NAME:

**TEST (5 points)**

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| B | D | C | B | D | C | C | D | C | B |

| 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|
| C | B | B | C | B | C |

**Multiple choice test (5 points) – Correct +1, incorrect -1/3, non-answered 0**

1 In a given wind turbine, how can we increase the capacity factor?

a) Installing shorter blades for the same power rating
b) Reducing the power rating keeping the same blades
c) Reducing the hub height and maintaining the same blade length and power rating
d) None of the previous answers

2 The wind shear explains why

a) wind turbines can be bigger in the southern hemisphere
b) wind turbines generate less at high altitude
c) the terrain roughness is higher for offshore wind
d) None of the previous answers

3 Wind turbine classes are determined by three parameters. Which of the following is not one of them:

a) The average wind speed
b) The wind extreme gust
c) The wind shear
d) The wind turbulence

4 In a wind turbine rated to 3 MW, we have a power generation of 500 kW with a wind speed of 6 m/s, what power will be generated with a wind speed of 9 m/s?

a) Less than 1 MW
b) Between 1 and 2 MW
c) Between 2 and 3 MW
d) 3 MW

5 The Betz limit is

a) The maximum efficiency which can be achieved with a wind turbine of 3 blades
b) a practical approximation of maximum turbulence
c) highly dependent on Reynolds number
d) A theoretical limit which cannot be achieved in practice

6 Which of the following element is **not** present in all types of horizontal axis wind turbines discussed in class

a) hub
b) transformer
c) power converter
d) nacelle

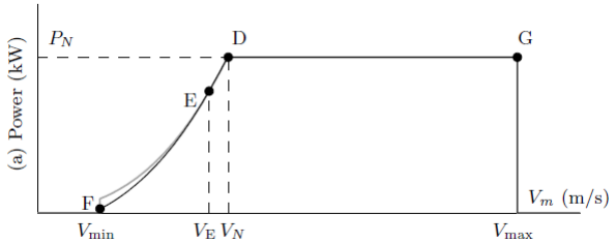
7 The power coefficient …

a) is constant for fixed-speed wind turbines
b) is constant for variable speed wind turbines
c) has to be maintained at its maximum value to extract maximum power from the wind
d) is proportional to the pitch angle when it is in power limitation mode

8 Fixed-speed wind turbines

a) are able to adapt the tip speed ratio when wind changes to extract the maximum available power
b) rotate exactly at constant speed even during wind speed changes
c) usually include a synchronous generator
d) use normally induction generators rotating above synchronous speed

9 In the following figure related to a fixed-speed wind turbine generator




a) The F point corresponds to the cut-out speed of the wind turbine
b) In the D-G sector the pitch system is maximizing the power
c) $V_E$ is the nominal wind speed of the wind turbine and maximizes the Cp
d) In the sector F-E the turbine is operating at nominal power

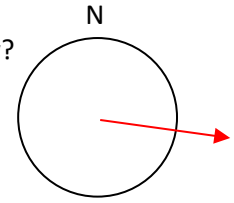
10 Variable speed type 4 wind turbines
a) always include a permanent magnet synchronous generator
b) include a full power converter which is rated at more apparent power than the generator
c) have an AC connection between the rotor inductances and the AC network
d) None of the previous answers

11 In a DFIG wind turbine
a) The machine cannot operate as a generator with positive and zero slip
b) The machine cannot operate as a motor
c) The converter nominal power is smaller than the generator nominal power
d) the speed can be controlled in a very narrow range around synchronous speed (2-3 %)

12 In a DFIG wind turbine
a) the stator currents have variable frequency
b) the rotor currents are DC if the slip of the generator is 0
c) the rotor currents are DC if the generator is blocked at 0 generator speed
d) None of the previous answers

13 Why is important to measure the temperature in order to estimate the wind resource?
a) It permits calculating the air pressure
b) It permits calculating the air density
c) It permits calculating the wind shear
d) It not relevant to measure the temperature

14 Which is the approximate wind direction considering the red arrow?




a) 180º
b) 100º
c) 280º
d) 340º

15 Considering the following 10-minutes data: a mean temperature of 10 ºC, a mean wind direction of 80º, a mean wind speed of 8 m/s with a standard deviation of 1.2 m/s. Which is the mean turbulence?
a) 9.6%
b) 15%
c) 18%
d) Cannot be calculated without air density data

16 When analyzing wind data, which is the main purpose of the “Measure-Correlate-Predict” (MCP) process?
a) Extrapolate to hub height
b) Estimate the wind shear
c) Estimate the long-term wind resource
d) Estimate the air density

NAME:

1 Sketch a diagram of type 4 wind turbine based on a PMSG and explain advantages and disadvantages of the different possible solutions regarding the gearbox and generator used (1 point)

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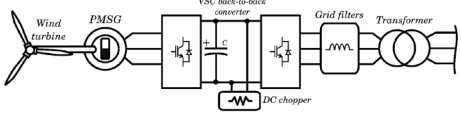
Variable speed with full scale converter - DD PMSG




**Concept**

- Variable speed concept
- Permanent Magnet Synchronous Generator (PMSG)
- Direct driven
- Multipolar machine

**Advantages and Disadvantages**

- Advantages of the variable speed concept
- Gearbox costs and failures eliminated
- Lighter and smaller than WRSG
- High efficiency
- Generator costs increased due to the magnets
- Complex design and manufacturing
- Non controllable rotor excitation
- Possible demagnetization of the rotor

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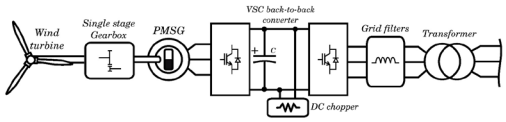
Variable speed with FPC - Single stage gearbox PMSG




**Concept**

- Variable speed concept
- Permanent Magnet Synchronous Generator (PMSG)
- Single stage gearbox
- Generator with a few number of poles
- Operated at a medium torque and medium speed

**Advantages and Disadvantages**

- Advantages of the variable speed concept
- Gearbox costs, complexity and wheight reduced
- Smaller generator, less number of poles
- Gearbox losses
- Non controllable rotor excitation
- Possible demagnetization of the rotor
- Complex manufacturing

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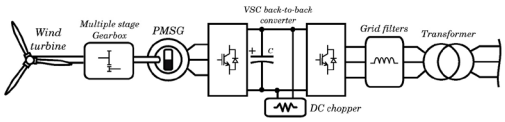
Variable speed with FPC - Multiple stage gearbox PMSG




**Concept**

- Variable speed concept
- Permanent Magnet Synchronous Generator (PMSG)
- Multiple stage gearbox
- Generator with a low number of poles
- Operated at a low torque and high speed

**Advantages and Disadvantages**

- Advantages of the variable speed concept
- Smaller generator with a lower number of poles than the DD
- Losses in the gearbox
- Complex gearbox design
- Non controllable rotor excitation
- Possible demagnetization of the rotor

2 For a PMSG type 4 wind turbine, calculate number of pole pairs needed for WT nominal speed of 15 $min^{-1}$ with nominal electrical frequency of 15 Hz for the following cases: (1 point)

a Direct drive WT

For a synchronous machine G N $(2\pi/60) = 2\pi f / P \rightarrow P G = 60 f / N$

P G= 60 f / N = 900 / 15 = 60

G=1 -> P = 60

b Double stage gearbox WT, G = 40 (gearbox ratio)

G=40 -> P = 1.5 *(students answering 1.5 get the full mark of this question, but we give the full answer below)*

As mentioned in slide 21, V6_partII "How could select the pole pairs for non-exact results?"

P can be 1 or 2.

If P=1, then we have to reducy frequency, which can not be appropiate (limitations of machine and converter)

If P=2, the we have to increase frequency

P G= 60 f / N -> 2*40 = 60 f / 15 -> f = 20 Hz

c For the previous wind turbine, how can the wind turbine rotate at 5 $min^{-1}$ - case a- Direct drive WT

| |
|---|
| We can do this adjusting the frequency.<br>For the case of question (a) f = PGN/60 = 60 N/60 = 5 Hz |

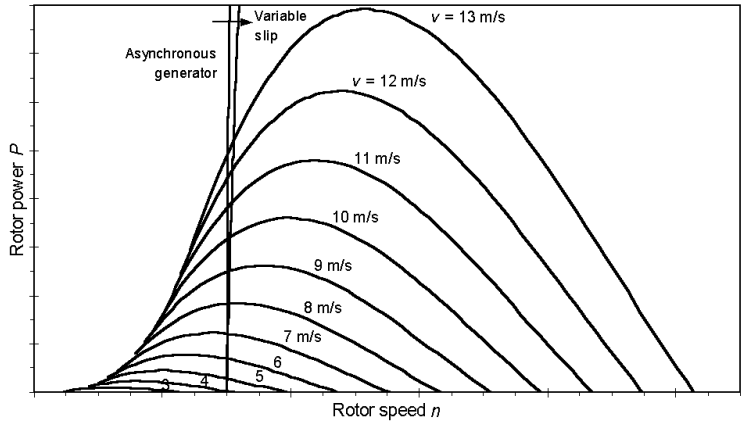
d For the previous wind turbine, how can the wind turbine rotate at 5 $min^{-1}$ - case b -Double stage gearbox WT

| |
|---|
| We can do this adjusting the frequency.<br>For the case of question (b) f = PGN/60 = 80 N/60 = 6.66 Hz<br>*(we also count correct if done f = PGN/60 = 60 N/60 = 5 Hz)* |

Sketch the model you programmed in Simulink to analyze the dynamic behavior of a fix-speed wind turbine (1 pt)

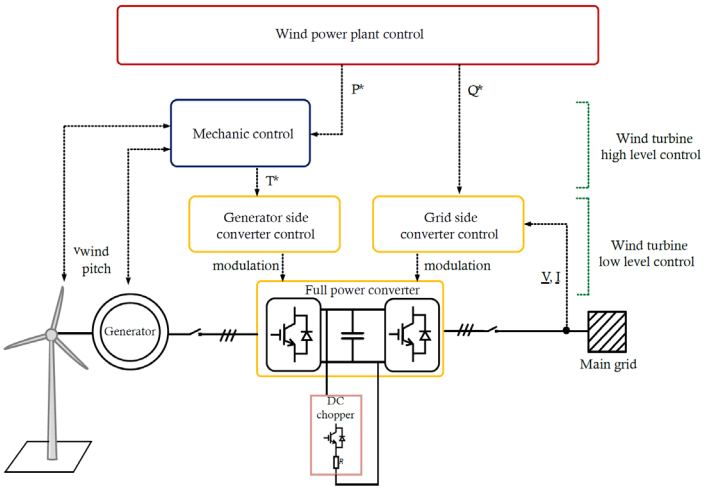
| |
|---|
| Work from Assignment 2 |

Draw a Figure with the electrical and mechanical power depending on generator speed in a fixed-speed wind turbine (for different wind speeds) and describe the procedure to calculate the steady-state wind turbine speed. (1 pt)




Procedure to calculate the steady-state wind turbine: Explain Exercise 1 and 2 from Exercises document

Sketch a general control diagram of a variable speed wind turbine and describe the main controllers and their functions (1 point)



# Overall control scheme

Wind turbine control

**Control parts**

- **Mechanical control**
  - Pitch angle (power limitation)
  - Yaw angle (nacelle orientation)
  - Torque reference (MPPT)
  - Advanced controls (load reduction)
- **Converter control**
  - Machine side converter
    - Torque control
  - Grid side control
    - DC bus control
    - Q control
    - Grid support