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Chapter 2

Fundamentals of Distributed Energy Resources

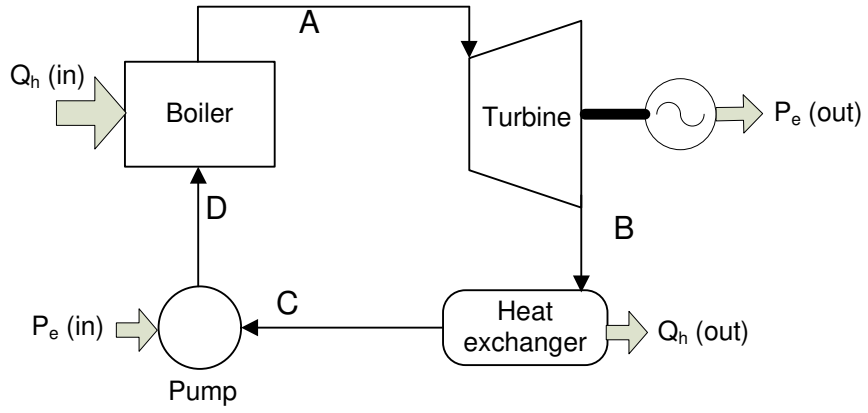
Question 2.1. List and explain the advantages and disadvantages of variable speed operation of large wind generators both for the wind turbine and the power system.

Solution:

- For maximum power extraction, the turbine should operate at a particular value of λ. In order to achieve this the generator speed should change with the wind speed.
- Under variable speed operation, the loading on the wind turbine is reduced.
- As variable speed wind turbine often has a power electronic interface, turbines will be able to meet the grid code requirements with less additional equipment.

Question 2.2. Draw the elements of a back-pressure steam turbine CHP generator. If the enthalpy of the steam just before the turbine is 3500 kJ/kg, just after the turbine is 2750 kJ/kg and mass flow rate is 10 kg/s, calculate the gross electrical power output of the CHP generator. Assume that the thermal efficiency of the turbine is 80% and the efficiency of the electrical generator is 95%. If the pump and other auxiliaries consume 5% of the gross output, what is the net electrical power output of the CHP generator?

Solution:



Elements of back-pressure steam turbine cycle

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Gross power output

$P_e(\text{out}) = \eta_T \eta_G \dot{m}\left[h_A - h_B\right] = 0.8 \times 0.95 \times 10 \times \left[3500 - 2750\right] = 5.7\ \text{MW}$

Net power output = 5.7(1-0.05) = 5.42 MW

Question 2.3. A crystalline silicon PV module has 36 cells connected in series. Each cell is square with sides 150 mm. Assume ISC=300 A/m^2 at standard conditions and the cells have a rectangular V-I characteristic (i.e. 100% fill factor)

a) Estimate the open-circuit voltage, the short circuit current and the power output of the module at an irradiance of 800W/m^2.

b) A solar array is formed by six modules, three in series and two strings in parallel. What is the open-circuit voltage, the short circuit current and the power output of the array at an irradiance of 500W/m^2?

Solution:

a) Each cell has an open circuit voltage of 0.6V. Therefore 36 cells in series gives a module open circuit of 21.6 volts.

Each cell has an area of 0.15 x 0.15m^2. With a short circuit current of 300A/m^2 at an irradiance of 1000W/m^2, this gives a current of 6.75A. However the irradiance is 800W/m^2 and so this reduces to 0.8 x 6.75 = 5.4A.

Hence the power output is the V x I or 116 W

b) Three modules in series gives an open circuit voltage of 21.6 x 3 = 64.8 V

As there are two strings of modules in parallel the total short circuit current at the irradiance of 500W/m^2 = 6.75 x 0.5 x 2 = 6.75 A

Hence the power output is V x I or 437.4 W

Question 2.4. The nameplate on a 400V, 600 kW, 50 Hz, 4 pole induction generator indicates that its speed at rated load is 1510 rev/min. Assume the generator to be operating at rated load. What is the

a) slip of the rotor?

b) frequency of the rotor current?

c) angular velocity of the stator field with respect to the rotor and stator?

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Solutions:

a) $\omega_s = 120f/p = 120 \times 50/4 = 1500$ rev/min

Slip = (1500-1510)/1500 = -0.67%

b) Frequency of the rotor current = sf = 0.0067x50 = 0.33 Hz

c) With respect to the rotor, the angular velocity = $s\omega_s$ = -0.0067x1500 = -10 rev/min (negative sign indicates in the reverse direction to ω_s)

With respect to the stator = 1510 -10 = 1500 rev/min = 157.08 rad/s

Question 2.5. A country needs a total generation of 12,000 GWh per annum. It was decided to meet 25% of this demand from renewable energy sources. This will be met by P_1 (MW) capacity of wind generation and P_2 (MW) capacity of solar PV with the ratio P_1:P_2 of 5:1.

a) Assuming that the average capacity factors of the wind generation is 35% and the solar generation is 20%, calculate P_1 and P_2.

b) If 2 MW wind turbines are used to obtain capacity P_1, how many wind turbines are required? If the rotor radius of each wind turbine is 100 m and the coefficient of performance of each wind turbine is 0.4, calculate the average wind speed required to obtain 2 MW. Assume an air density of 1.25 kg/m^3.

Solutions:

a) Generation from renewables = 12000 x 0.25 = 3000 GWh

$0.35 \times P_1 \times 8760 + 0.2 \times P_2 \times 8760 = 3000$ GWh

$0.35P_1 + 0.2P_2 = 342.47$ MW

Since $P_1/P_2 = 5$

$P_1 = 878.1$ MW and $P_2 = 175.62$ MW

b) No of wind turbines required = 878.1/2 = 440

$$P_{out} = 0.5 \times C_p \rho A U^3$$

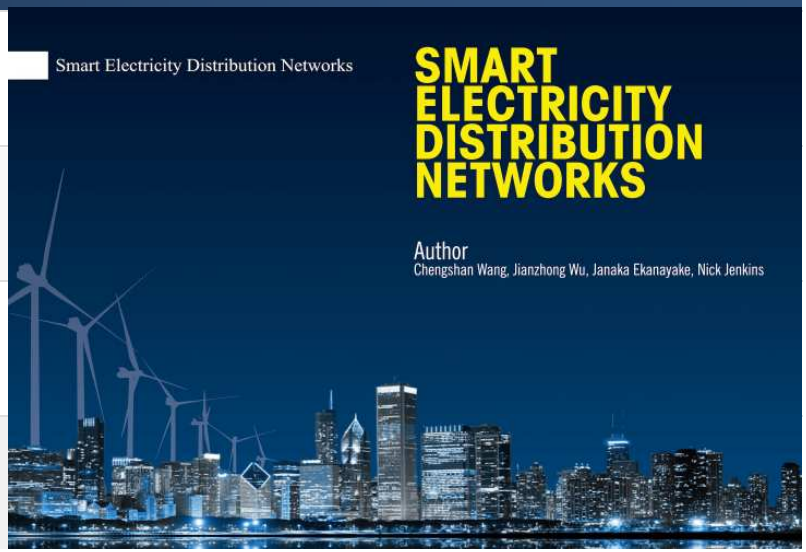
$2x10^6 = 0.5 \times 0.4 \times 1.225 \times \pi \times 100^2 \times U^3$

U = 6.38 m/s

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Chapter 2



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Fundamentals of Distributed Energy Resources



2.1 Introduction

2.2 Combined Heat and Power plants

2.3 Photovoltaic Energy Systems

2.4 Wind Energy Systems

2.5 Electrical Energy Storage

2.6 Flexible demand

2.1 Introduction

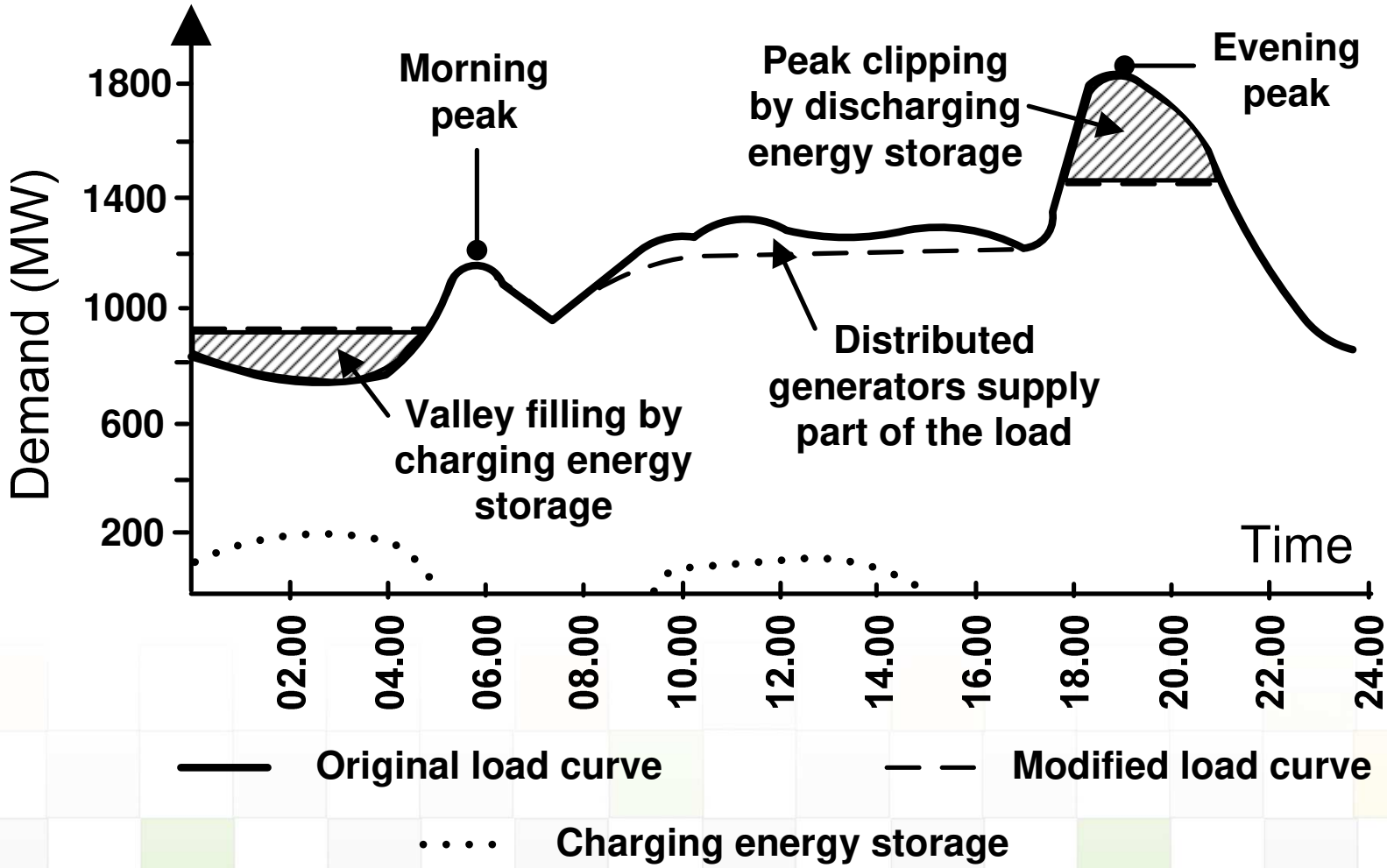


Figure 2.1 Benefits of DER

2.2 Combined Heat and Power plants

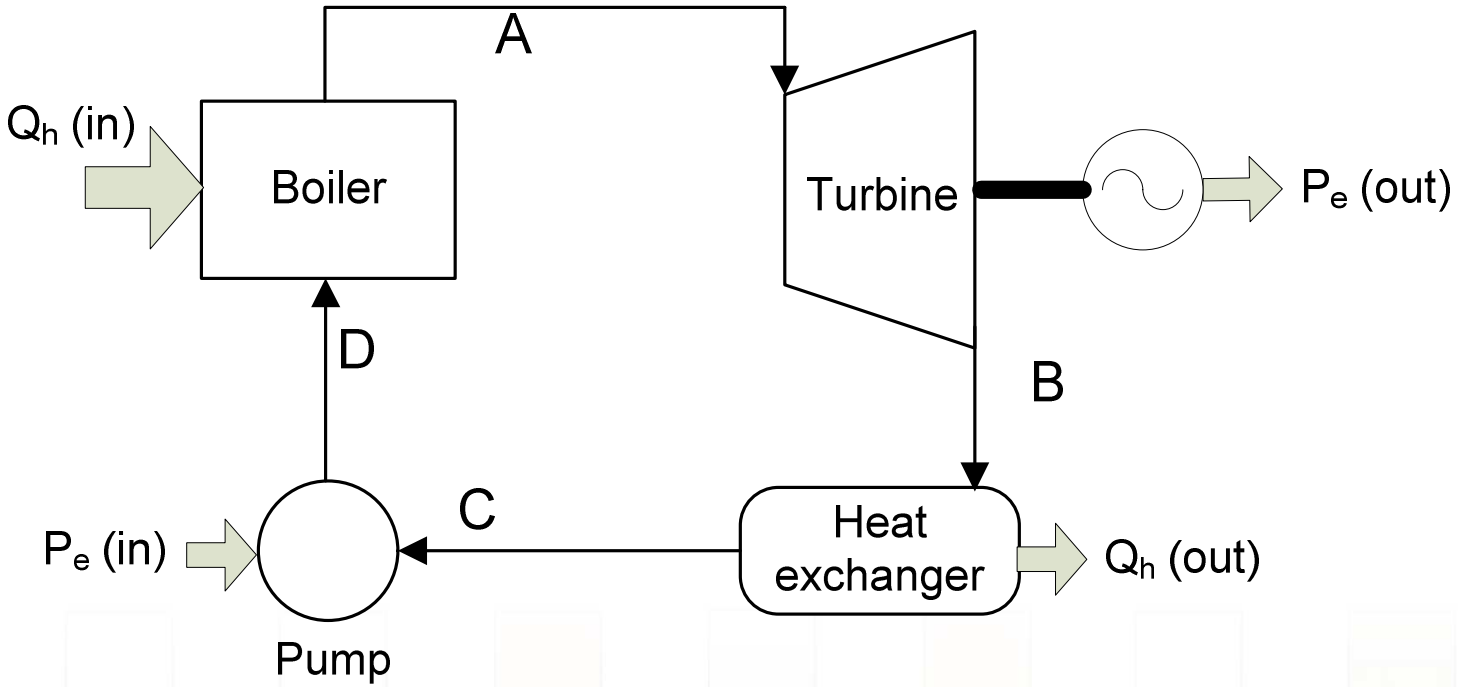


Figure 2.2 Elements of back-pressure steam turbine cycle

2.2 Combined Heat and Power plants

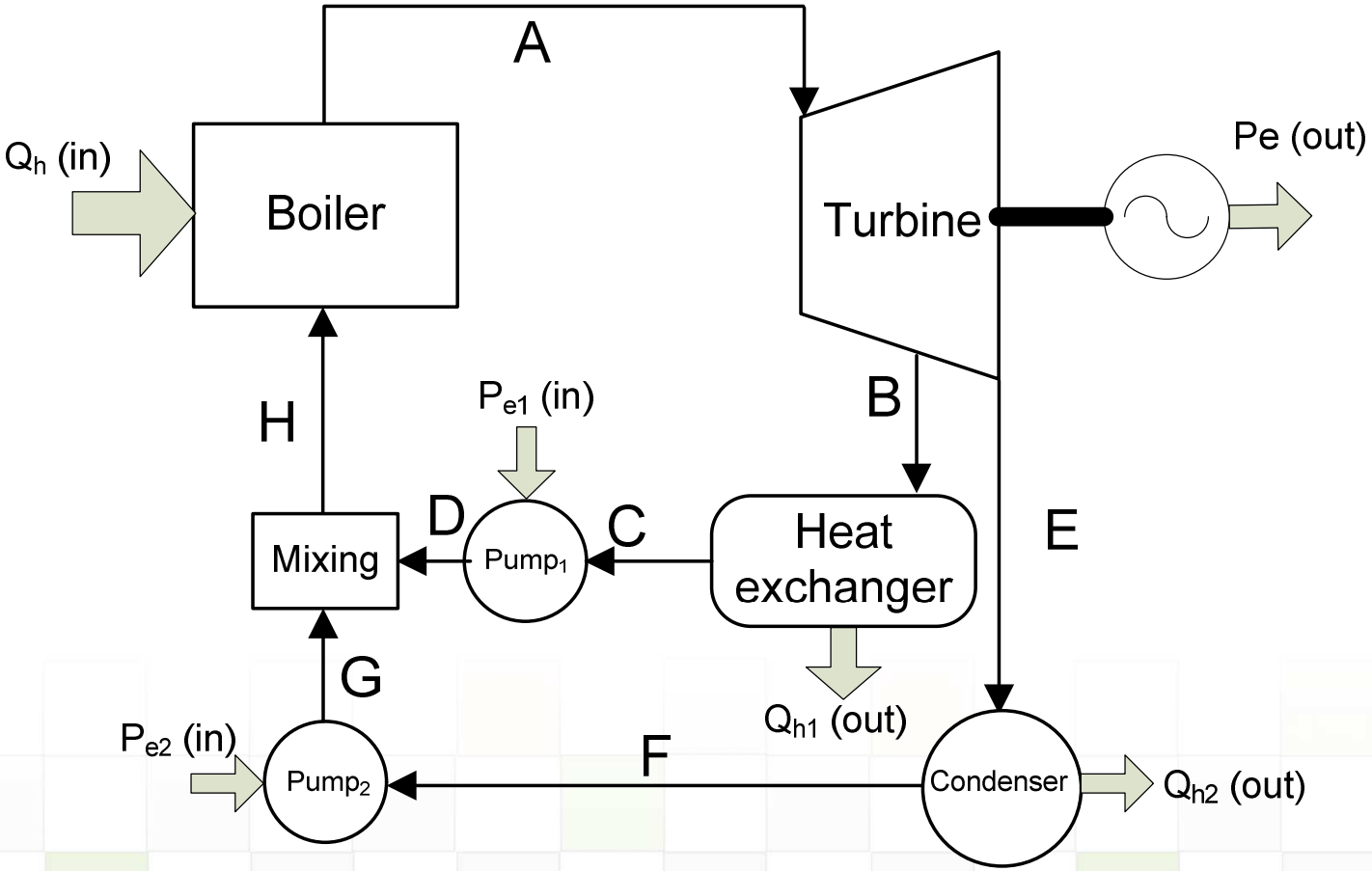


Figure 2.3 Elements of pass out condensing steam turbine cycle

2.2 Combined Heat and Power plants

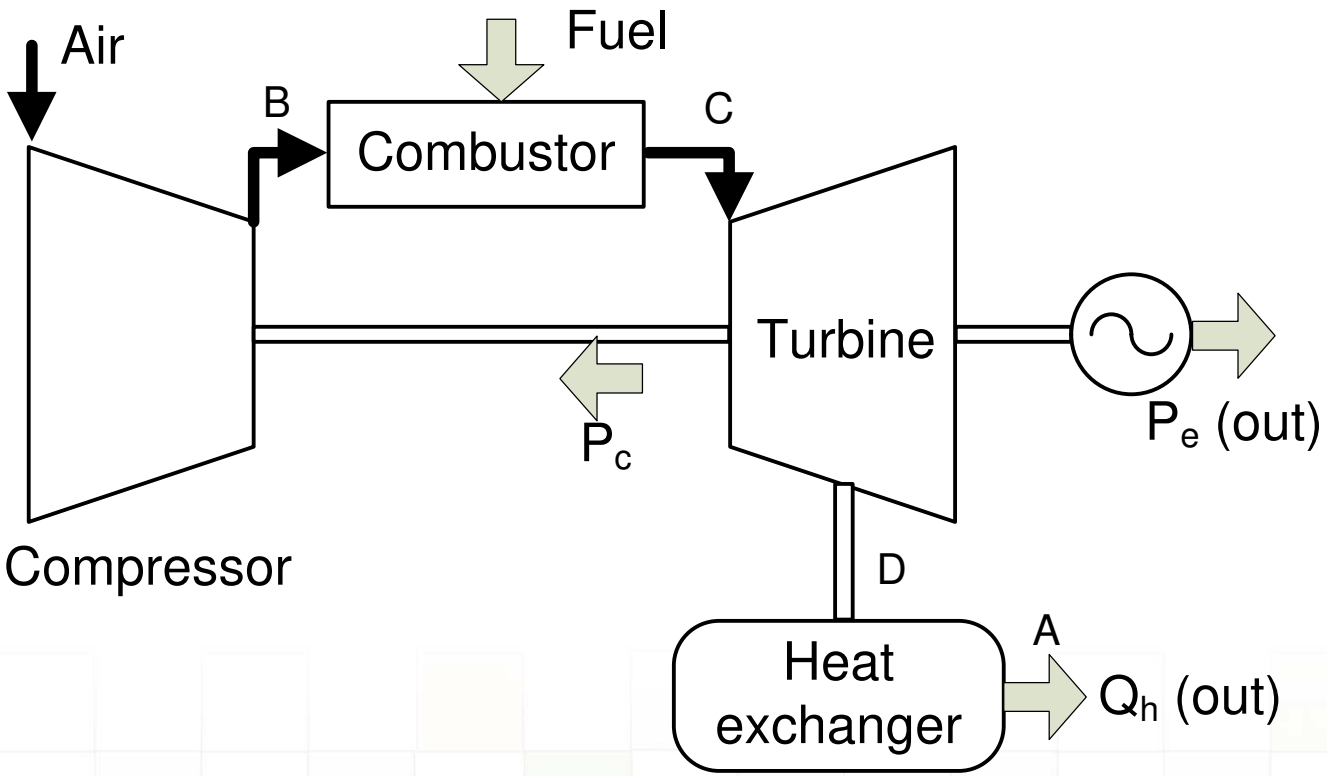


Figure 2.4 Simple cycle, single shaft gas turbine

2.2 Combined Heat and Power plants

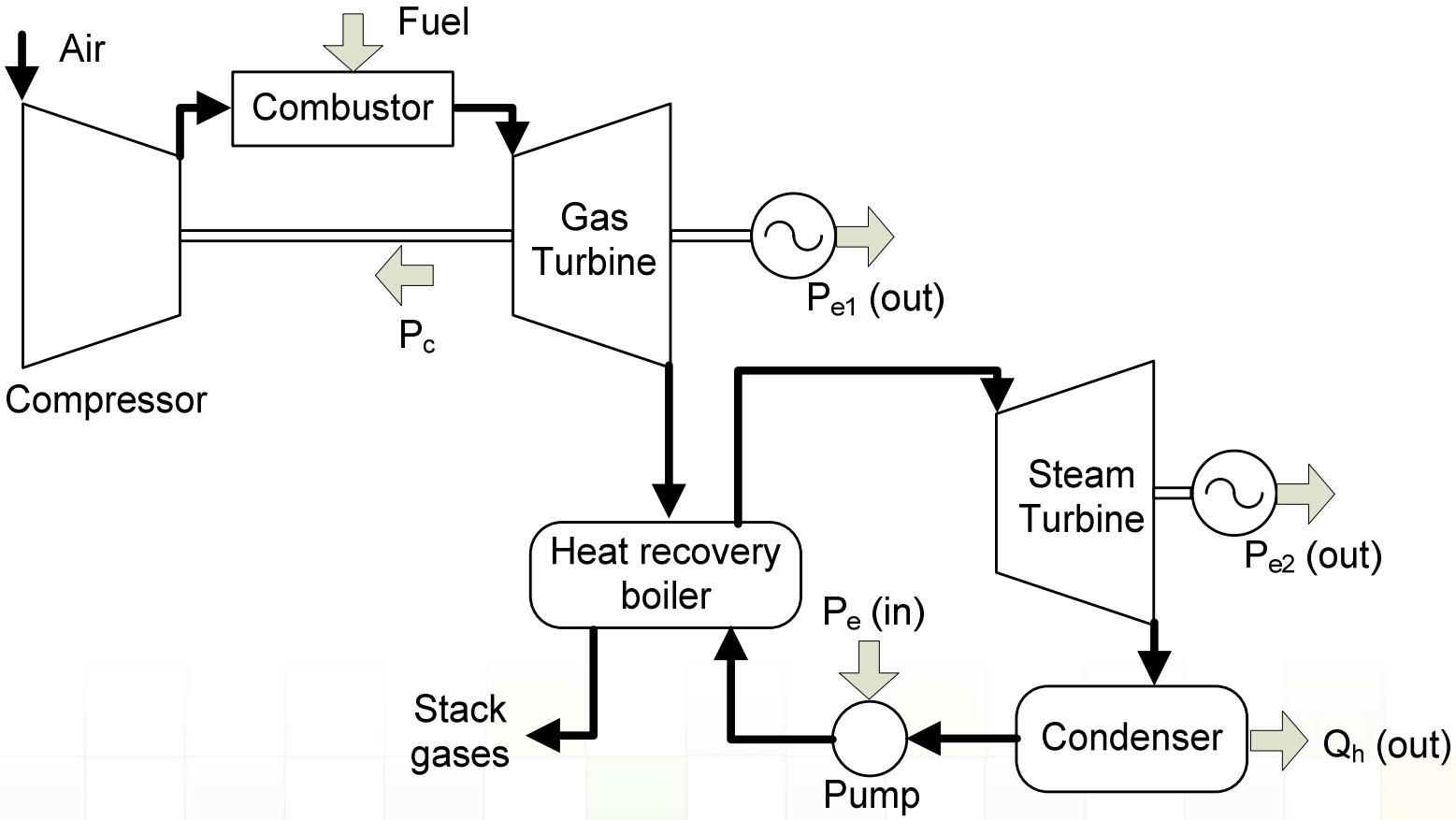


Figure 2.5 Combined cycle gas turbine

2.2 Combined Heat and Power plants

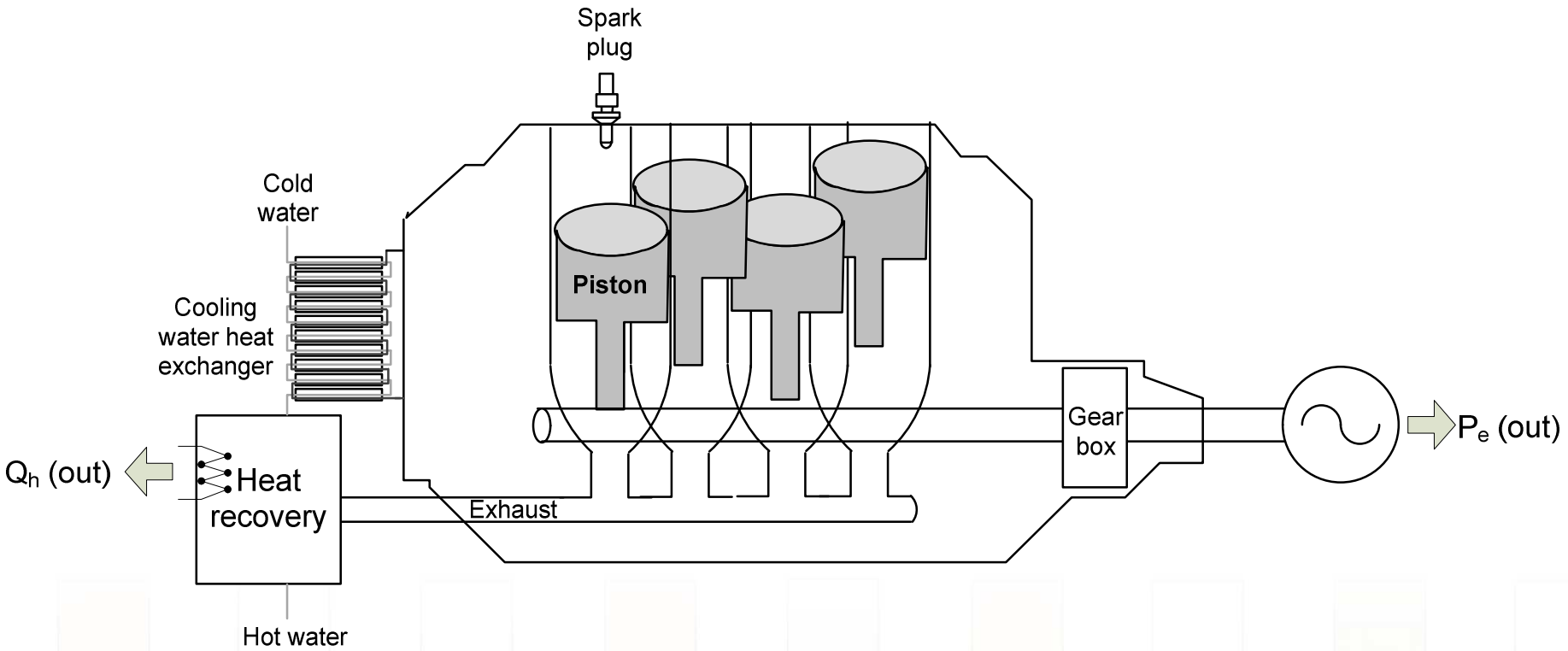


Figure 2.6 Components of an Otto engine based CHP unit

2.2 Combined Heat and Power plants

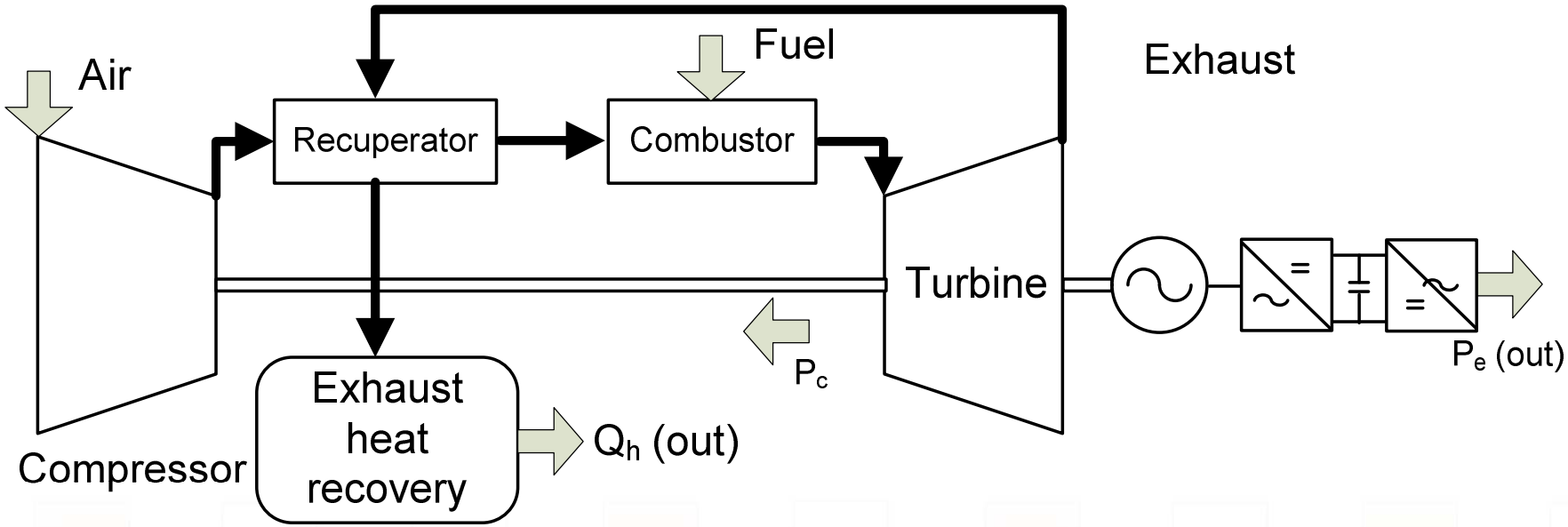


Figure 2.7 Components of an internal combustion based CHP unit

2.2 Combined Heat and Power plants

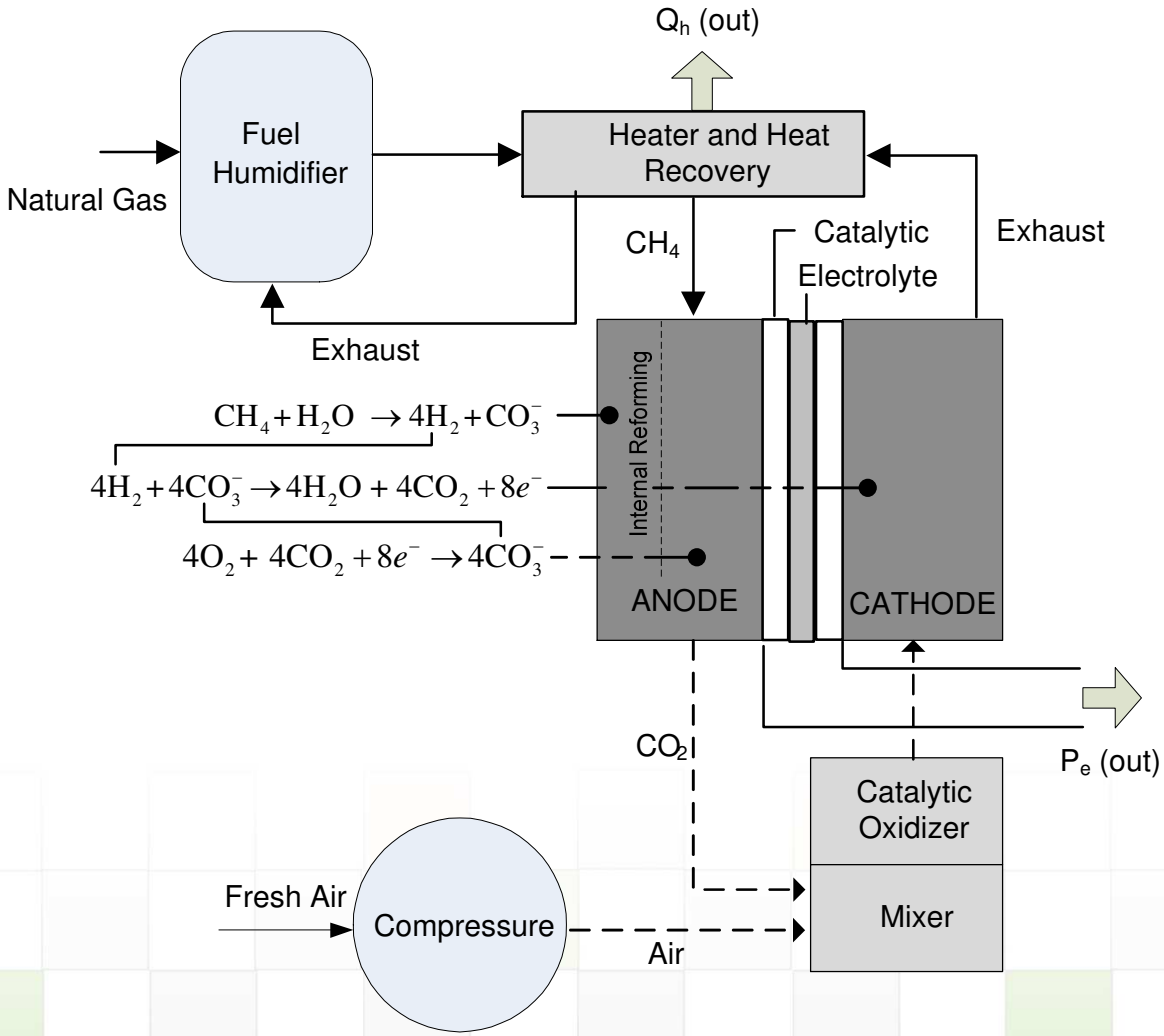


Figure 2.8 Fuel cell based CHP

2.3 Photovoltaic Energy Systems

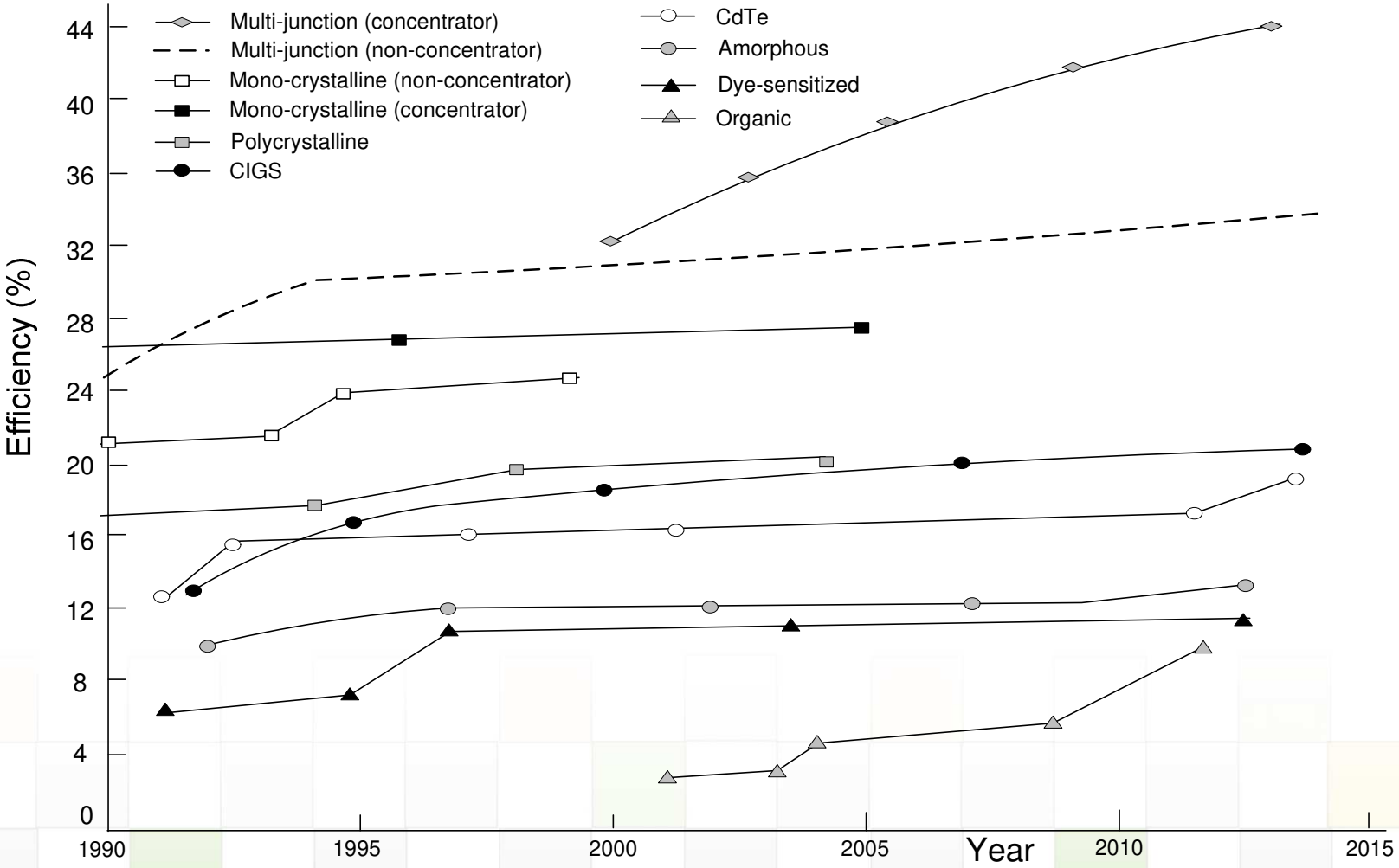
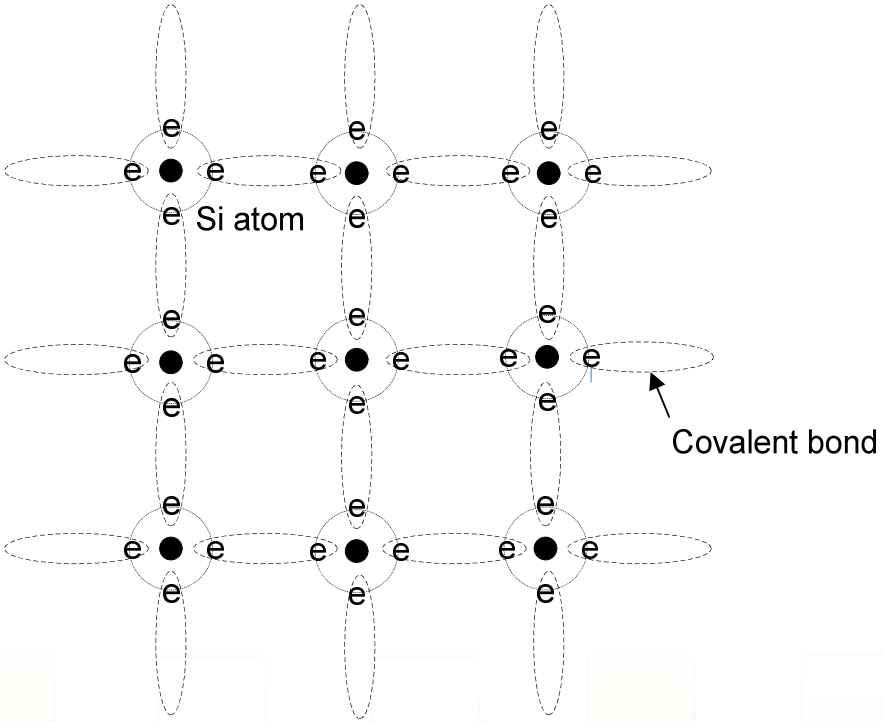
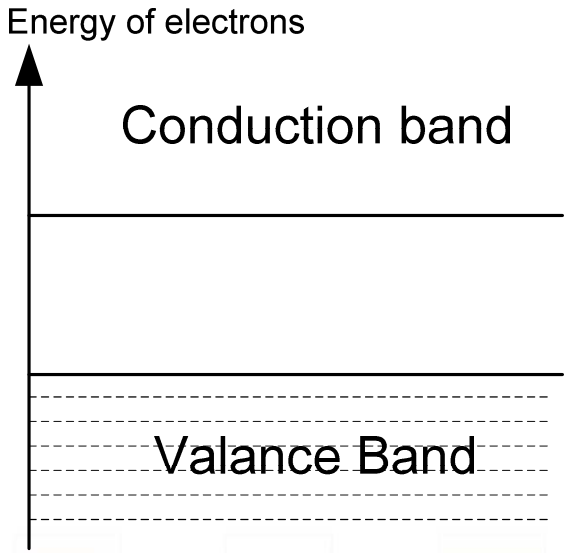


Figure 2.9 Trend lines of efficiencies of different PV technologies

2.3 Photovoltaic Energy Systems



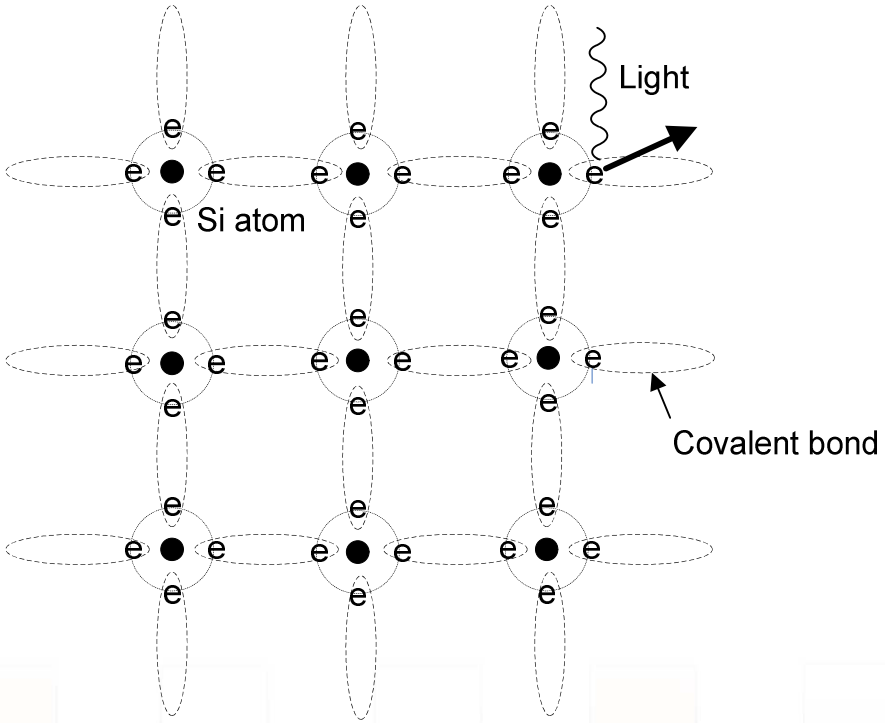
(a) Crystalline Si structure



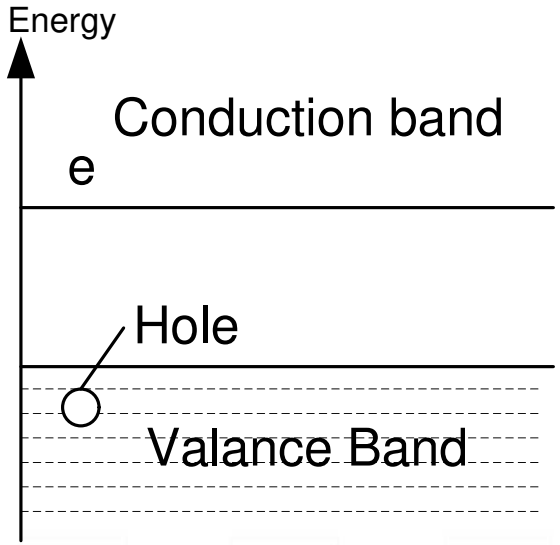
(b) Energy bands

Figure 2.10 Intrinsic Si at absolute zero temperature

2.3 Photovoltaic Energy Systems



(a) Crystalline Si structure



(b) Energy bands

Figure 2.11 Intrinsic Si at when exposed to light

2.3 Photovoltaic Energy Systems

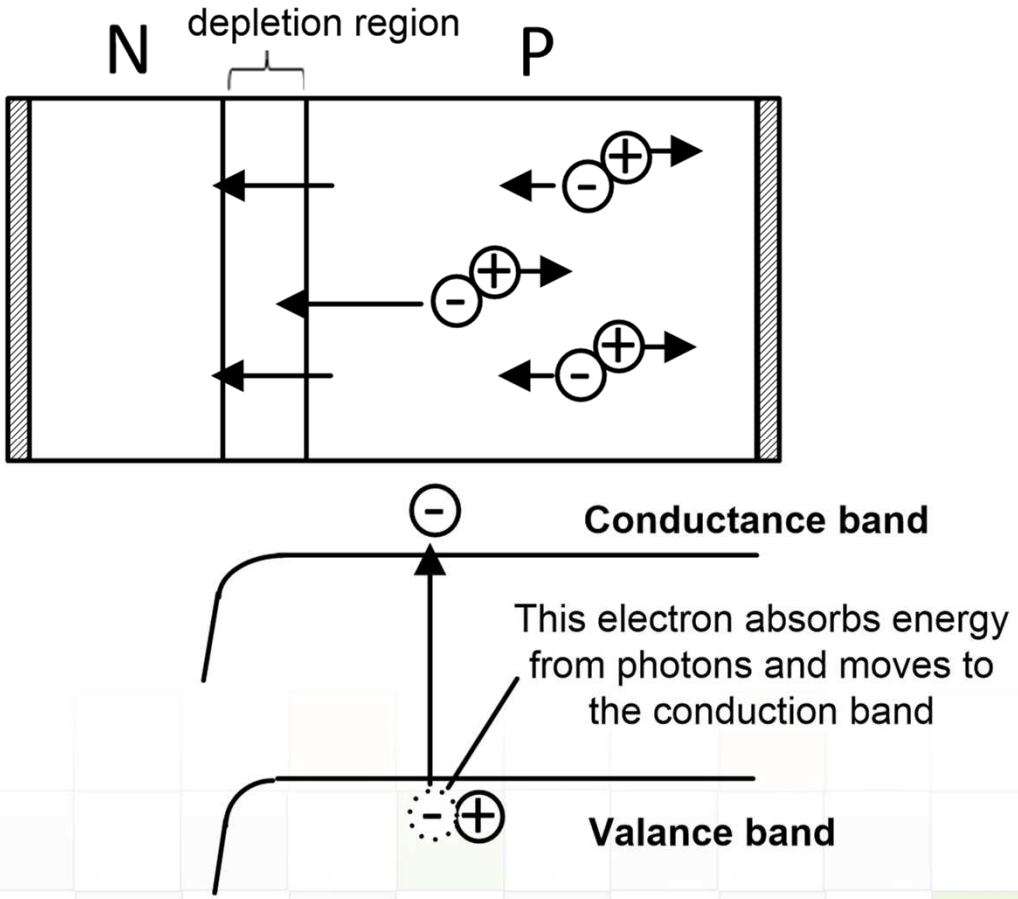


Figure 2.12 PN junction

2.3 Photovoltaic Energy Systems

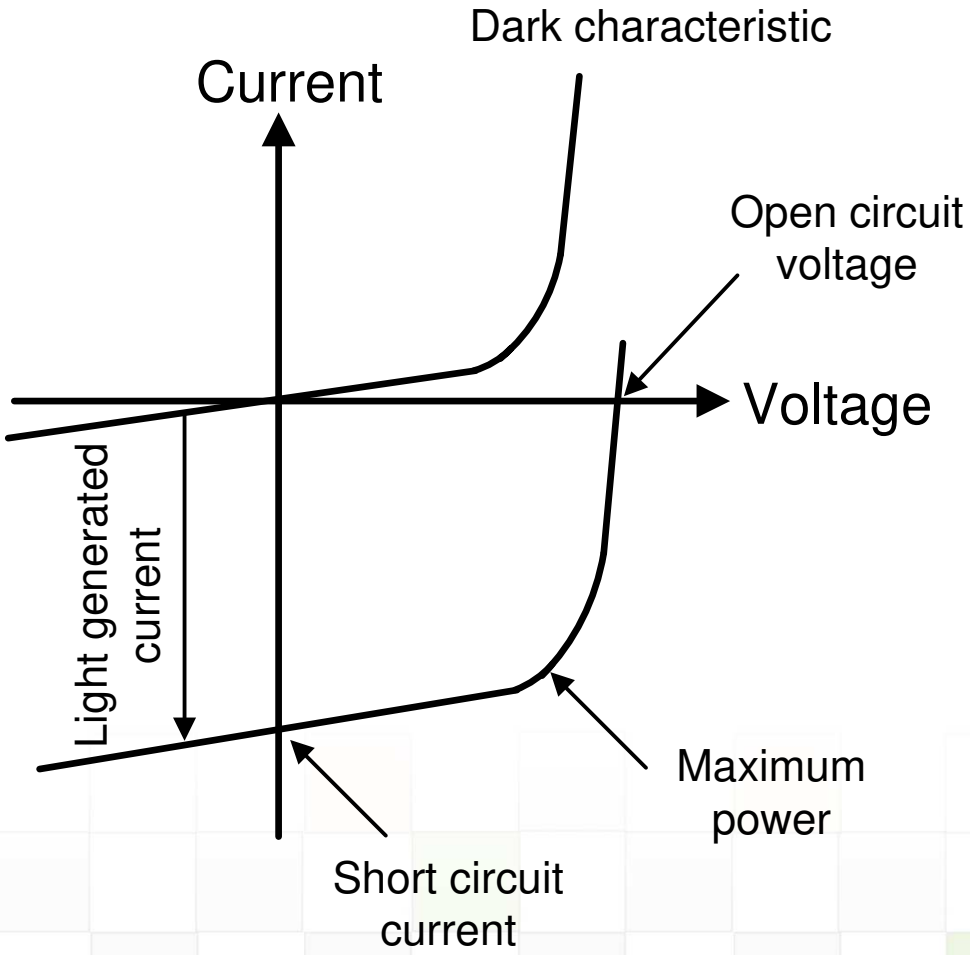


Figure 2.13 I-V characteristic

2.3 Photovoltaic Energy Systems

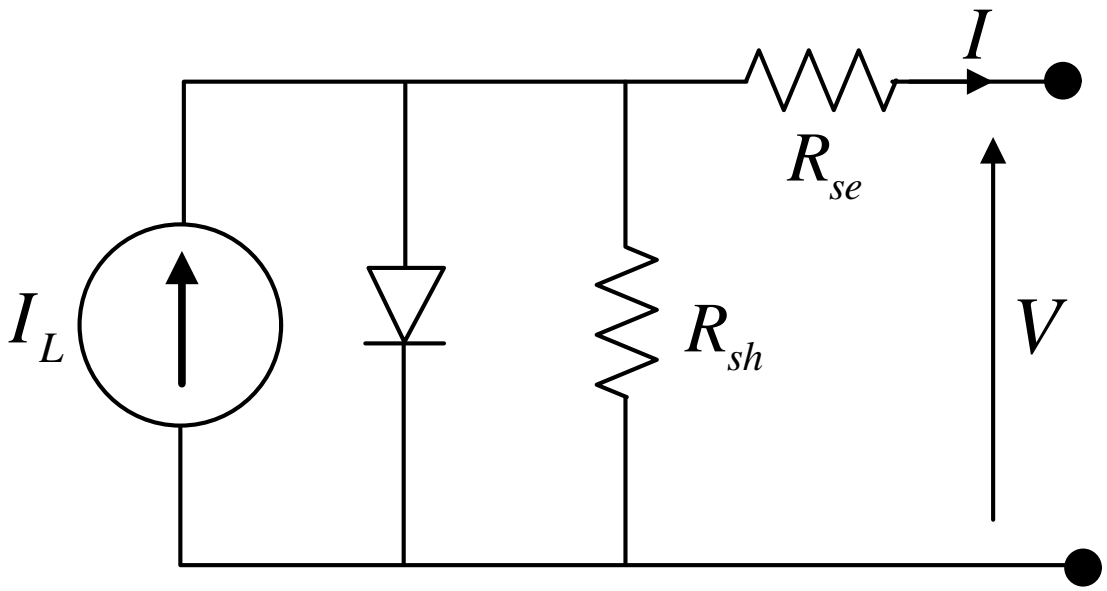


Figure 2.14 Equivalent circuit of a PV cell

2.3 Photovoltaic Energy Systems

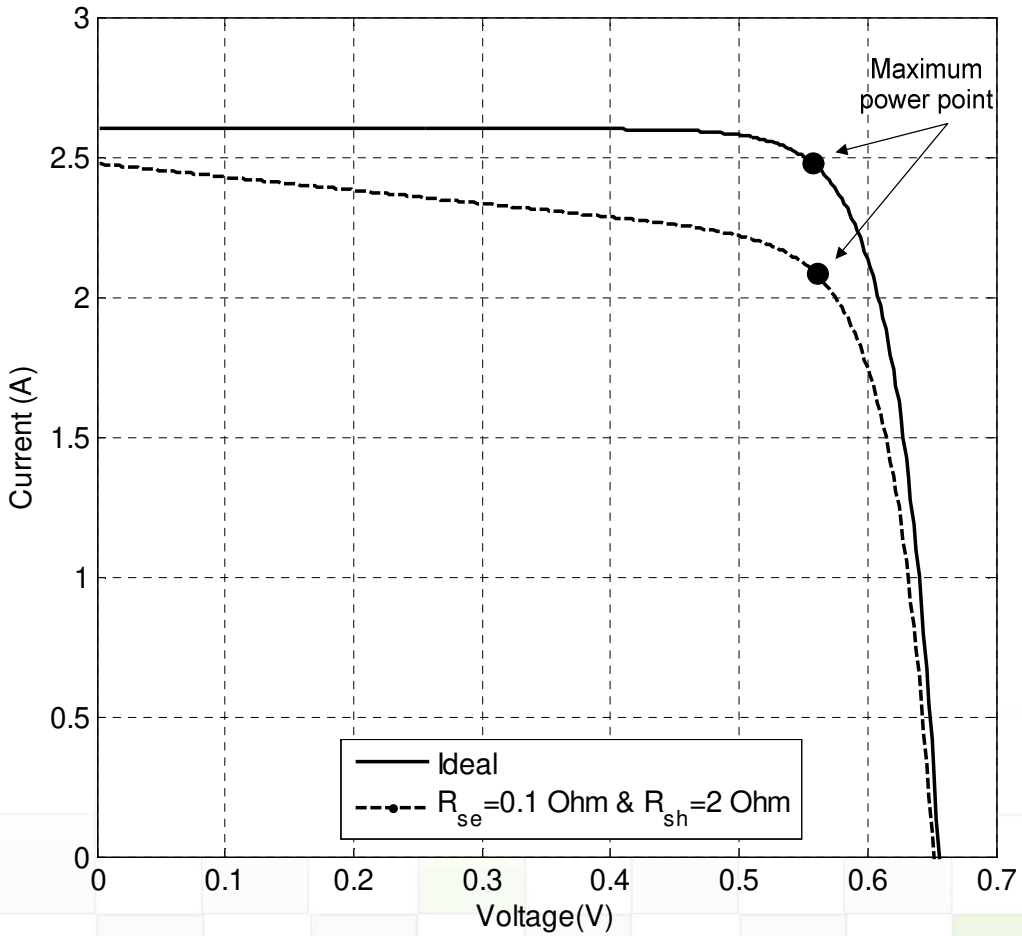


Figure 2.15 The effect of series and shunt resistance

2.3 Photovoltaic Energy Systems

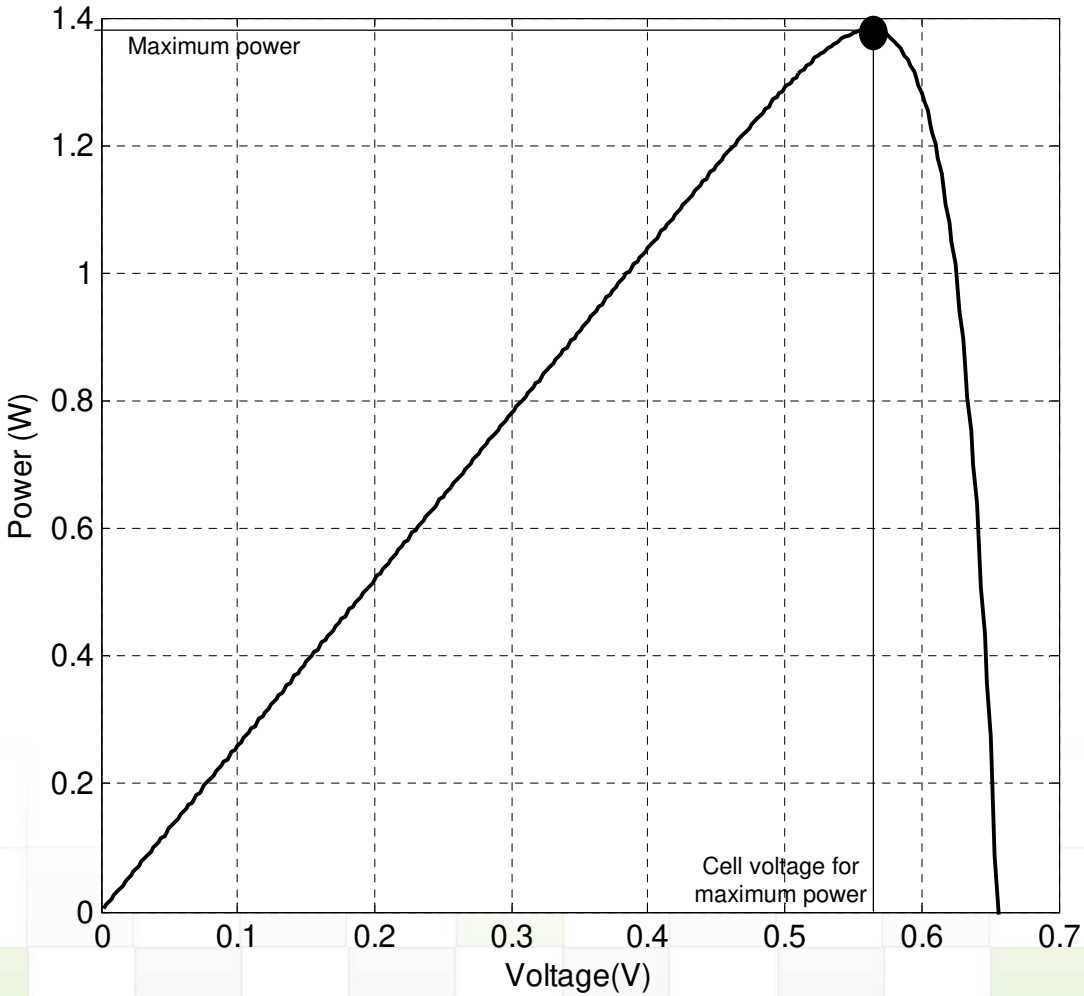
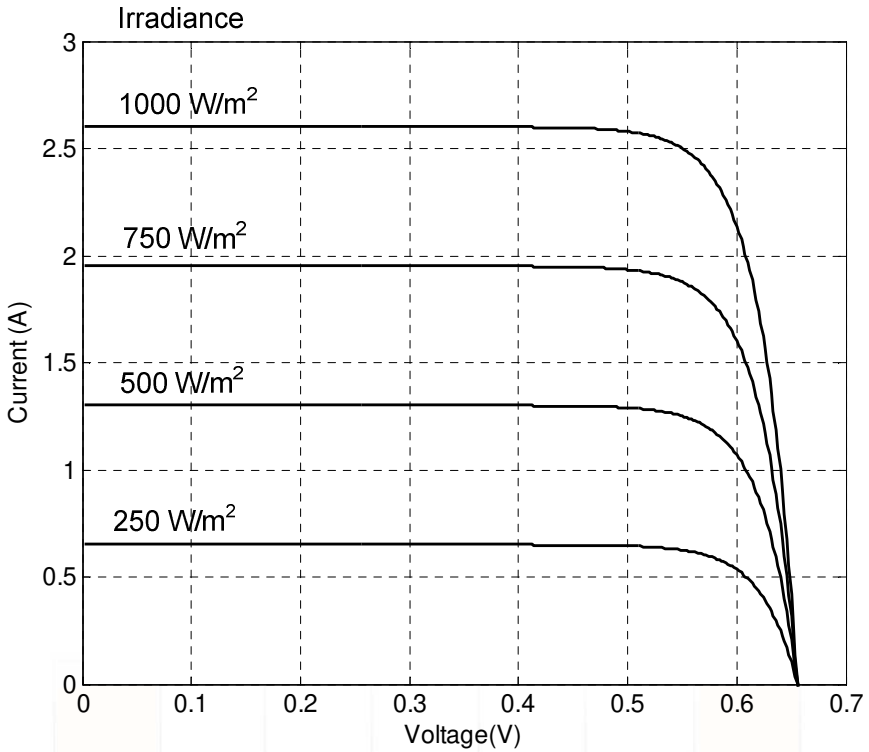
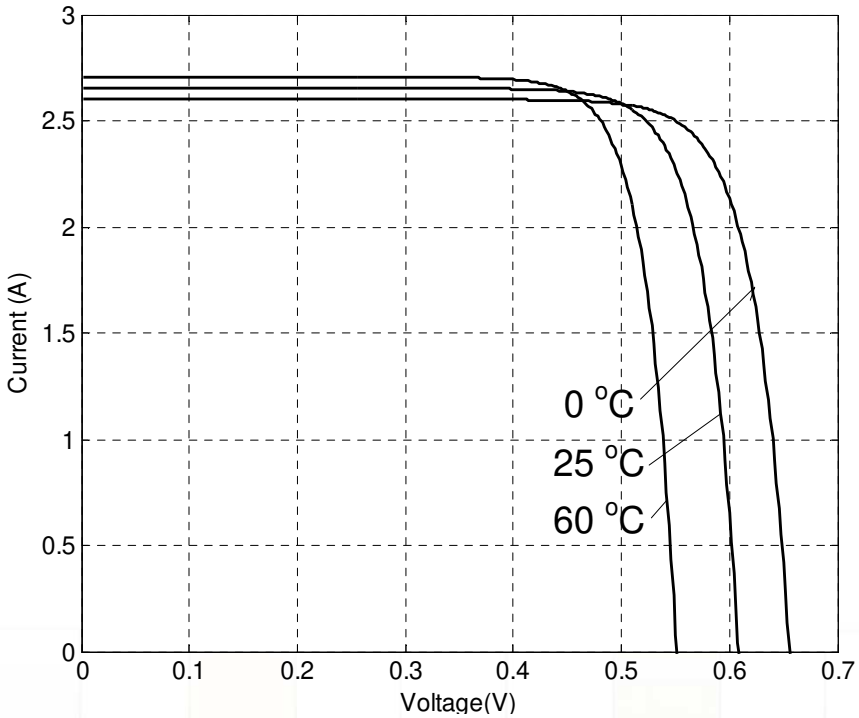


Figure 2.16 Power vs voltage characteristic

2.3 Photovoltaic Energy Systems



(a) Variation with irradiance



(b) Variation with cell temperature

Figure 2.17 The effect of series and shunt resistance

2.3 Photovoltaic Energy Systems

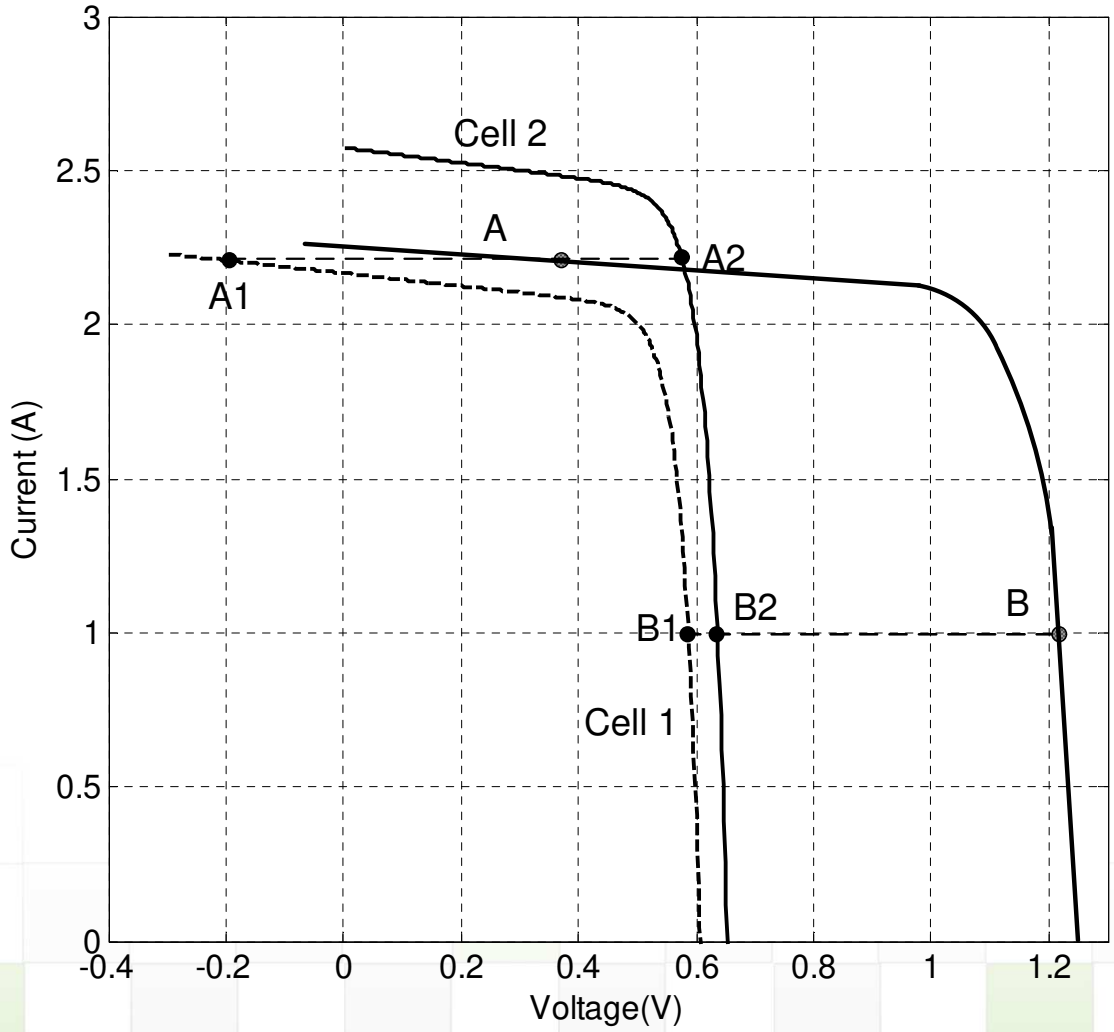


Figure 2.18 The effect of connection of non-identical PV cells in series

2.3 Photovoltaic Energy Systems

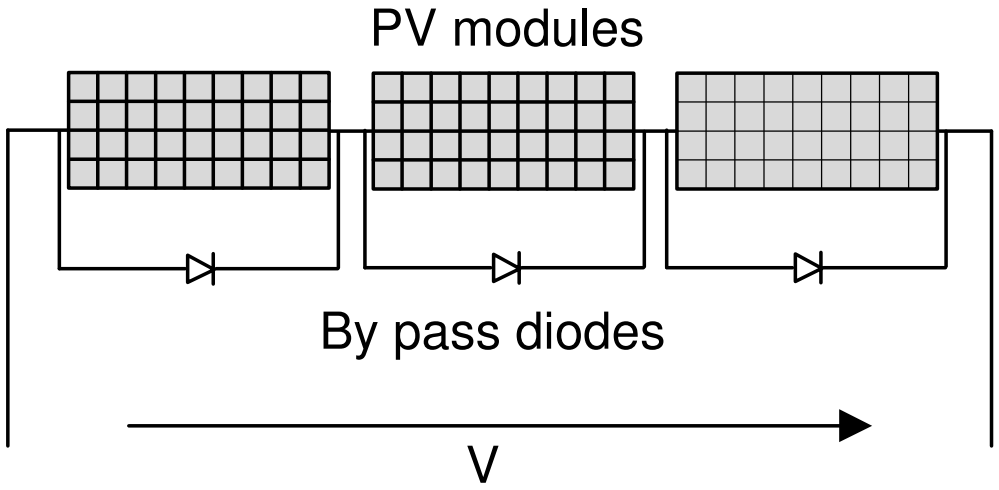


Figure 2.19 Connection of a string of PV modules

2.3 Photovoltaic Energy Systems

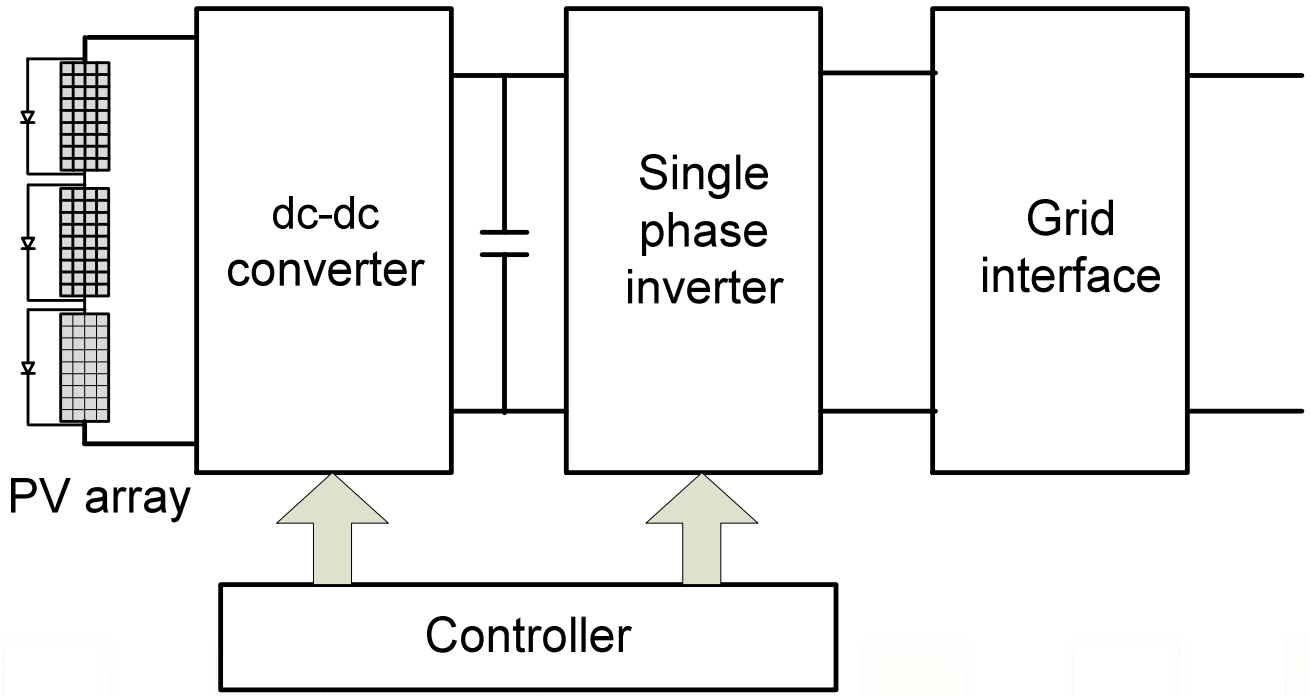


Figure 2.20 Grid connected PV arrays

2.3 Photovoltaic Energy Systems

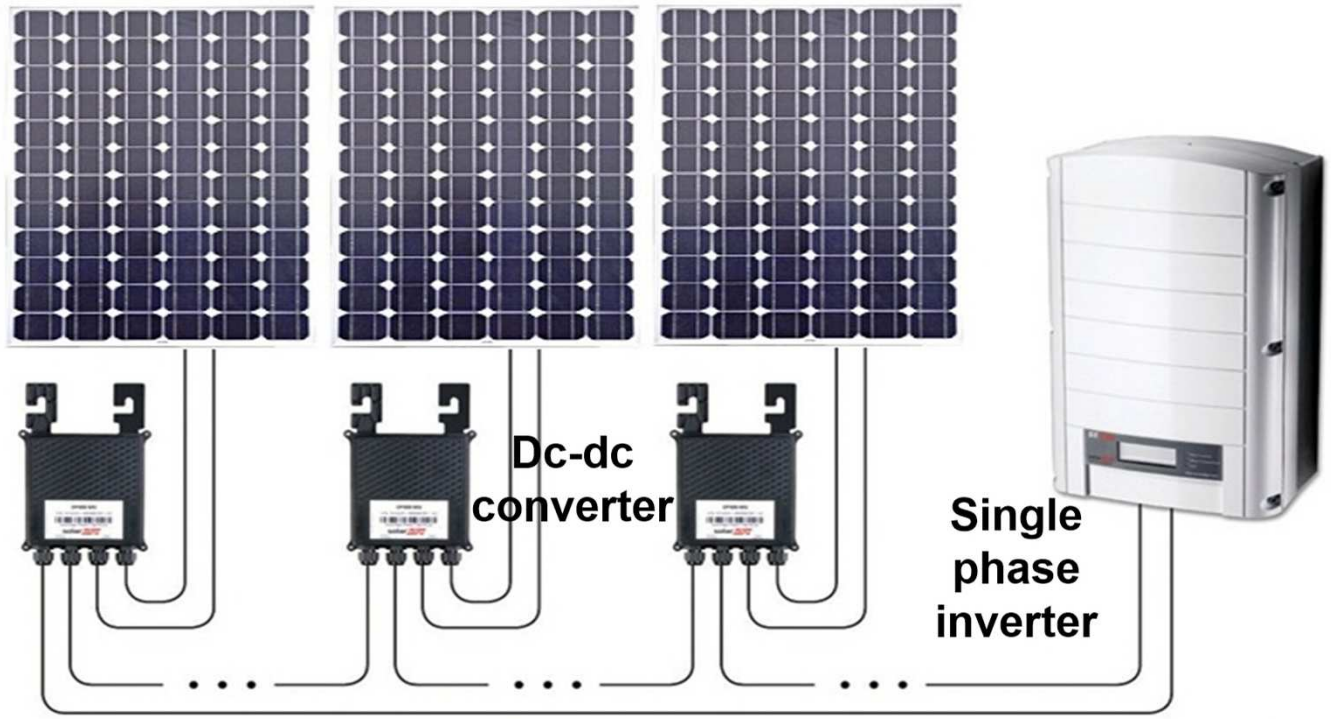


Figure 2.21 PV array with a single inverter and dc-dc converter for each module

2.3 Photovoltaic Energy Systems

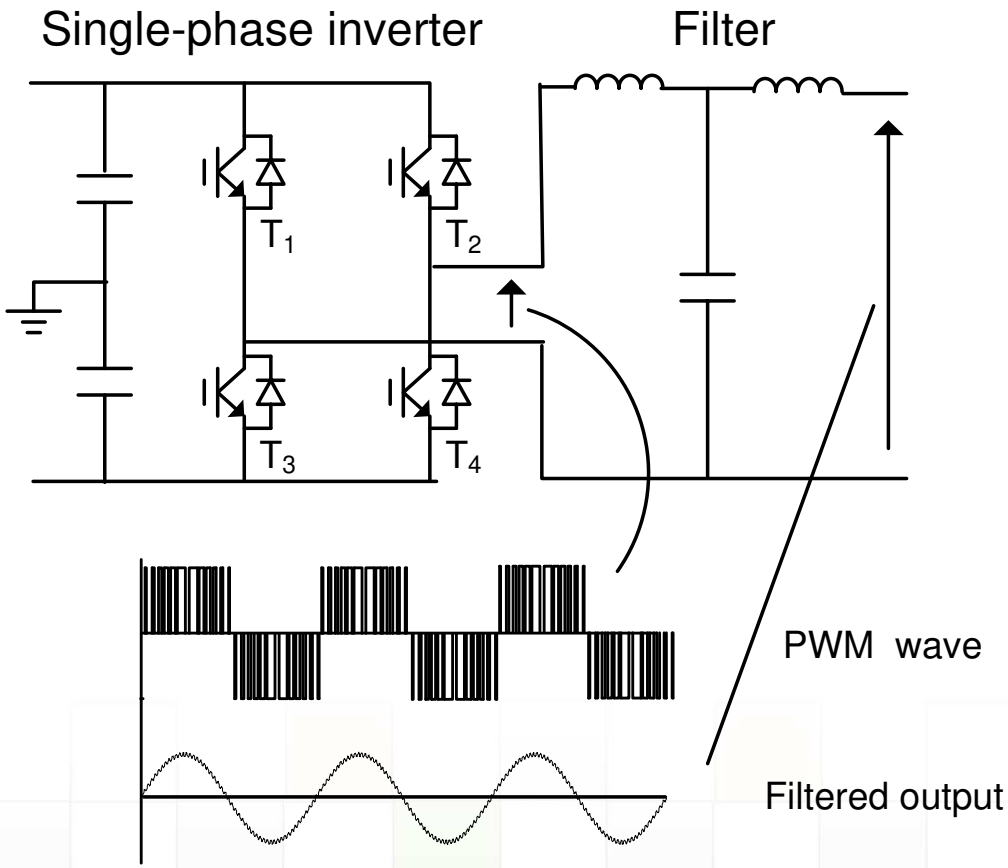
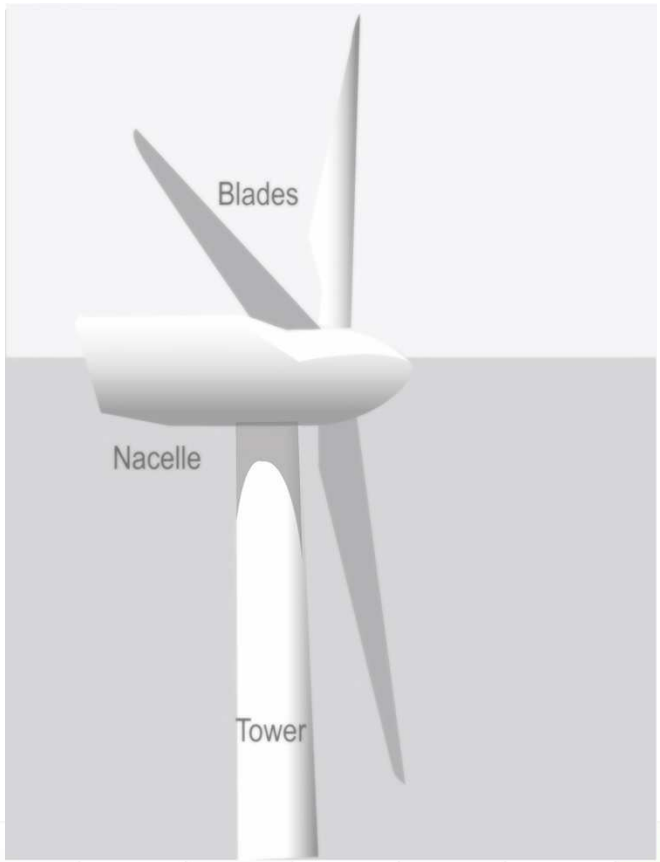


Figure 2.22 Single phase inverter

2.4 Wind Energy Systems



(a) Horizontal axis wind turbine (Courtesy of Wind Force (Pvt) Ltd)



(b) Vertical axis wind turbine

Figure 2.23 Vertical axis wind turbine

2.4 Wind Energy Systems

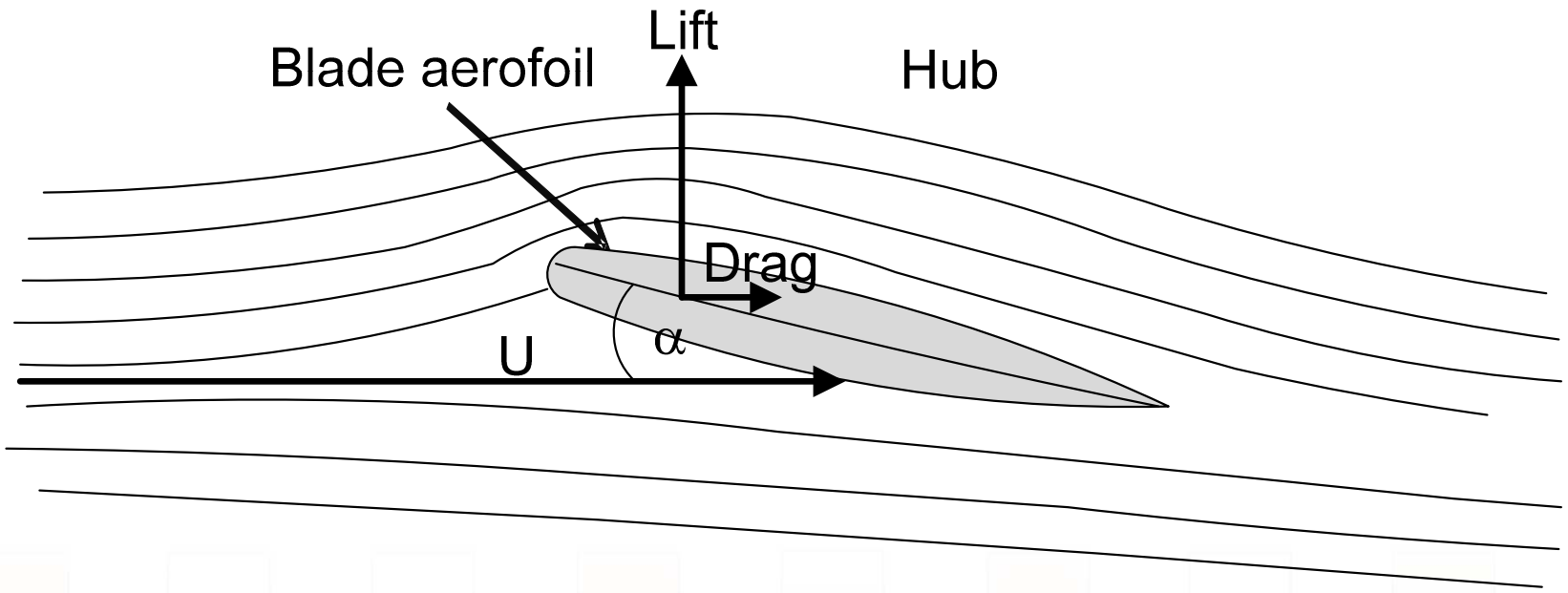


Figure 2.24 Flow of air past an aerofoil

2.4 Wind Energy Systems

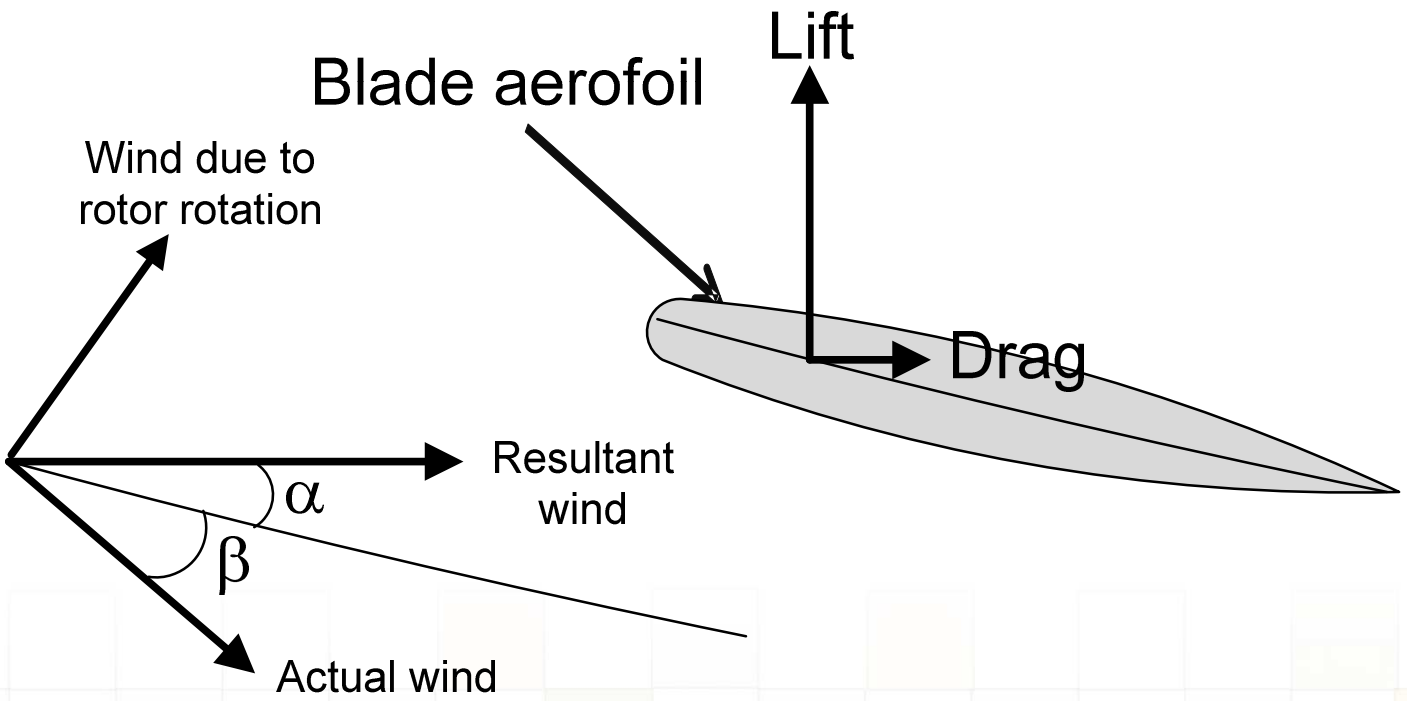


Figure 2.25 Relative wind

2.4 Wind Energy Systems

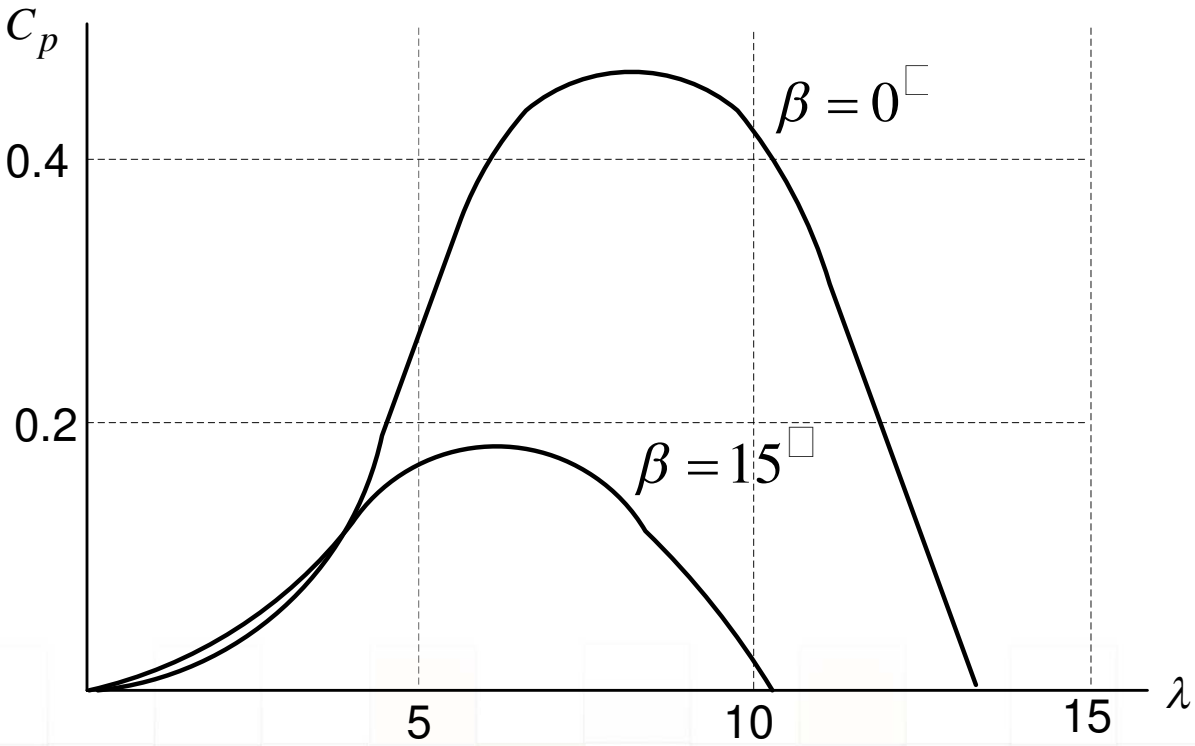


Figure 2.26 Variation of power coefficient with α and β

2.4 Wind Energy Systems

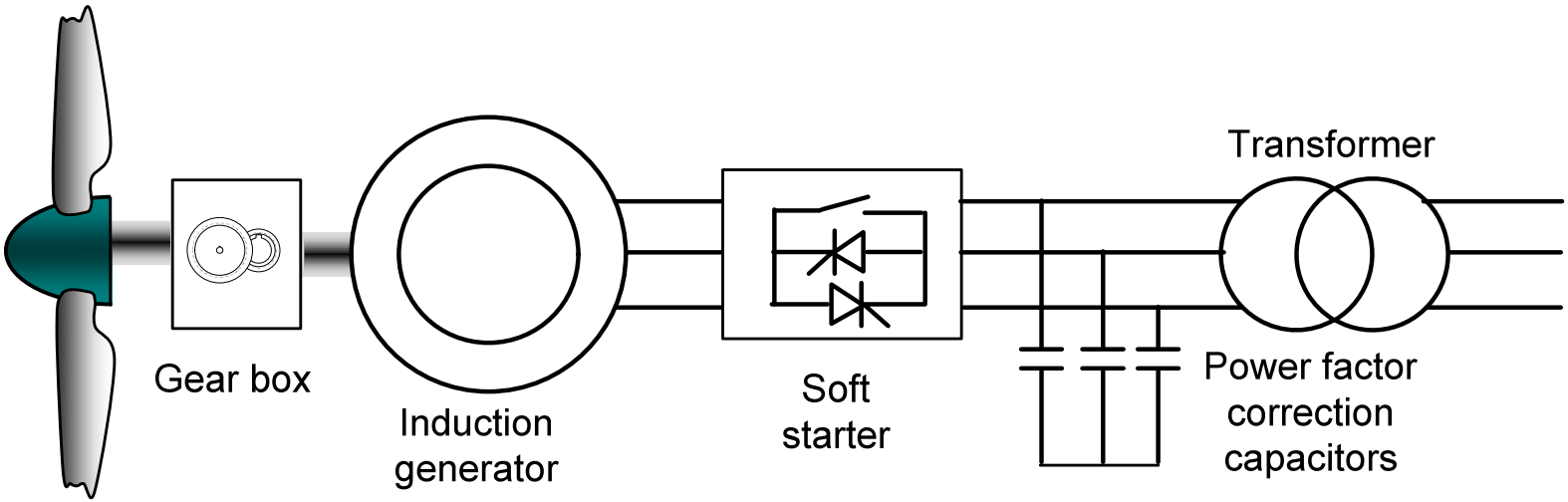


Figure 2.27 Component of a fixed speed wind turbine

2.4 Wind Energy Systems

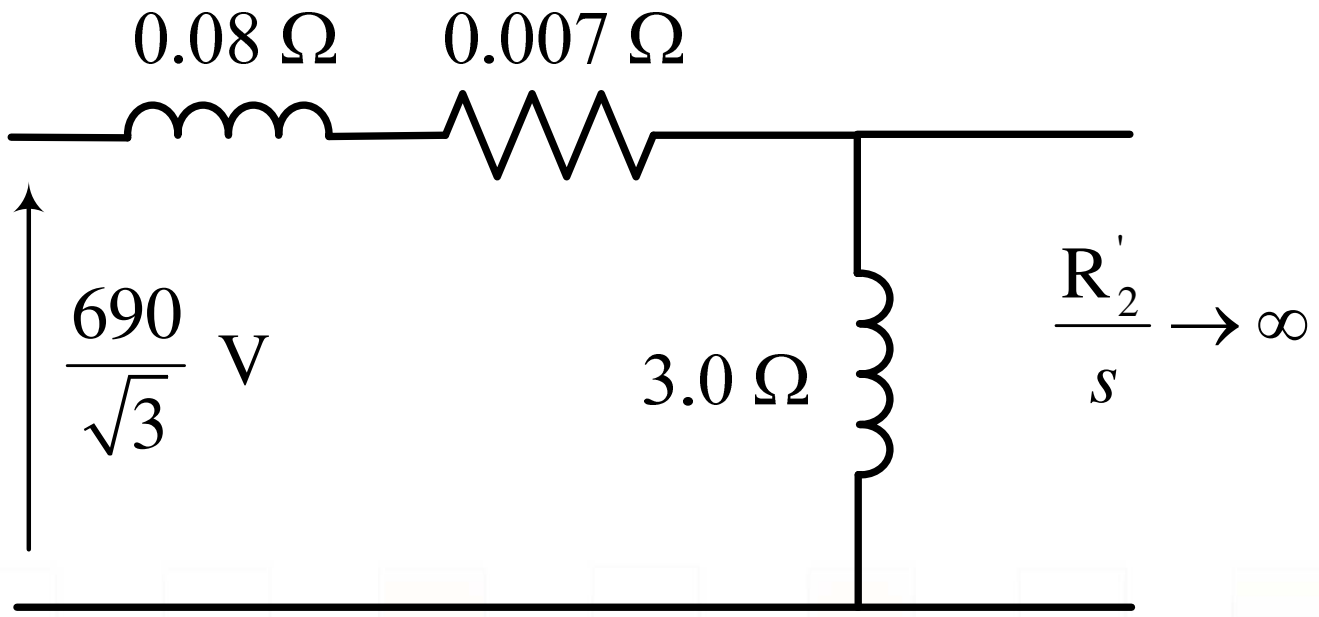


Figure 2.28 No-load equivalent circuit of the induction generator

2.4 Wind Energy Systems

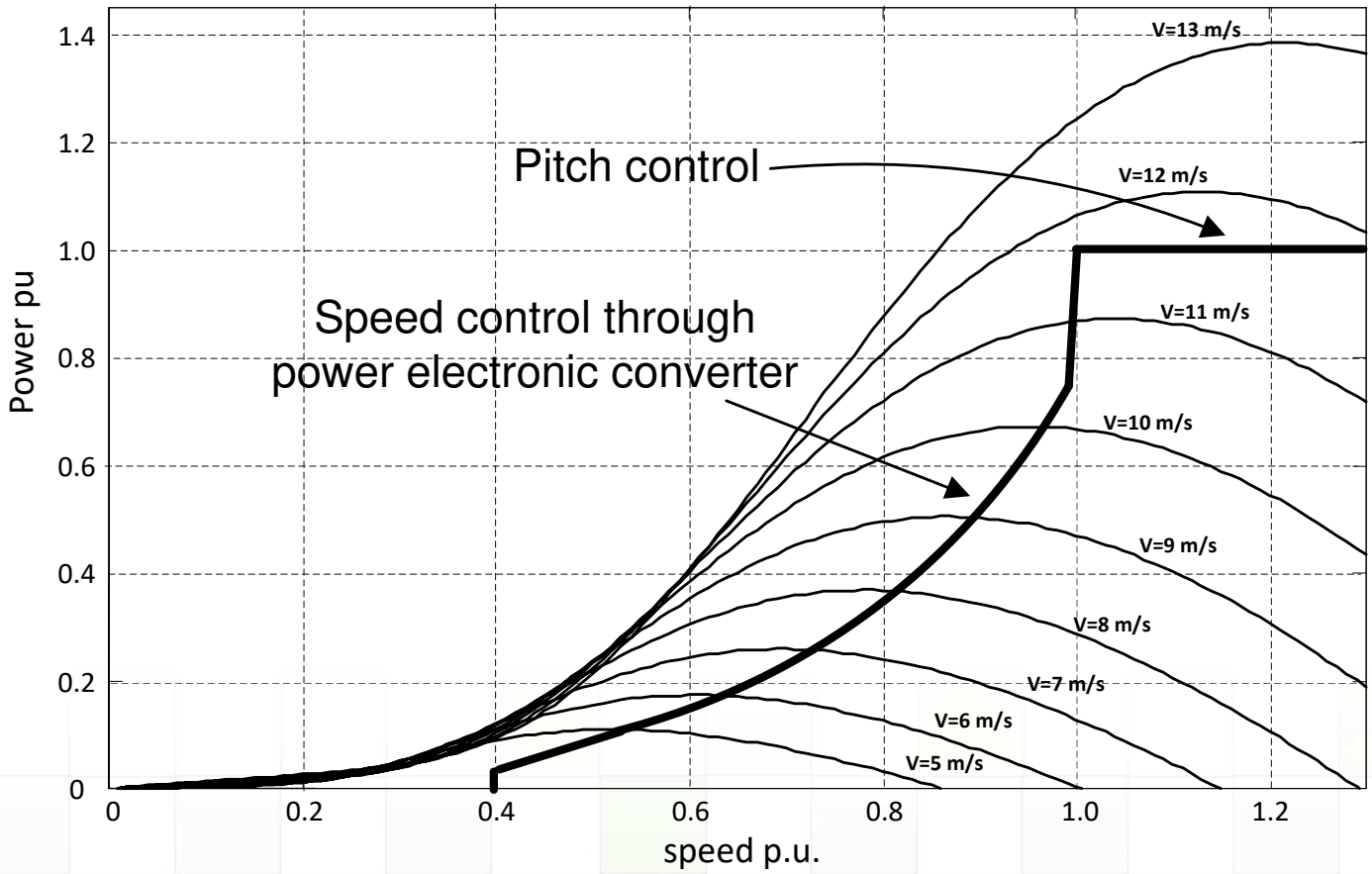


Figure 2.29 Operation of a variable speed wind turbine

2.4 Wind Energy Systems

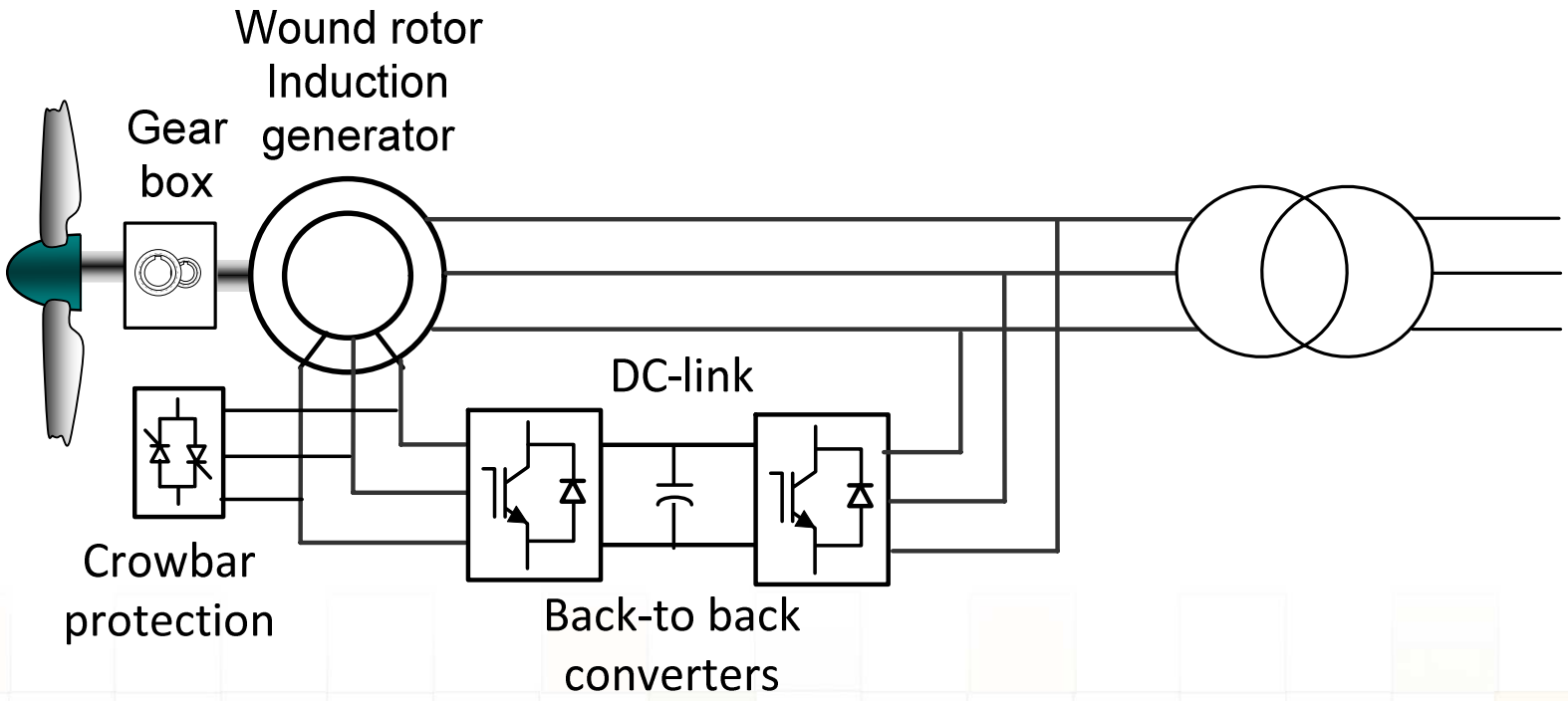


Figure 2.30 DFIG wind turbine

2.4 Wind Energy Systems

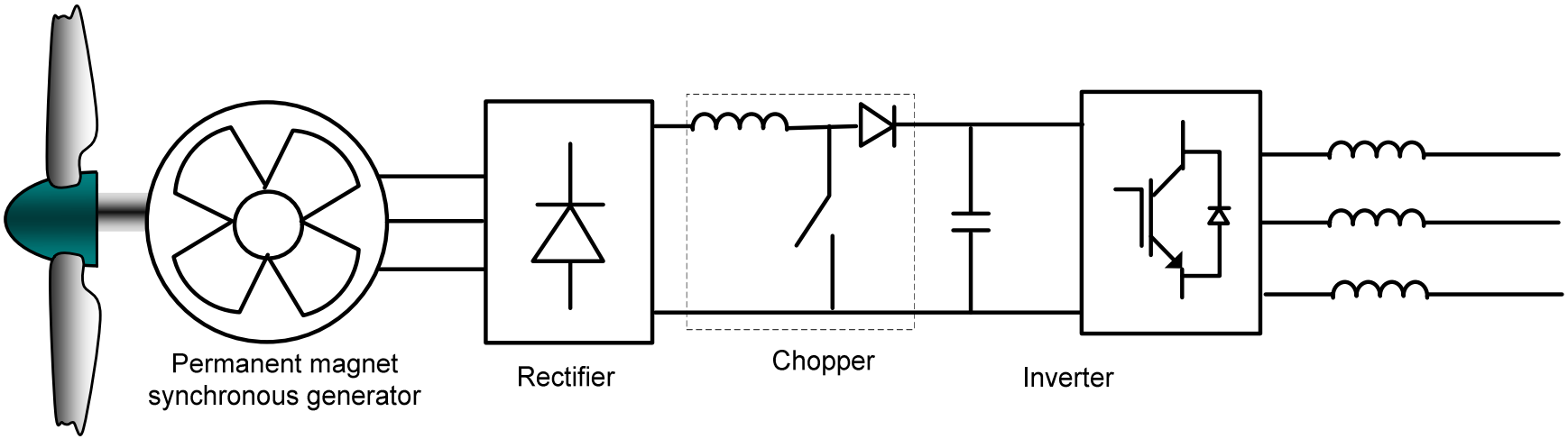


Figure 2.31 Gearless FSFC wind turbine with a diode rectifier

2.4 Wind Energy Systems

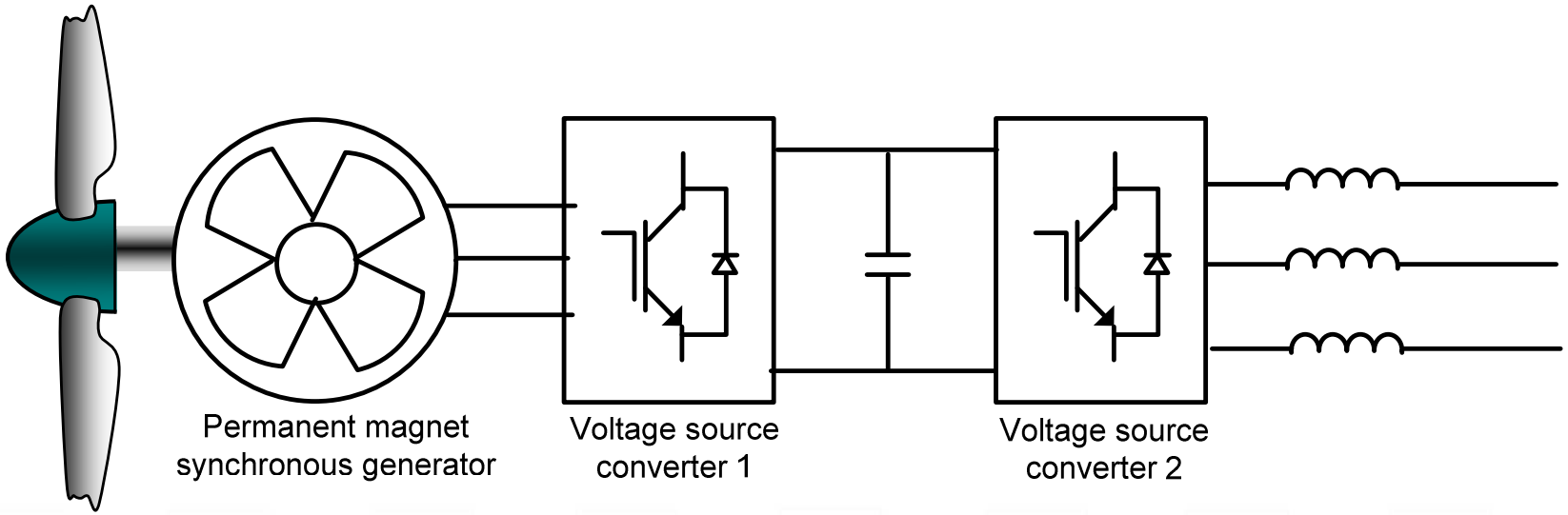


Figure 2.32 Gearless FCFS wind turbine with back-to-back converters

2.5 Electrical Energy Storage

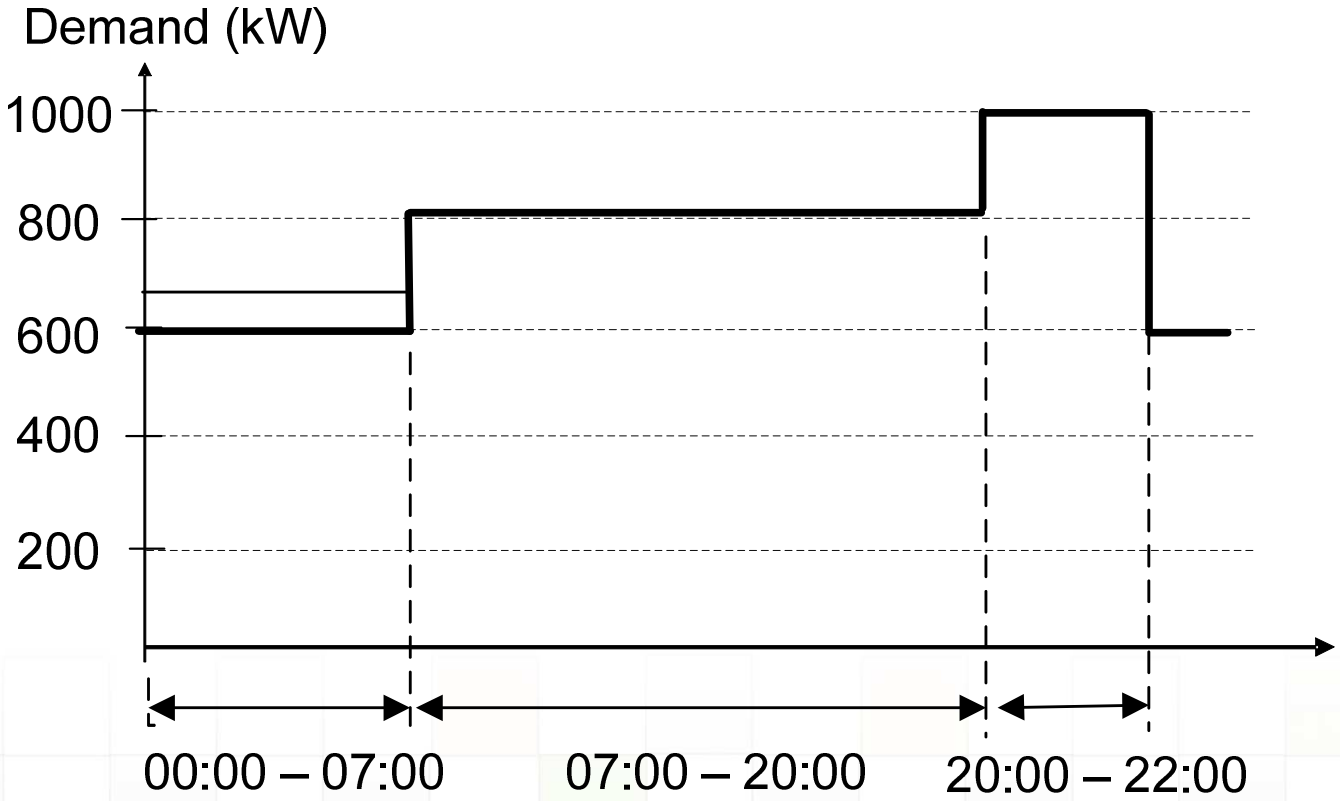


Figure 2.33 Demand profile

2.5 Electrical Energy Storage

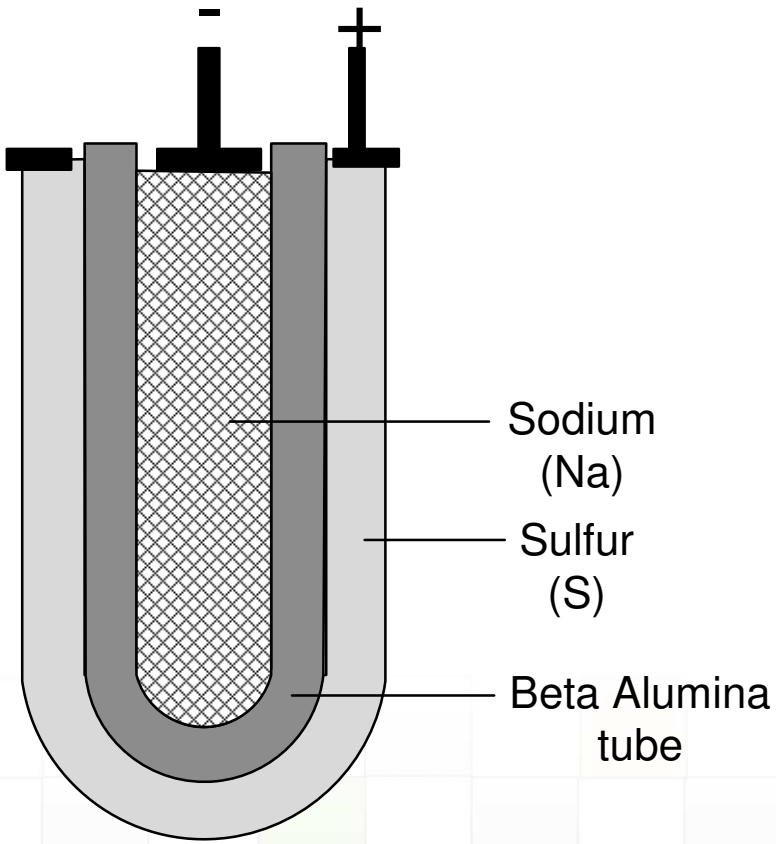


Figure 2.34 NaS battery

2.5 Electrical Energy Storage

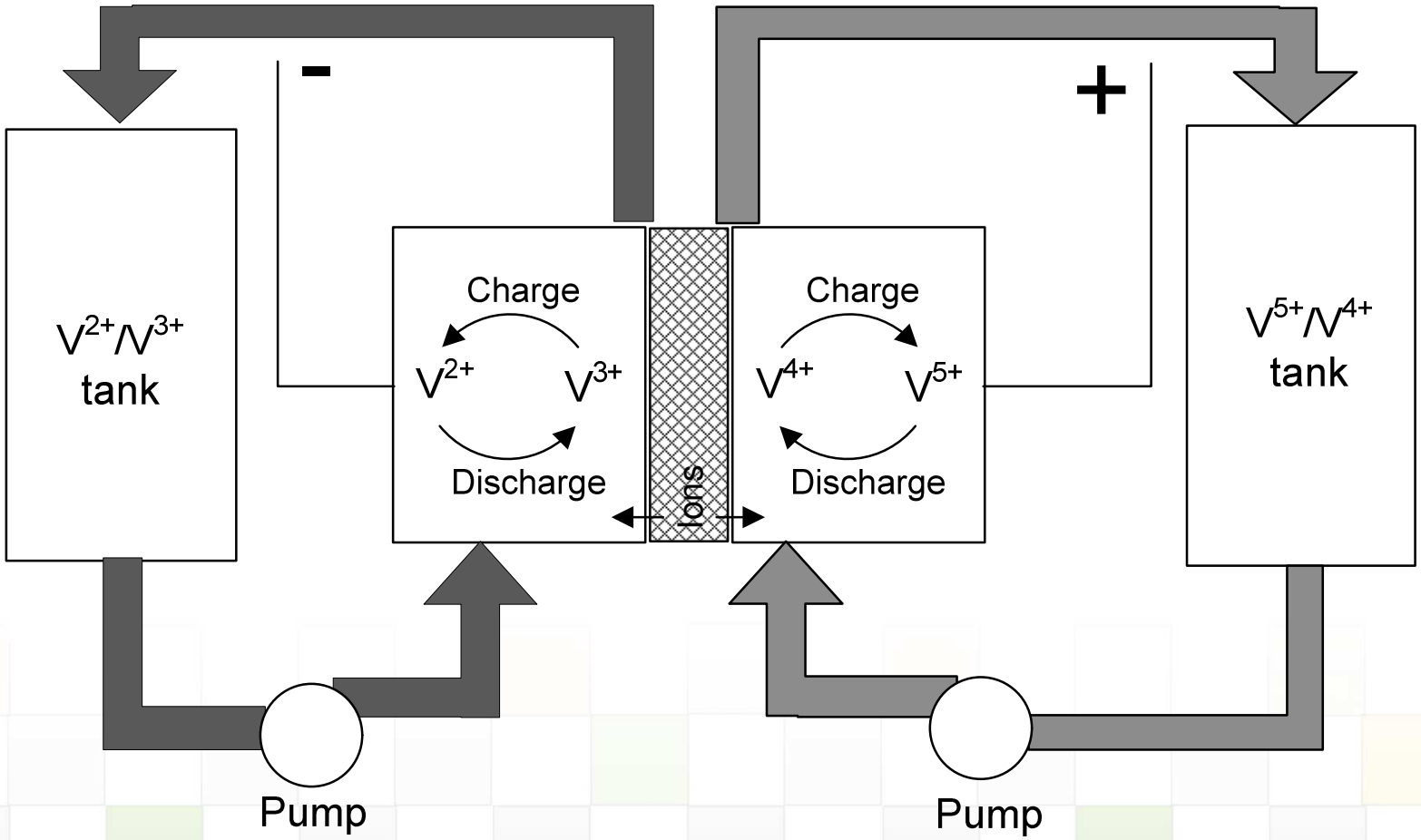


Figure 2.35 VRB flow battery system

2.6 Flexible Demand

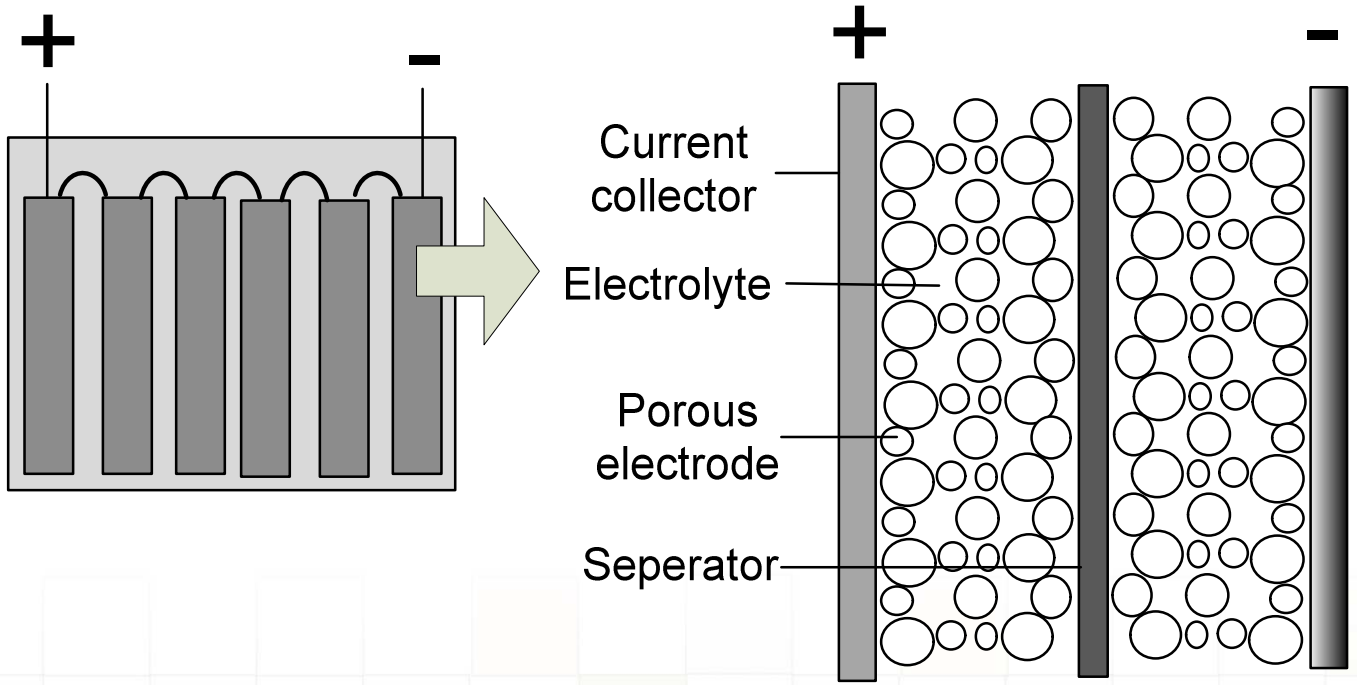


Figure 2.36 Ultra-capacitor module and cell



Thank You!

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