Tampere University of Technology
Electrical Engineering

Wind Power Systems DEE-54107 20.12. 2017

Enrique Acha Programmable calculator allowed 5 questions/ á 6 p

Question 1:

A) State three different types of information contained in a wind rose. (1p)

B) Sketch a typical characteristic of power coefficient versus wind speed for a practical wind turbine, labelling all its relevant points, e.g., cut-in wind speed. (1p)

C) Draw the output power-wind speed characteristic of a wind turbine and label all its relevant parts. (1p)

D) Sketch a family of characteristics of the power output (P_T) of a wind turbine versus rotational speed of the shaft turbine (ω_r), for three wind speeds (say $V_3>V_2>V_1$). (1p)

E) Describe how the power take-up may be controlled in a fixed-speed 1.5 MW wind turbine. (1p)

F) Describe briefly the role of the gearbox in a commercial 5 MW variable speed wind turbine using a Fully Rated Converter, Permanent Magnet Synchronous Generator (FRC-PMSG). (1p)

Question 2:

A) Discuss briefly the advantages and disadvantages of offshore wind farms compared to onshore wind farms. (2p)

B) Explain the term *array loss* in connection with a wind farm. (1p)

C) Consider the layout of an offshore wind farm with 16 turbines with the disposition shown in Figure 1. Each turbine is rated at $P_R = 6$ MW. The rotor diameter D of each turbine is 126 m. The turbine hub height is 135 m. The wake decay coefficient κ is 0.037251.

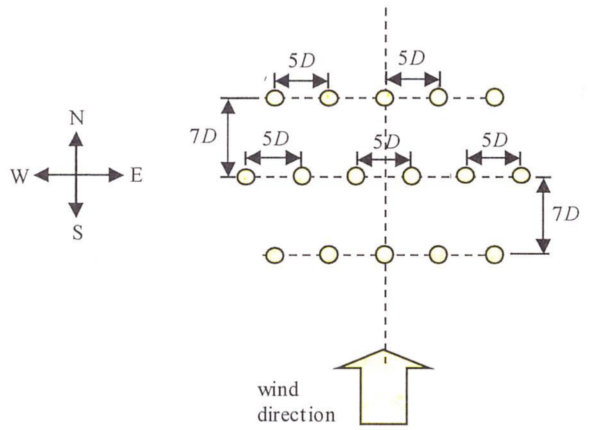

Figure 1

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The wind speed V_{wi} at the *i*-th turbine in the row may be determined using the following empirical equation (notice that the front row is row zero):

$$V_{wi} = V_w \cdot \left(1 - \left(1 - \sqrt{1 - C_F}\right) \cdot \left(D/(D + 2\kappa \cdot d2)\right)^2\right)^i$$

Assume that the wind speed reaching the first row of turbines is 10 m/s, the torque coefficient C_F is 8/9 and d_2=7*D* is the vertical distance between adjacent rows of turbines. The power output of the turbine is represented by the following analytical expression between the cut in and cut out wind speeds:

$$P_T = 3743 \times V_w^3 - 0.077977 \times P_R$$

The cut-in wind speed is 5 m/s and the rated speed is 12 m/s. Determine: (a) the wind speed that reaches each turbine in the wind farm for the case when the prevailing wind is from the South, as indicated by the thick arrows in Figure 1; (b) the total power output of the wind farm. (3p)

Question 3:

A) State the main differences, in terms of connection to the AC system, between a doubly fed induction generator (DFIG) and a FRC PM synchronous generator when used in a wind turbine application. What advantages does the former generator have over the latter? (2p)

B) State briefly the main construction differences that exist between a three-phase PM synchronous generator and a conventional three-phase synchronous generator. (2p)

C) Sketch the power-angle characteristic of a PM synchronous generator of the type used in wind power applications. (2p)

Question 4:

A) Sketch the per-phase equivalent circuits of a three-phase, doubly fed induction generator and a three-phase PM synchronous generator, labelling carefully all the resistance and reactance components in both equivalent circuits. (2p)

B) Derive expressions for the active powers and the reactive powers at the generators' terminals, as a function of their equivalent impedances as seen from their respective terminals and their terminal voltages. (4p)

Question 5: Describe in detail the role that power electronics-based technologies may play in providing reactive power support and in evacuating the electrical power output of large wind parks. Use as many equations and diagrams that you may find appropriate to aid your description. (6p)