Wind Lab. Assignment – Overview

Submission due date: **21. 02. 2021** electronically on ISIS and as hard copy in postbox **EMH 1**.

The submission is performed on ISIS in groups of **maximal two students**. Three documents are handed in, a zip file with one MATLAB code (Code2021_lastname1_lastname2) and Simulink models of all tasks with extension **.slx** (Model2021_lastname1_lastname2), a report in pdf format (RET2021_lastname1_lastname2). The report includes your names and matriculation number, a brief description of all Wind assignments, an explanation and interpretation of your results, plots, your code and calculated results. Furthermore, the report needs to be printed **in duplex and submitted as a hard copy.** The execution of your MATLAB code is conducted in only one m.file (**as script, not function**) called "ExeRet21.m". The code that cannot be run will be graded with zero points.

Assignments:

Table 1: Parameters for wind lab. assignment

Symbol	Quantity	Value
P_{tur}	Rated Power	3.5 MW
V_{W}	Rated wind speed	12 m/S
n	Rated mechanical angular velocity	20 rpm
$C_{\mathrm{p,opt}}$	Maximum power coefficient	0.4378
r	Rotor radius	50 m
λ_{opt}	Optimal tip speed ratio	6.7
H	Inertia constant of turbine and PMSG	6 s
p	Number of poles	180
R_{s}	Stator resistance	60 mΩ
L_{sd}	Stator d-axis inductance	6 mH
L_{sq}	Stator q-axis inductance	8 mH
Φ_{m}	Flux induced by magnets	17.3 Wb
V_{dc}	DC voltage	6.5 kV
ρ	Air density	1.225 kg/m^3

1. **Electric System Modeling and Current Command Synthesizer:** Can be used purely with Matlab
   (Assume that P_{e} equals P_{tur} and the stator is in star connection)

1.1) Calculate rated electrical angular frequency ω_e [rad/s], rated electrical torque T_{e}, rated generator voltage v_{s} (given as RMS, phase-to-phase value).

1.2) Vary T_{e} from zero to rated value with reasonable step size (too large not precise, too small computational cost heavy), calculate the corresponding $i_{\mathrm{sd,ref}}$ and $i_{\mathrm{sq,ref}}$ for each point in the vector of T_{e}. Plot $i_{\mathrm{sd,ref}}$, $i_{\mathrm{sq,ref}}$ and i_{s} versus T_{e} together.

1.3) Please doucument each step of transformation from following equation

$$i_{\mathrm{dc}}(t) = \frac{1}{2}\left(m_{\mathrm{a}}(t)i_{\mathrm{sa}}(t) + m_{\mathrm{b}}(t)i_{\mathrm{sb}}(t) + m_{\mathrm{c}}(t)i_{\mathrm{sc}}(t)\right) \tag{1}$$

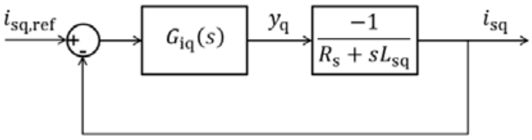
into dq-frame:

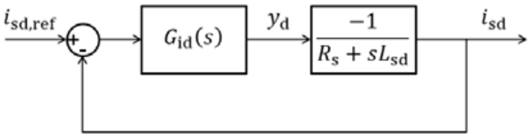
$$i_{\mathrm{dc}}(t) = \frac{3}{4}\left(m_{\mathrm{d}}(t)i_{\mathrm{sd}}(t) + m_{\mathrm{q}}(t)i_{\mathrm{sq}}(t)\right) \tag{2}$$

(For signal m, current i, the transformation matrix remains the same as shown on slide 7, write down the detailed process in your report).

2. Control and Stability in Wind Energy Converters Using Transfer Function Analysis:

2.1) Calculate the current controller parameters $K_{\mathrm{d,I}}$, $K_{\mathrm{d,p}}$, $K_{\mathrm{q,I}}$, $K_{\mathrm{q,P}}$ for $\tau_{\mathrm{i}} = 3\ ms$. Include the results in the report. Models needed are shown below:





a) Validate your controller parameters for an operating point of the wind energy conversion system. Set rated operating point as the initial condition, then apply a step down of -25 A for i_{sq} after one second of simulation time. Run the simulation and plot reference and measured current.

b) Calculate the i_{sd} that corresponds to the new i_{sq} ($i_{\mathrm{sq,rated}} - 25\ A$), explain your choice of the i_{sd} from the current vector with regard to the step size and the validity of the linear model.

c) Please mark time constant τ_{i} in each of your plots (as for time constant, please refer to Fig. 9 on the paper). Is the value of the measured current at this time point as expected? Justify your answer also by calculations.

d) Is the current controller behavior dependent on the operating point? Explain your answer.

2.2) Implement the following block diagram (Fig. 1) in Simulink:

a) Plot reference and measured currents for the rated operating point.

b) Moreover, plot m_{d}, m_{q} and v_{sq}, v_{sd}.

c) Plot the resulting current i_{dc} and verify with regard to v_{dc} and the expected power generation for this operating point that this value is as expected ($v_{\mathrm{dc}} = 6$ kV).

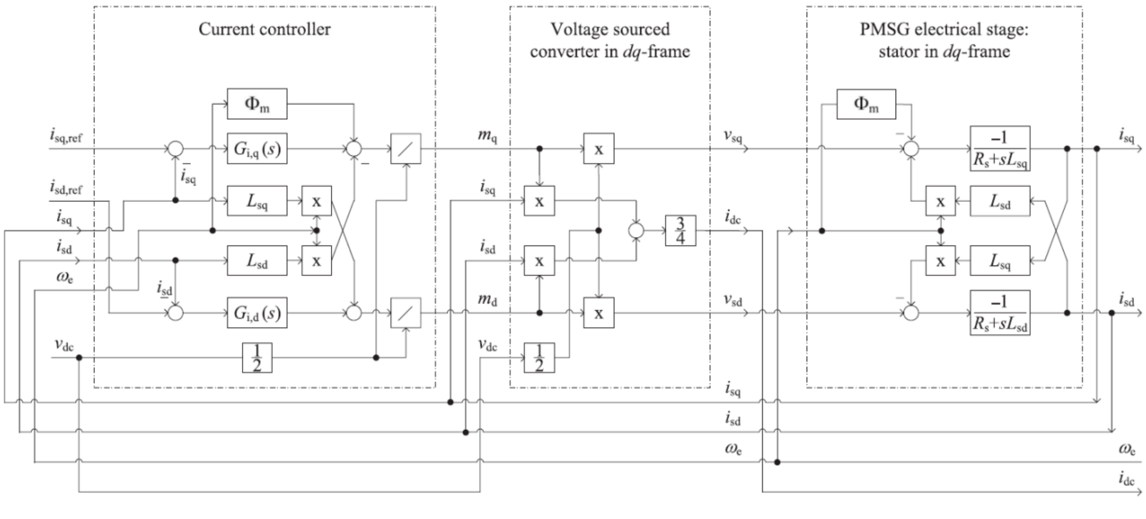


Figure 1: Block diagram of current control

3. Torque Generation and Turbine-Rotor Interaction Process:

3.1) Please implement both block diagrams shown below (Fig. 2) to simulate a torque change of $\Delta T_\text{e} = 1 \times 10^5$ Nm under a stable wind speed ($\Delta V_\text{w} = 0$) and plot the resulting speed change and power change, respectively. Explain the reaction of speed and power on a torque change. Simulate again with $\Delta T_\text{e} = 1 \times 10^5$ Nm and $\Delta V_\text{w} = 0.1$ m/s. Plot the results for both cases (both $\Delta\omega_e$s in one figure, both ΔP_es in another one). Explain the results.

Turbine-rotor interaction process for torque-to-speed change

Turbine-rotor interaction process for torque-to-power change

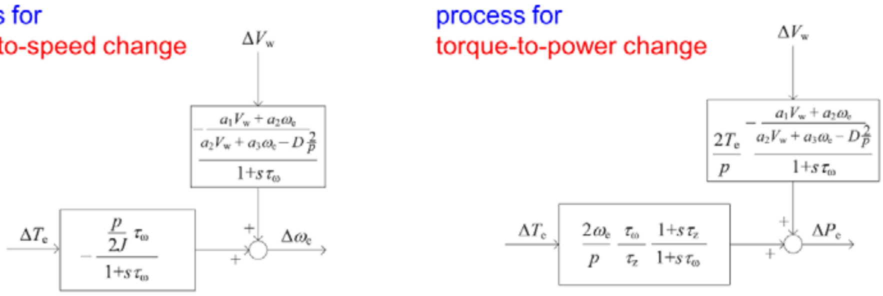


Figure 2: Turbine-rotor interaction process of torque-to-speed change and Torque-to-Power Change

a) Calculate the overall inertia J of generator and turbine, using equations:

$$H = J \frac{1}{2} \frac{w_\text{om}^2}{S_\text{base}} \tag{3}$$

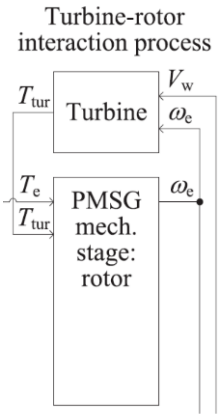
$$S_\text{base} = P_\text{e} \tag{4}$$

b) calculate the optimal operating point $P_\text{tur,opt}$, $\omega_\text{e,opt}$, $T_\text{e,opt}$ of the wind turbine at a wind speed of 10 m/s in your .m-file under the assumption that $P_\text{e,ref} = P_\text{tur,opt}$ (optimal tip speed ratio applied).

c) Calculate the corresponding time constants τ_w and τ_z for this operating point, $c_0 = 2.25 \times 10^{-2}$, $c_1 = 2.18 \times 10^{-2}$, $c_2 = -0.23 \times 10^{-2}$.

d) Implement both block diagrams shown below in Simulink.

3.2) Implement both blocks of the turbine-rotor interaction process (Fig. 3) in Simulink.



What should I expect?

Ttur closes to Te, because that is our reference value?

Figure 3: Turbine-rotor interaction process

a) Assume $V_\text{w} = 10$ m/s, *set* T_e accordingly (T_e under the wind speed 10 m/s). Define the initial value of the integrator in your Simulink model as $\omega_\text{e,opt}$ (anything unclear about integrator and its initial value please refer to Simulink Introduction slide 11-14). Plot T_tur, compare T_tur to T_e and explain the result.

b) For turbine:

$$T_{\mathrm{tur}} = \frac{1}{2}\pi\rho R^3 V_w^2 C_{\mathrm{T}}(\lambda) \quad (5)$$

$$\lambda = \frac{\omega_m R}{V_W} \quad (6)$$

(In this task, V_w already given, air density $\rho = 1.225\ \mathrm{kg/m^3}$ please use a lookup to determine $C_{\mathrm{T}}(\lambda)$)

c) For rotor:

$$J\frac{2}{p}\frac{d\omega_{\mathrm{e}}}{dt} = T_{\mathrm{tur}} - T_{\mathrm{e}} - T_{\mathrm{d}} \quad (7)$$

Rearrange equation (7) to calculate ω_{e} (don't forget initial condition for integrator or wrong results will be obtained. Additionally, set damping torque T_{d} as 0 for our task).

3.3) Implement the torque generation as a subsystem (Fig. 4) in Simulink, similar to the block shown on the left.

a) Run a simulation for the optimal current values i_{sq} and i_{sd} at a wind speed of $V_{\mathrm{w}} = 10$ m/s. Chose a suitable simulation time in order to show that your torque generation works.

b) Then connect this subsystem to your Simulink model of the turbine-rotor interaction process, see task 2. Run a simulation and plot ω_{e}.

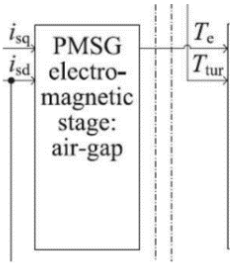


Figure 4: Subsystem of torque generation

Graph converges to 120.68, why is that?
Maybe because we_opt value isn't as optimal as it actually is.
The real value of we_opt is 120.68

4. Nonlinear Wind Turbine Model:

4.1) Design of the power controller

a) $V_w = 10$ m/s, the closed-loop time constant τ_{PI} is 5 % of the mechanical lag time constant. Calculate the values of the controller parameters.

b) Apply a change of the reference power of -50 kW to the linear model.

c) Plot the resulting power change. Based on the simulation results, show that your controller is well designed: Are the closed-loop time constant and the steady-state power change reached as expected (please refer to Fig. 9. on the paper)?

d) Include the Simulink model in your report.

4.2) Power command synthesizer and power measurement

a) Implement the power command synthesizer. Include the Simulink model in your report.

b) Implement the power measurement block. Neglect PL. Give the Simulink model in your report.

4.3) Simulation Case 1

a) Run the simulation for a constant wind speed of $V_w = 10$ m/s for a simulation time of 100 s. Plot T_e, ω_e, and P_e. Store the final values in a vector because they are gonna be used as initial values for the second simulation with varying wind speed.

4.4) Simulation Case 2

a) Create a wind speed profile for 300 s with fluctuations around $V_w = 10$ m/s. Show the plot in your report.

b) Carry out a simulation for 300 s using the created wind profile.

c) Plot air-gap torque T_e and stator currents i_{sd} and i_{sq} over time.

d) Plot P_e versus ω_e and C_P versus T_e.

e) From your simulation results: Give the value of P_e for the lowest wind speed and the highest wind speed of your wind speed profile. For both wind speeds, compare the simulation result of P_e with the expected P_e from theory.