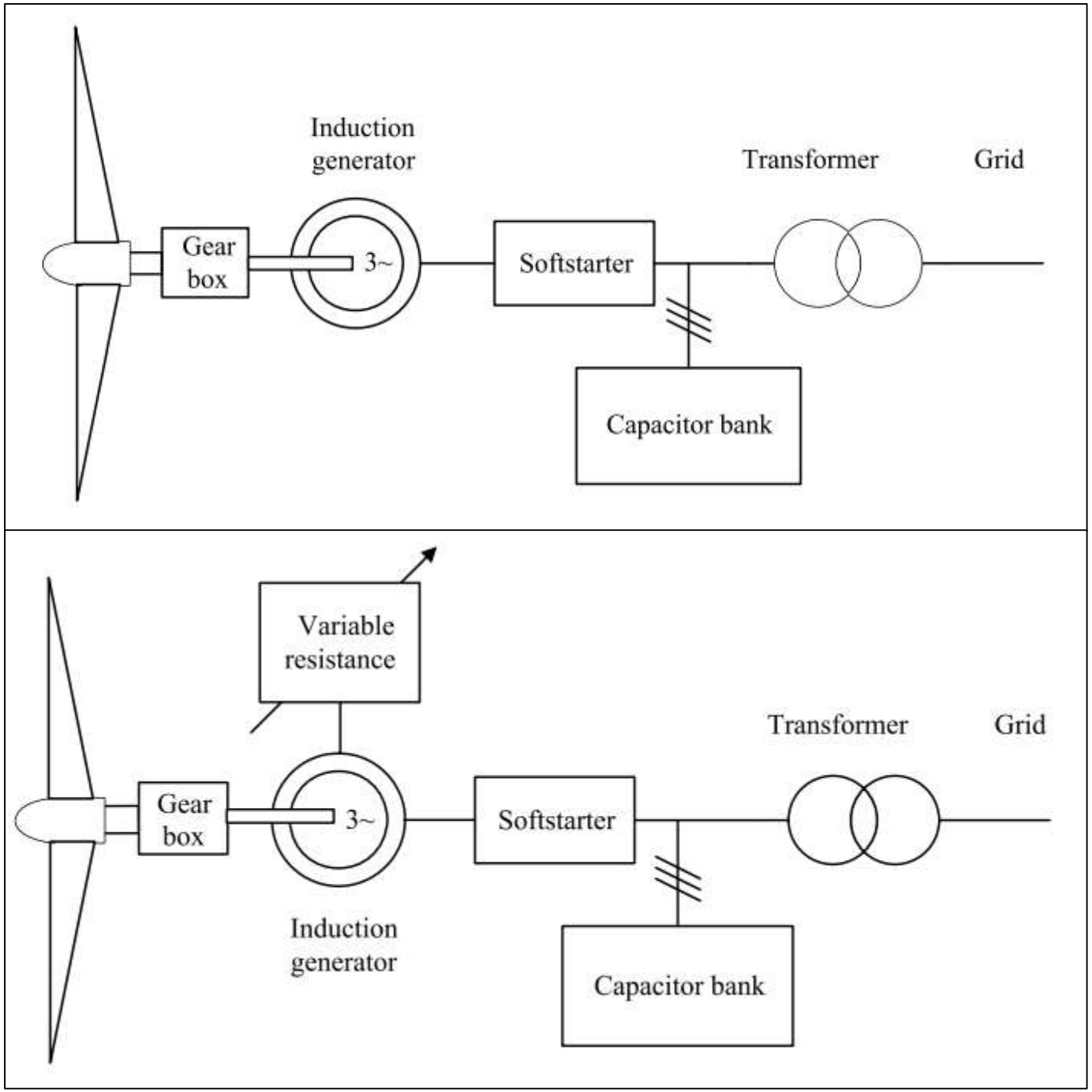
Power Coefficient Cp(λ) performance curve shows that the Maximum value of Cp occurs at λ_{opt}. It is lower than the Betz limit (Cpmax = 0.59).



Power Generation System

Fixed-speed WECS:

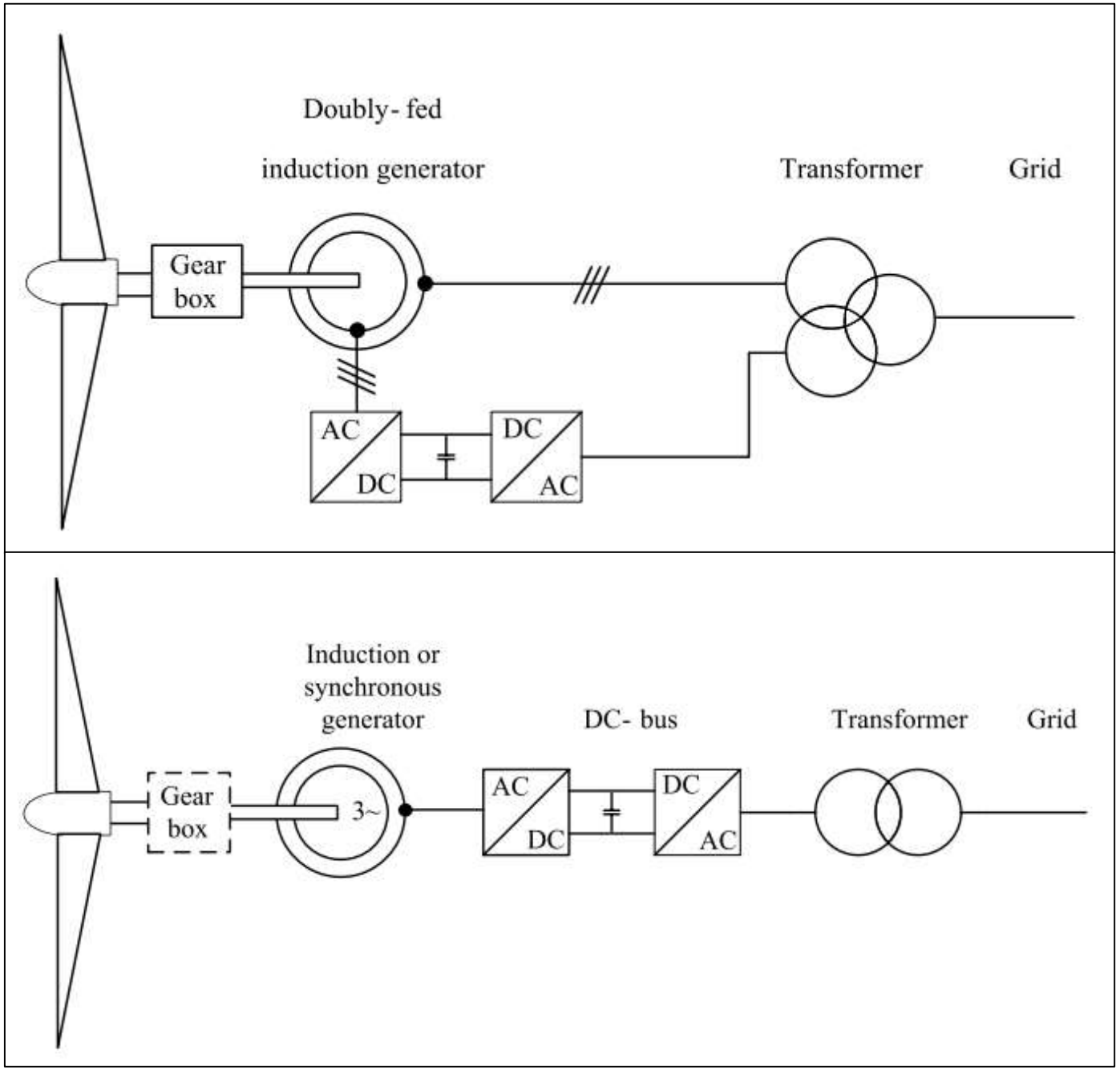
1. General structure of a fixed-speed WECS (Squirrel Cage Induction Generator)
2. General structure of a limited variable-speed WECS (Wound Rotor Induction Generator)



Power Generation System

Variable-speed WECS:

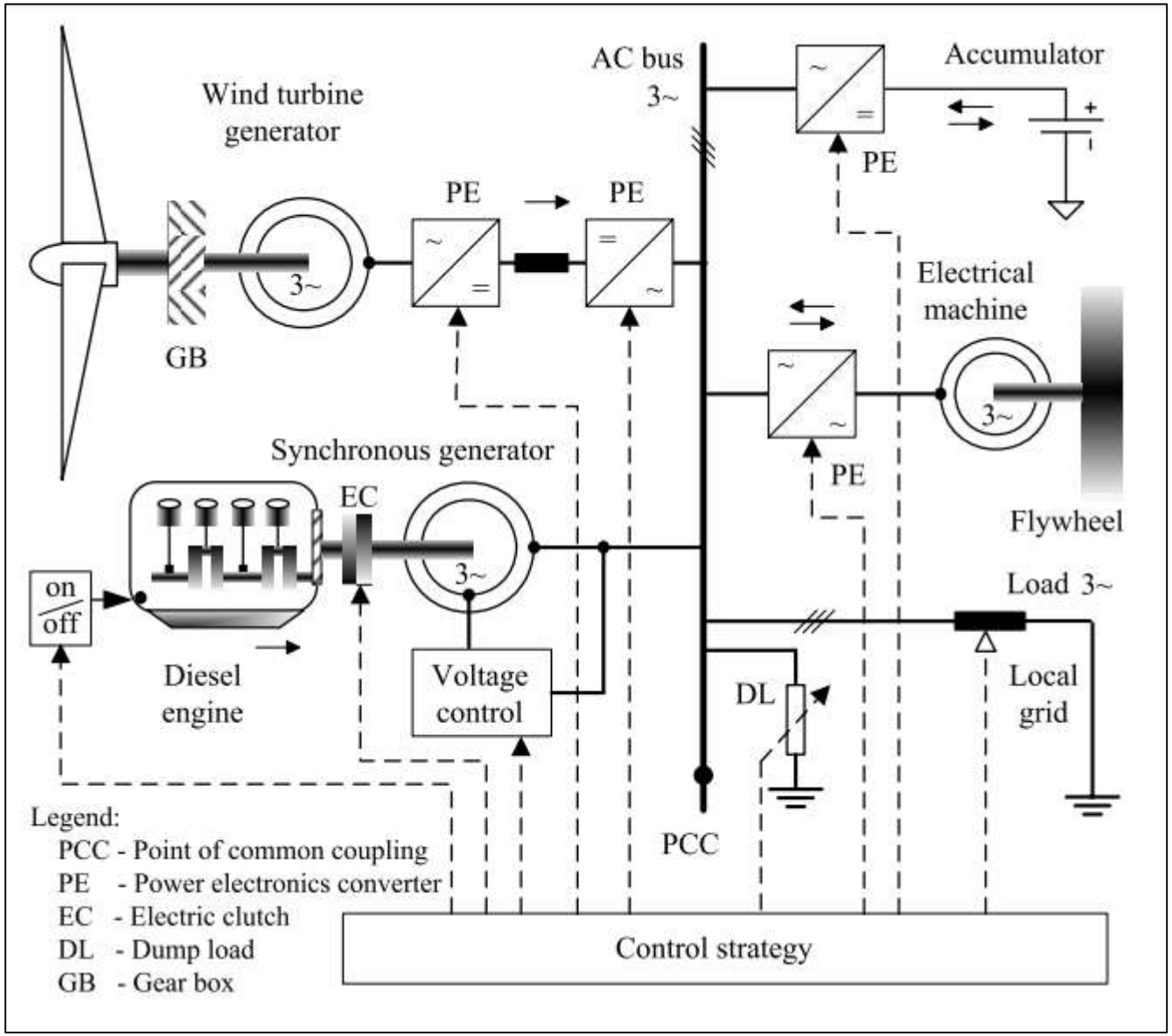
1. General structure of an improved variable-speed WECS (Doubly Fed Induction Generator)
2. General structure of a full variable-speed WECS (Squirrel Cage Induction Generator or Synchronous Generator)



Wind Turbine Generators in Hybrid Power Systems

AC-coupled hybrid generation system:

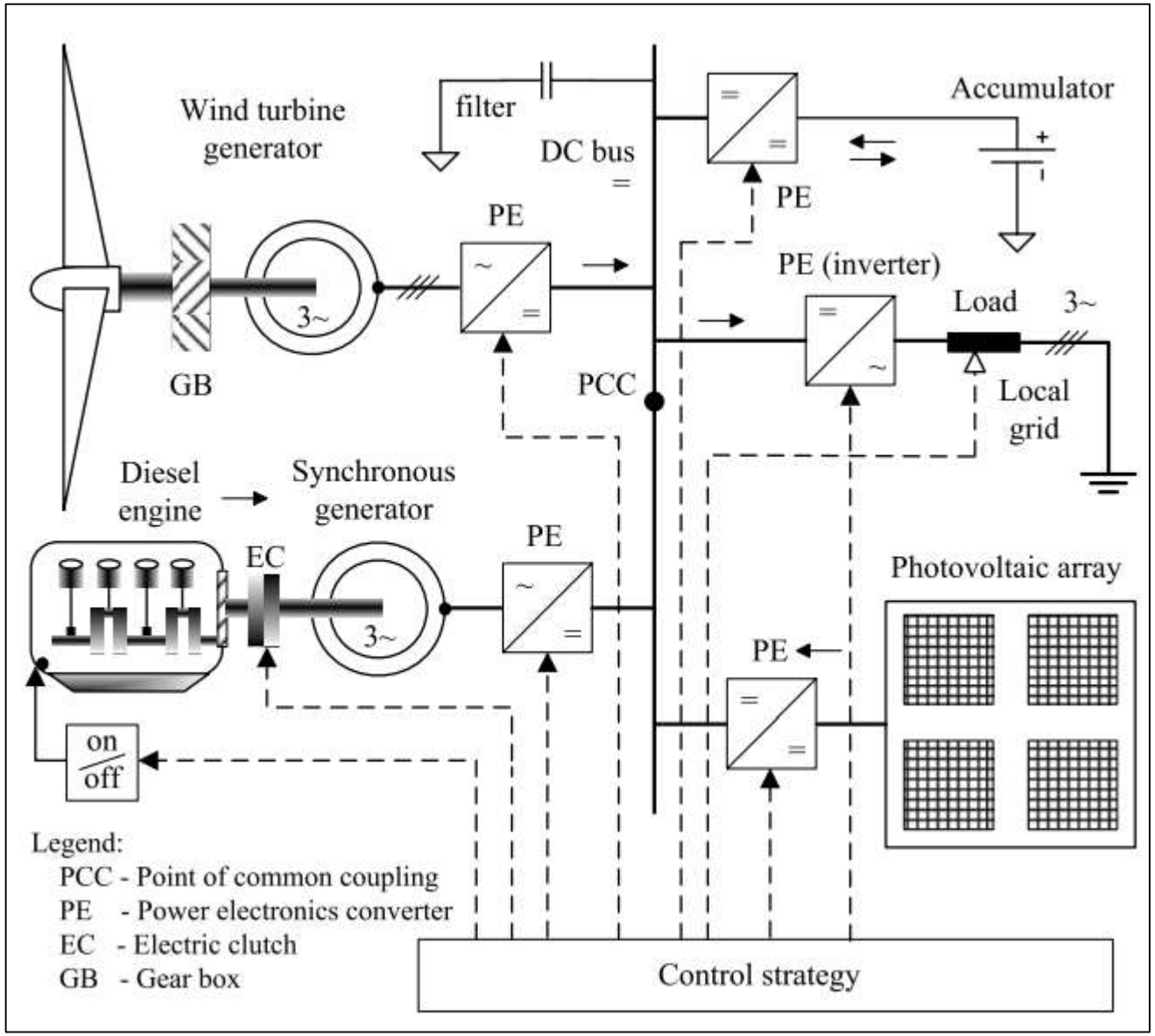
1. Generators (Wind Turbine Generator, Diesel Power Plant)
2. AC Bus
3. Energy Storage (Accumulator, Flywheel)
4. Loads
5. Control System



Wind Turbine Generators in Hybrid Power Systems

DC-coupled hybrid generation system:

1. Generators (Wind Turbine Generator, Diesel Power Plant, Photovoltaic Cells)
2. DC Bus
3. AC Filter
4. Energy Storage (Accumulator)
5. Loads
6. Control System



Control Objectives

1. Aerodynamic power control through pitch/ stall control
2. Variable-speed operation and energy capture maximization, by means of generator control.
3. Grid Power Transfer Control, through the power electronics converter.