Chapter 2

Fundamentals of Distributed Energy Resources

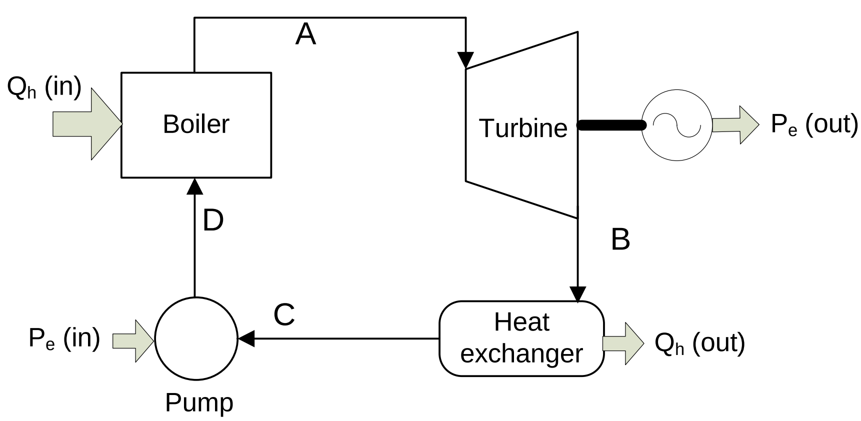
Question 2.1. List and explain the advantages and disadvantages of variable speed operation of large wind generators both for the wind turbine and the power system.

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

Gross power output

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

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?

Solutions:

a) ω_s = 120f/p = 120 x 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 x P_1 x 8760 + 0.2 x P_2 x 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

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

$2\text{x}10^6$ = 0.5 x 0.4 x 1.225 x π x 100^2 x U^3

U = 6.38 m/s