Energy Resources and Policy

Tutorial:
Wind power

1. The Betz analysis for wind turbines specifies three velocities in the flow domain: V_∞ well upstream, V in the plane of the rotor and V_e in the wake, far downstream. It can be shown that

$$V = \frac{V_\infty + V_e}{2}.$$

By making the substitution $V = V_\infty(1 - a)$, obtain an expression for the power produced by the turbine in terms of V_∞ and a.

[$2\rho A V_\infty^3 (1 - a)^2 . a$]

A wind turbine is proposed which reaches its rated power with a value of a (averaged over the rotor) of 0.3. What (according to the Betz theory) would be the value of the power coefficient for this condition?

[0.588]

The cut-out wind speed for the turbine is twice the rated wind speed. Power should ideally be maintained constant between cut-out and rated speeds. Estimate (by trial and error) the 2 values of a which would give rated power output at the cut-out speed. State, giving reasons, which of these is preferable.

[0.019; 0.853]

2. A survey at a proposed wind turbine site gave a velocity exceedence curve (a plot of wind velocity V_∞ against number of days T) of the form shown in Figure Q2. The central portion of the curve is described by the equation

$$V_\infty T^n = C$$

where n and C are numerical constants.

Specific points on the curve are (V_∞ = 11 m/s, T = 106 days) and (V_∞ = 4 m/s, T = 268 days). The proposed wind turbine has a rotor of 15 m diameter, and its cut-in, rated and cut-out wind speeds are 4 m/s, 11 m/s and 22 m/s respectively. Wind speed exceeds 22 m/s for 17 days in the year. If turbine power coefficient between cut-in and rated conditions is constant at 0.42, and the air density is 1.25 kg/m^3, calculate

(a) the turbine's rated power output;
(b) the total energy in kWh delivered in one year; and
(c) the turbine's capacity coefficient, based on a full year of operation.

[61.74 kW; $192.6 x 10^3$ kWh, 0.356]

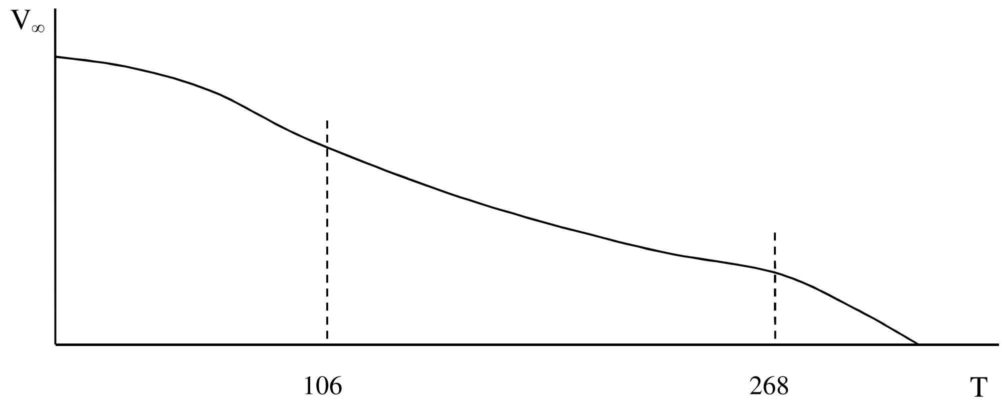

Figure Q2

3. The estimated capital cost of the turbine featured in Q2, including the foundations and electrical connections, is £50,000. If this money is borrowed from a bank, the annual repayment required is given by the formula

$$\frac{C\, r\, (1 + r)^n}{(1 + r)^n - 1}$$

Where C is the value of the capital loan, n the number of years to complete the repayment, and r the rate of interest on the loan.

Assuming annual maintenance costs of 4% of the capital cost of the turbine, calculate the cost of energy production, in pence per kWh. Use n = 15 years and r = 8%.

[4.07]

4. An alternative version of the turbine has its rated power increased by 30%, by raising the rated wind speed. Its peak power coefficient remains at 0.42, and it has a capital cost of £60,000. Comparing this with the original design, what would happen to
   (a) the total energy capture per year;
   (b) the capacity coefficient; and
   (c) the cost of energy production?

[(a) 230.10^3 kWh, a rise of 19.4%; (b) falls to 0.327; (c) rises to 4.09 p/kWh]