Universitat Politècnica de Catalunya

Renewable Energy Systems

AY 2021/2022

UNITE! Programme

SECOND LABORATORY ACTIVITY

Professor:

Yolanda Vidal Seguí

Students (PoliTO):

Di Francesco Luisa

Gigliotti Sara

Summary

INTRODUCTION

Wind turbine control strategies are important to ensure efficient performances and low cost of operation and maintenance.

In order to compare different wind turbines, the “per unit” normalization concept is used, it consists in normalizing each parameter by its nominal value. In this way when a parameter is equal to the rated parameter, the value “per unit” is equal to one.

BENCHMARK SIMULATION

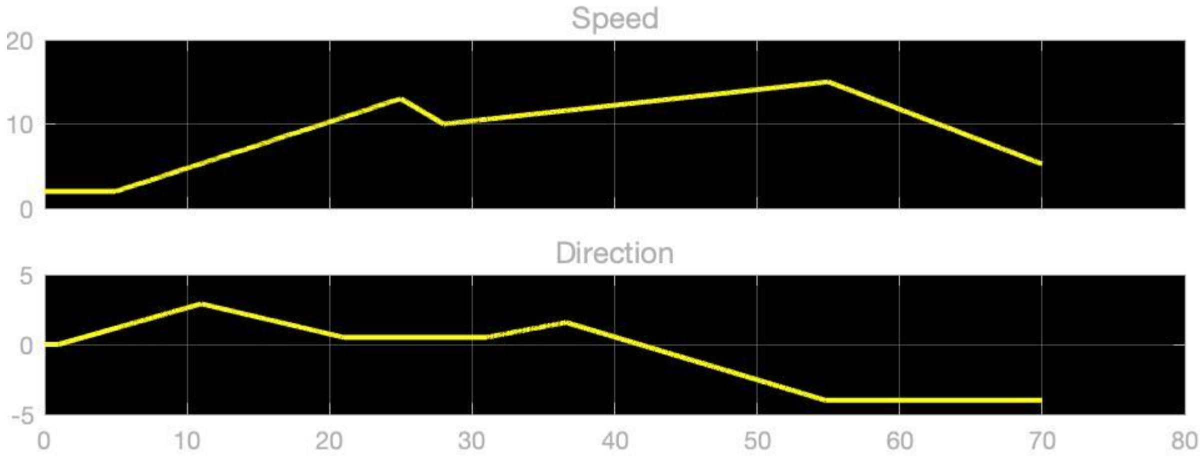
In the benchmark simulation the pitch system is set to “ideal actuator”, this means that the pitch control system adjusts the blades by rotating them, therefore changing the pitch angle which is the angle between the wind velocity and the cord of the air foil.

When the wind speed is too high and the power risks to exceed the nominal one, the angle of attack is reduced, this reduces the lift coefficient and therefore the power output. Since the wind speed changes very fast because of turbulence, we need a high responsive pitch system in order to maintain the power constant.

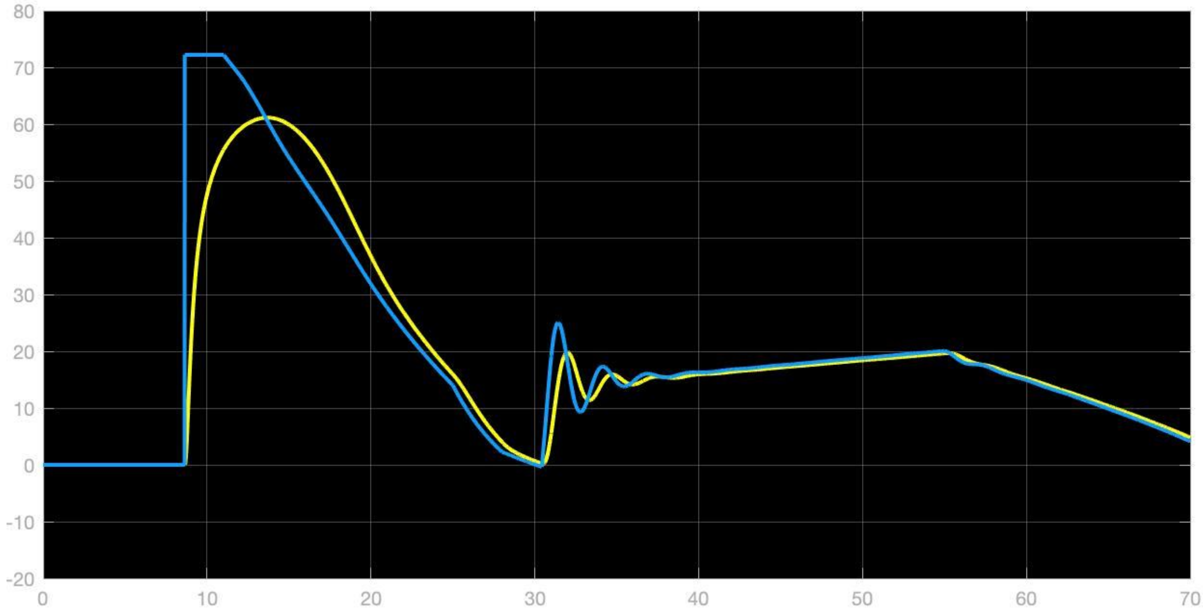
In this simulation the hub axis can rotate, this means that we can adjust the yaw angle which is the angle between the hub axis and the direction of the wind. The yaw system is set to ideal actuator, to keep the rotor perpendicular to the primary wind direction and therefore to maximise the power obtained from the wind.

The obtained plots are shown in the graphs below:

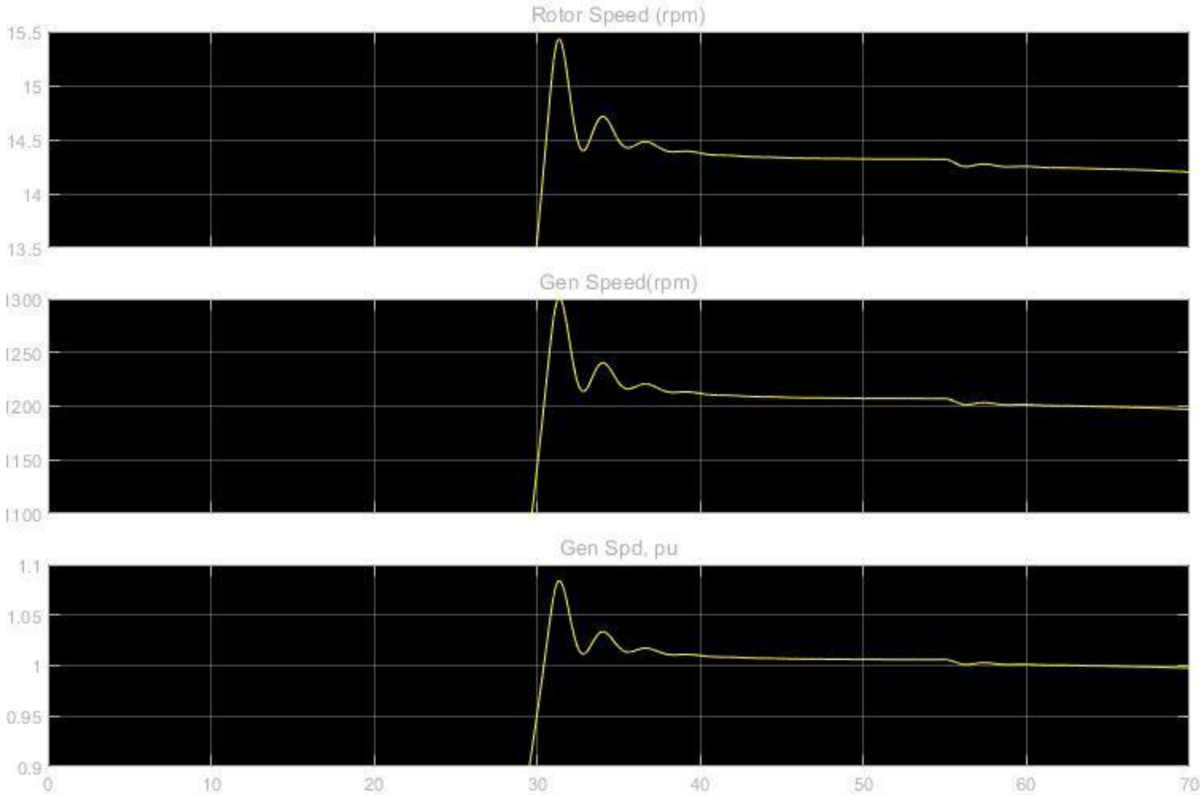
1. Wind speed and direction versus simulation time



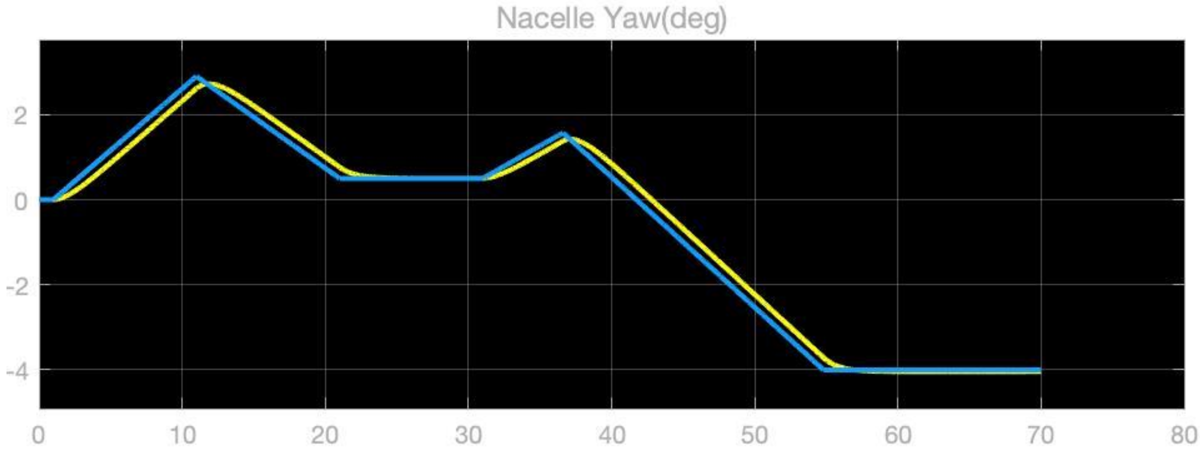
2. Pitch command (blue) and real pitch angle (yellow) versus computational time



3. Rotor speed, generator speed and per unit generator speed versus computational time



4. Yaw command (blue) and real yaw angle (yellow) versus computational time



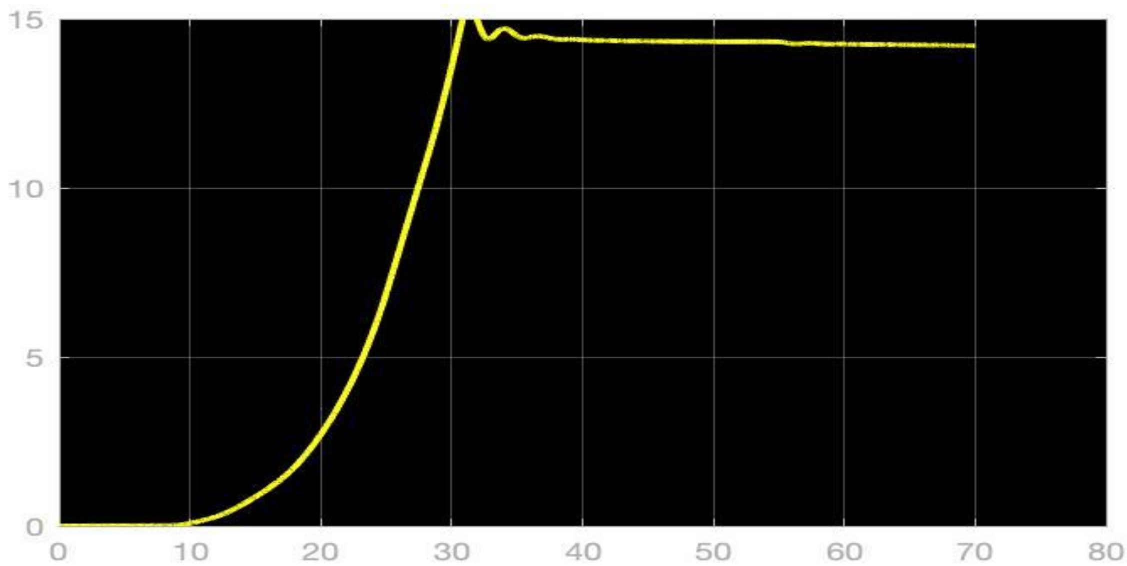
As we can see the wind direction plot and the yaw command and angle plot share the same trend, in fact the yaw angle follows the wind direction in order to be always perpendicular to it.

The rotor speed and the generator speed also have the same trend, but the generator rotates at higher velocities since the gearbox increases the rotational speed from 13.5-15.5 rotations per minutes to about 1100-1300 rotations per minutes.

We also have the plot of the generator speed per unit, in it we can see that after an initial transient (from 30 to 40 seconds), this normalized speed approaches the value of one which means that the rated speed has been reached.

We can deduce approximately the cut in velocity from the graph of the rotor speed in time (shown below), in fact the cut-in velocity is the wind velocity at which our rotor starts to move. In this case the rotor starts to move at 10 s, the wind velocity at this time corresponds to 5 m/s (from figure 1) which is our cut in velocity.

5. Rotor speed versus computational time



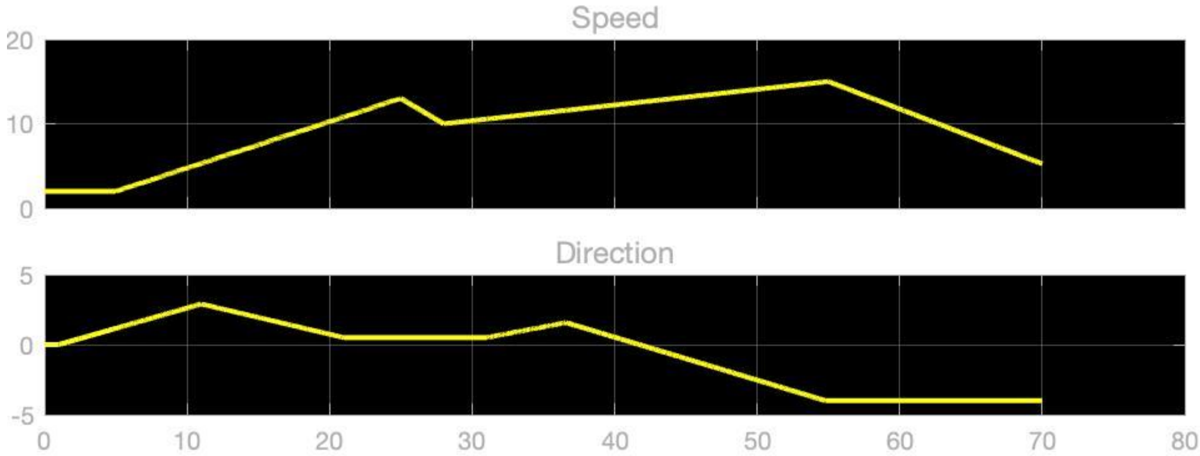
We can also deduce the rated velocity; it is the rotor velocity at which we produce the rated power. From the graph of the generator speed per unit (figure 3) we can see that the rated speed (that corresponds to the rated power) is reached at about 40 s, in fact at this time the generator speed per unit reaches the value of one. The wind speed at 40 s is equal to 12.5 - 15 m/s that therefore will be our rated velocity.

MODIFICATION ON THE PITCH SYSTEM

To analyse different control strategies, we block the pitch control system leaving the other settings unchanged with respect to the benchmark simulation, this means that our pitch angle will remain fixed, and this regulation will not be performed.

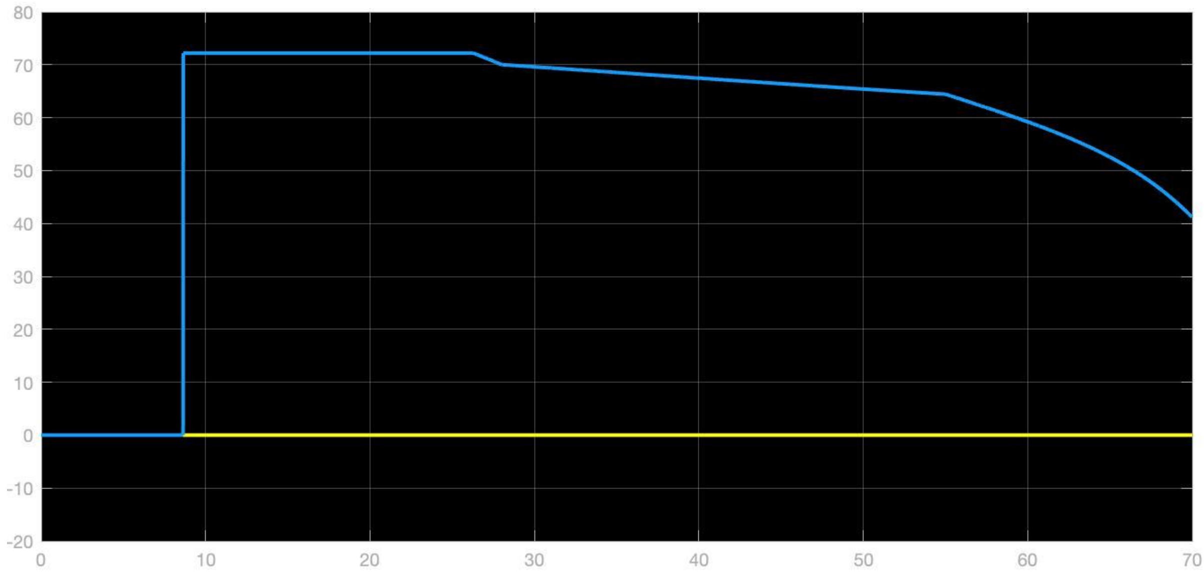
The obtained plots are shown in the following figures:

1. Wind speed and direction versus simulation time



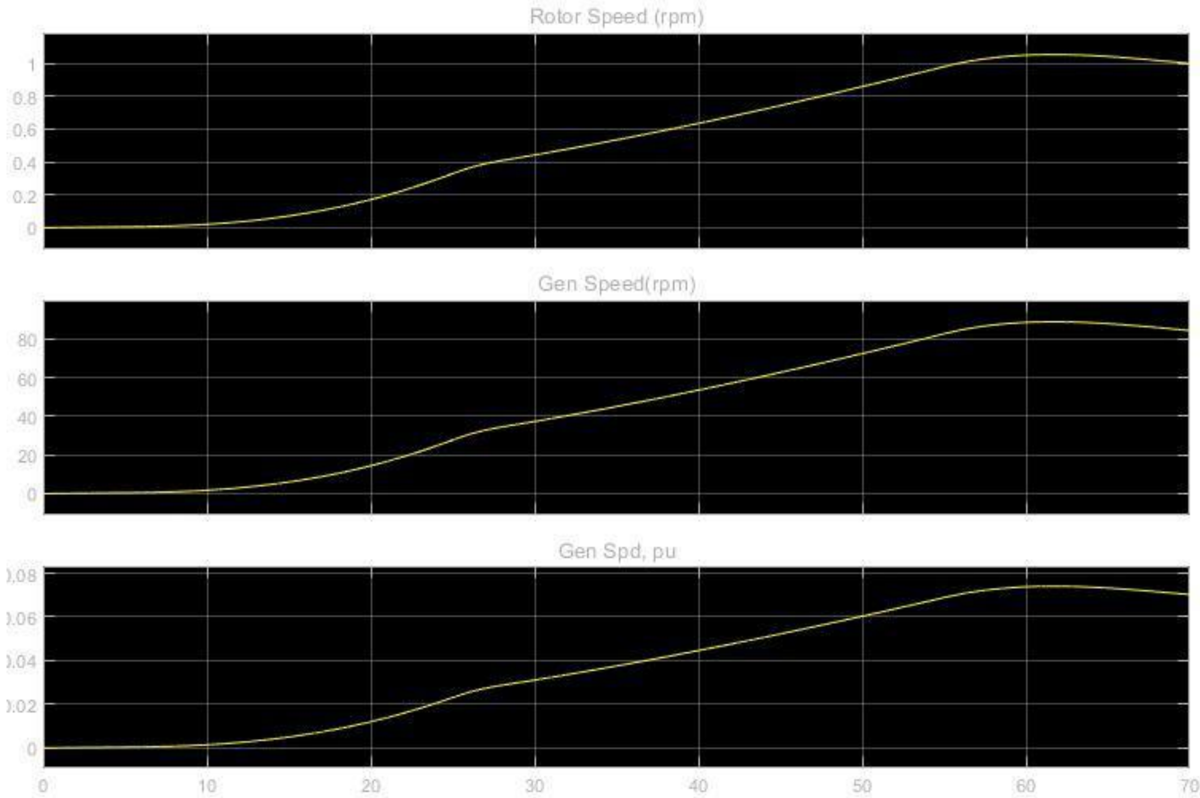
This first figure is the same as the previous simulation since our wind data have not changed.

2. Pitch command (blue) and real pitch angle (yellow) versus computational time



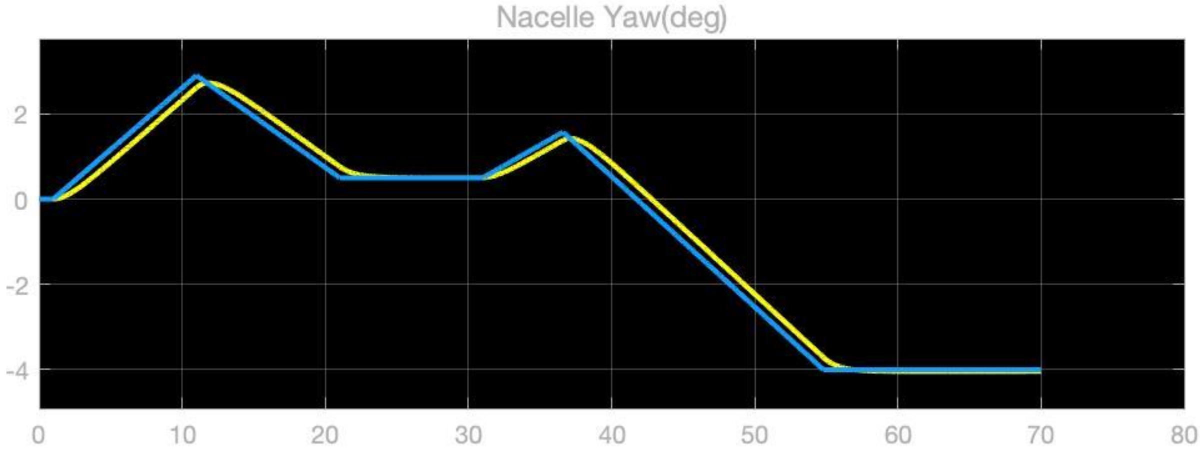
In this second figure we can see that the pitch angle is fixed at a value of 0°, this is because we have deactivated the pitch control system and therefore, we are not performing this regulation strategy.
From the point of view of the power output we cannot reduce the lift coefficient anymore, but the power is limited anyway by the stall effect on the blades, the disadvantage of this control strategy is that we rely on external conditions.

3. Rotor speed, generator speed and per unit generator speed versus computational time



With respect to the previous case, we can see that the rotor speed does not stabilize itself after a transient, but it has a more linear trend, this is because the pitch angle control is locked and we cannot perform the adjustments on the lift coefficient.

4. Yaw command (blue) and real yaw angle (yellow) versus computational time



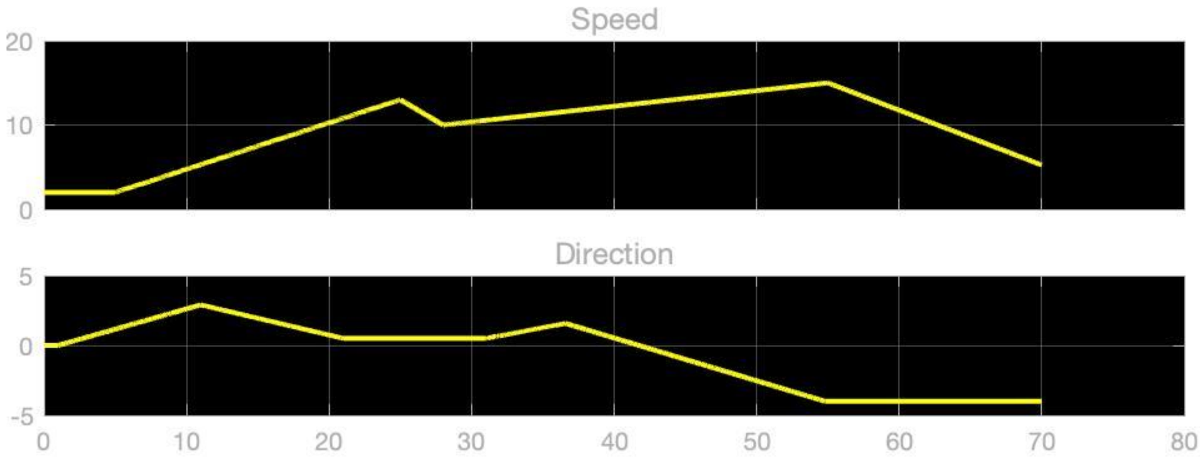
This plot is the same as the benchmark simulation since we have not changed the yaw system which is set on “ideal” as before.

MODIFICATION ON THE YAW SYSTEM

Starting now again from the benchmark simulation, we change the yaw control system to “locked” in order to block the yaw angle from changing. It is important to point out that the pitch control system is active and just the yaw control system is blocked.

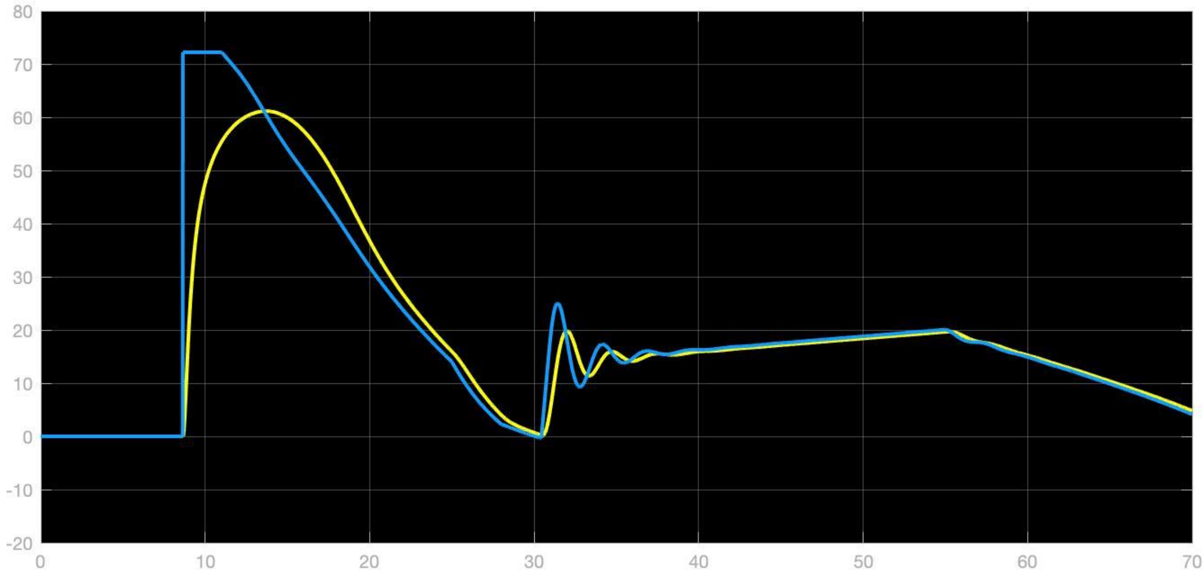
The obtained plots are shown in the following figures:

1. Wind speed and direction versus simulation time



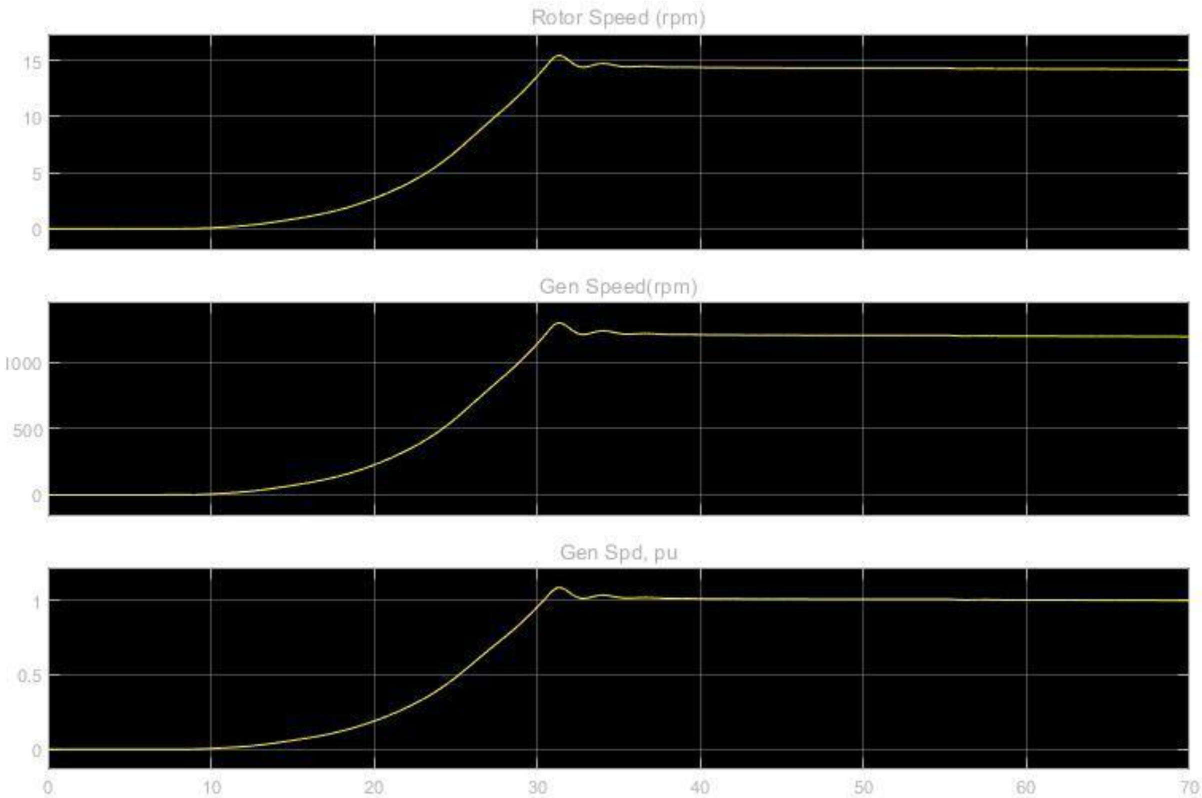
This first plot is the same since the wind data has not changed.

2. Pitch command (blue) and real pitch angle (yellow) versus computational time



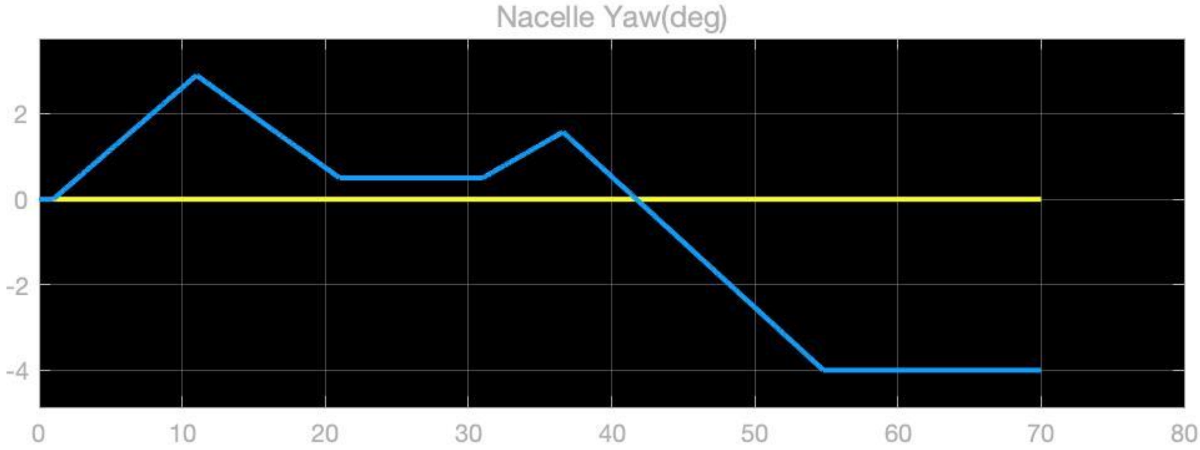
The pitch angle plot is the same as the benchmark since the pitch angle control system is active.

3. Rotor speed, generator speed and per unit generator speed versus computational time



Regarding this third figure we can say that the rotor speed and the generator speed have not changed that much, in fact after the initial transient the velocities stabilize just as in the benchmark simulation. This is because the pitch angle control system is active and can regulate the lift coefficient that influences the rotor speed.

4. Yaw command (blue) and real yaw angle (yellow) versus computational time



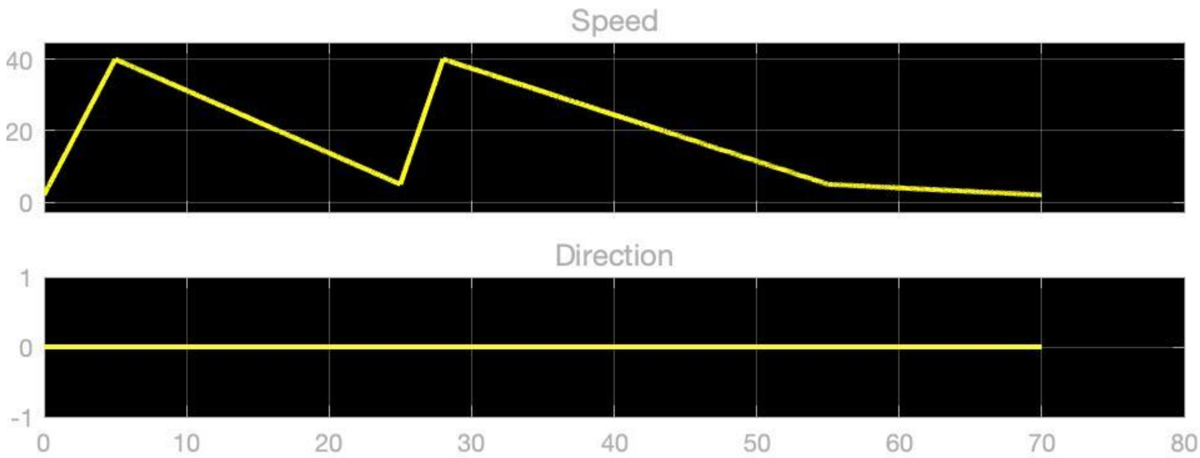
As expected in this plot we notice that the yaw angle is fixed and equal to 0°, because we locked the yaw control system.

MODIFICATION ON WIND DATA

In this last simulation we modified the input wind data, in particular the wind velocity and direction have been changed as required.

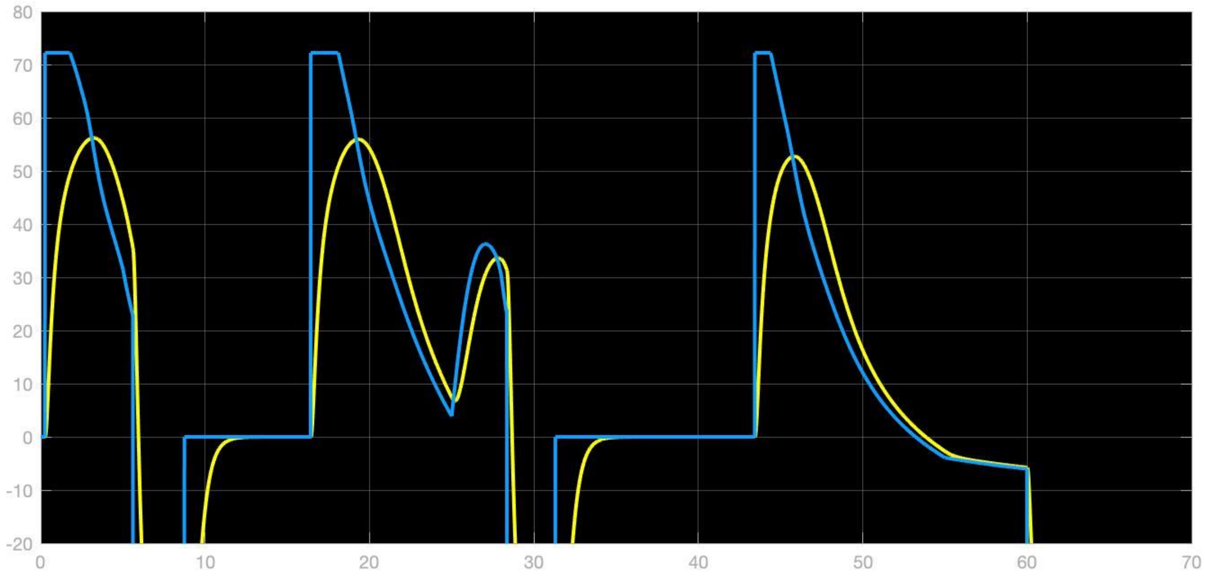
The obtained plots are shown in the following figures:

1. Wind speed and direction versus simulation time



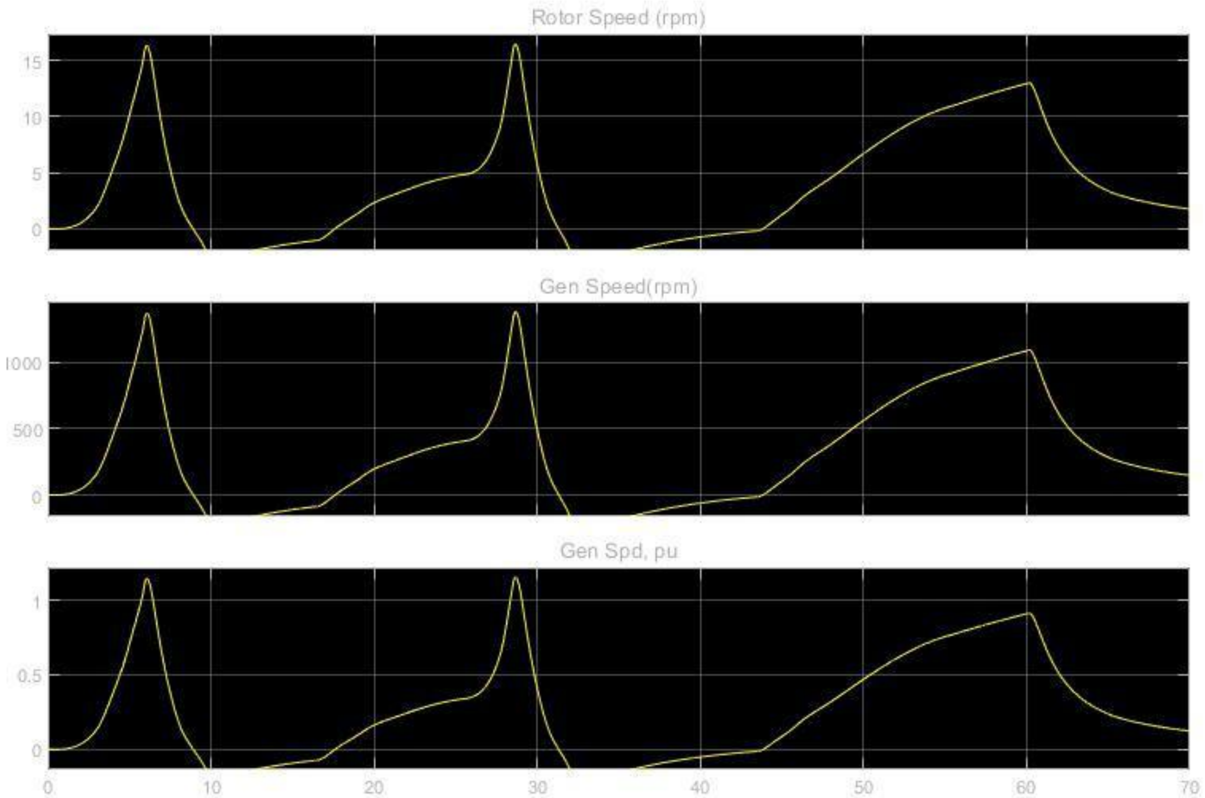
This is the new input data, with respect to the first one the wind speed reaches much higher values and the wind direction remains constant and does not change.

2. Pitch command (blue) and real pitch angle (yellow) versus computational time



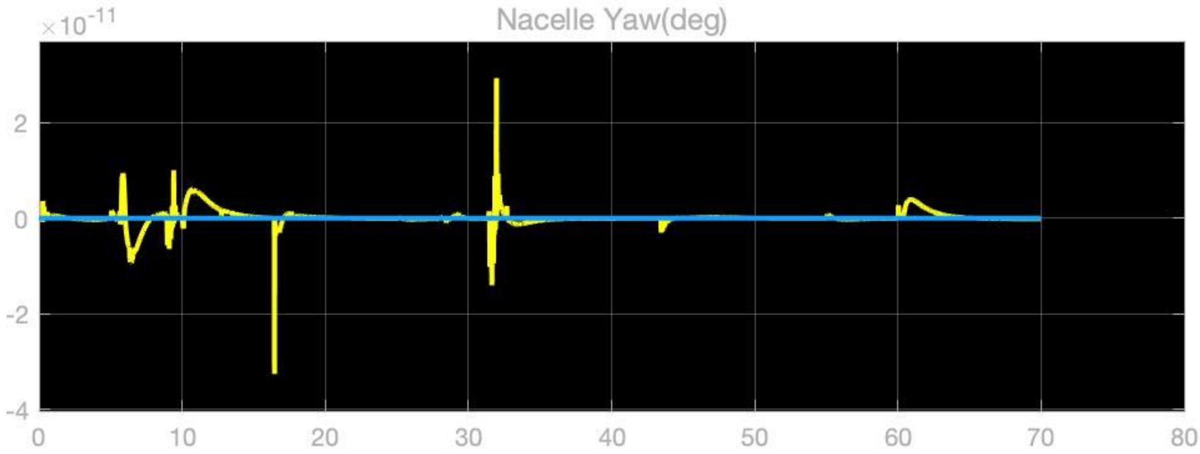
In this case the pitch control system is not locked, so the pitch angle is changing in time. We notice that the plot is quite different from the previous simulations, since we have changed the wind direction and velocity, we can say that this angle depends on them. We can also see that when we have a peak in the wind velocity the angle of attack decreases in order to decrease the lift coefficient and also the power produced, on the contrary when the wind speed decreases the angle of attack increases in order to produce more power.

3. Rotor speed, generator speed and per unit generator speed versus computational time



With respect to the benchmark simulation, we notice that the rotor and generator speed do not stabilize, they have more peaks and valleys. The generator speed per unit does not stabilize on the unitary value, this might be because the wind speed is not constant and reaches very high values, so it is possible that we reach the cut off velocity and our rotor stops its motion. On the contrary when the wind speed decreases the rotor starts to move again.

4. Yaw command (blue) and real yaw angle (yellow) versus computational time



Since in the new wind input the direction of the wind does not change, also the yaw angle remains constant and equal to zero even if the yaw control system is not locked. This means that the wind speed direction is always perpendicular to the rotor. The real yaw angle (represented by the yellow line) has some minor variations due to the fact that we are working with a limited machine precision, so there are some computational uncertainties.

CONCLUSIONS

In the benchmark simulation all the control systems are unlocked, the pitch and yaw angle are free to move in order to regulate the power output of the turbine.
In the second simulation the pitch control system is locked, so the angle between the wind direction and the blades is fixed. A drawback is that in this case we can not change the lift coefficient and therefore regulate our power output.
In the third simulation we fix the yaw angle, so the wind direction is not perpendicular to the rotor anymore and therefore the configuration is not the optimal one.
In the last simulation the wind speed and direction change with respect to the previous ones, since the wind direction is constant, even if all the control systems are activated, the yaw angle does not change.
So, the aim of this laboratory activity is to vary the different control systems of the wind turbine to see how these affect the rotor speed and as a consequence also the power produced. Therefore, we can say that the best solution is the one proposed in the benchmark because all the angles can be optimized, even if there is an additional initial cost for the installation of the control systems, these costs can be recovered during the lifetime of the turbine by optimizing the power produced.