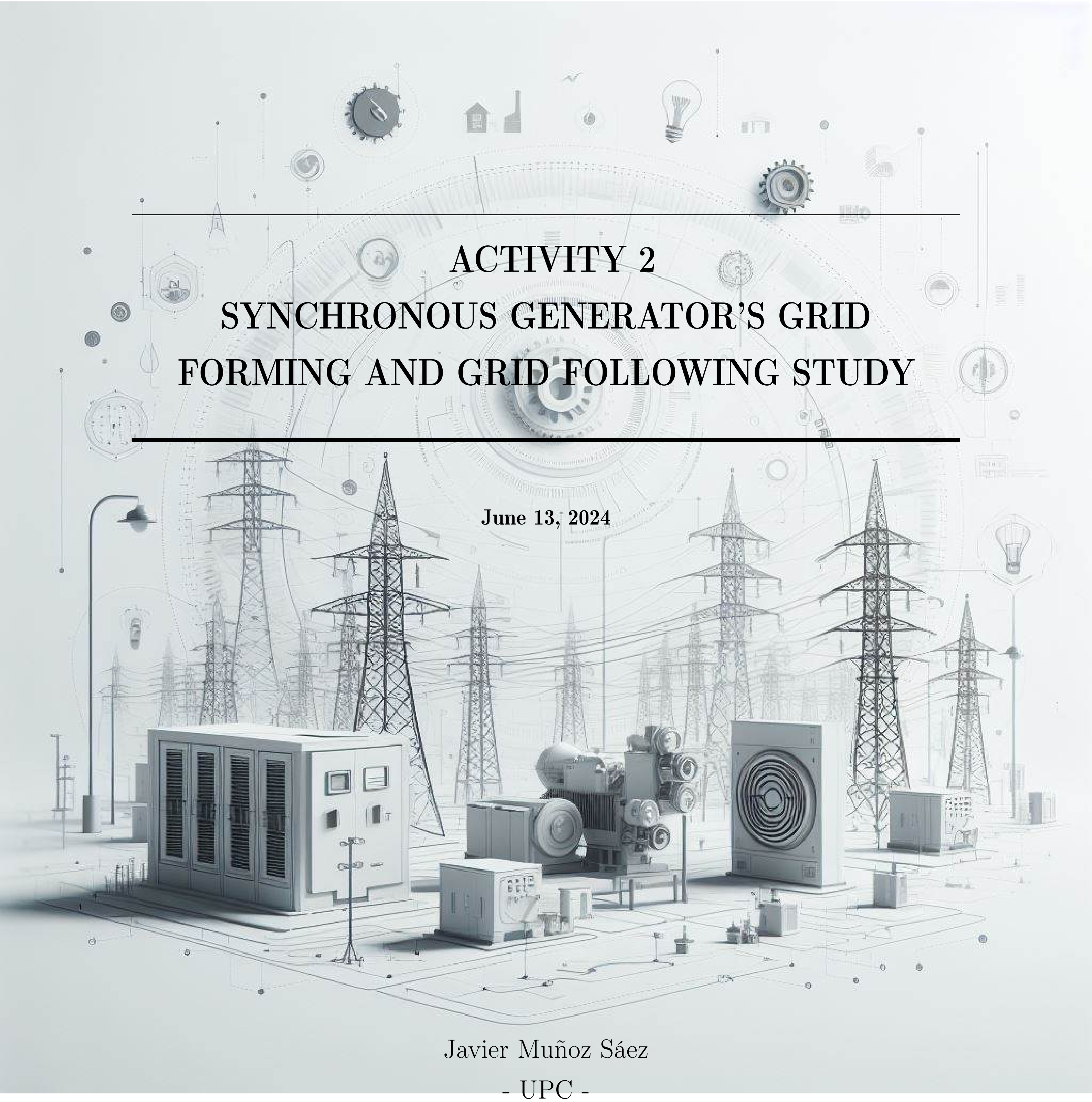
ACTIVITY 2
SYNCHRONOUS GENERATOR'S GRID FORMING AND GRID FOLLOWING STUDY



June 13, 2024

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- UPC -

Contents

1 Inertia, droop control and multi-machine systems

Opening the files "Ex1_parameters.m" and "Ex1_inertia2020a.slx" and studying all three models contained, discussing the effects of inertia variations.

1.1 Response of the system without freq control

As there is no control loop (Figure 1), any load change will directly impact in the synchonour generator's spinning,

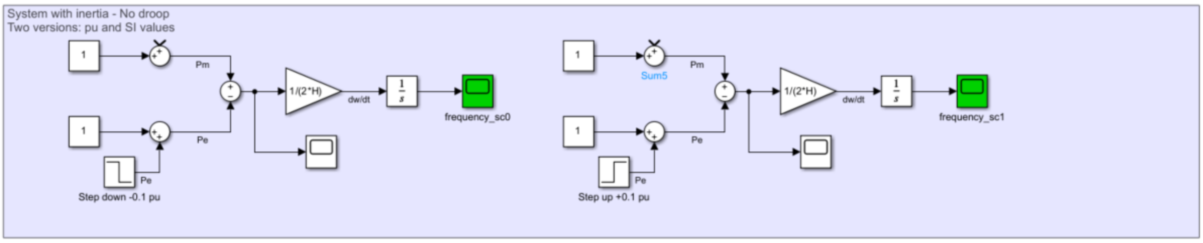
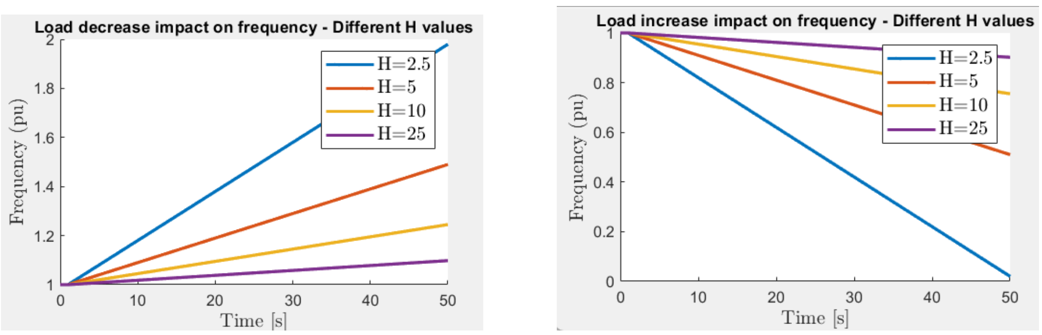


Figure 1: Simulink models, Step down and step up perturbances for control-less generators

The load variation Figure 2 will have steeper impact in the generator's frequency the lower its inertia is.

Inertia acting as mechanical energy storage and opposing to variations in spinning speed. The higher the inertia the slower the generator will ramp up or down its speed.



(a) load step down **(b)** load step up

Figure 2: Load variaton effect on generator's frequency

1.2 Response of the system with droop frequency control

The Synchronous generator now has a control in place Figure 3 ,with frequency feedback and direct action on Mechanical power.

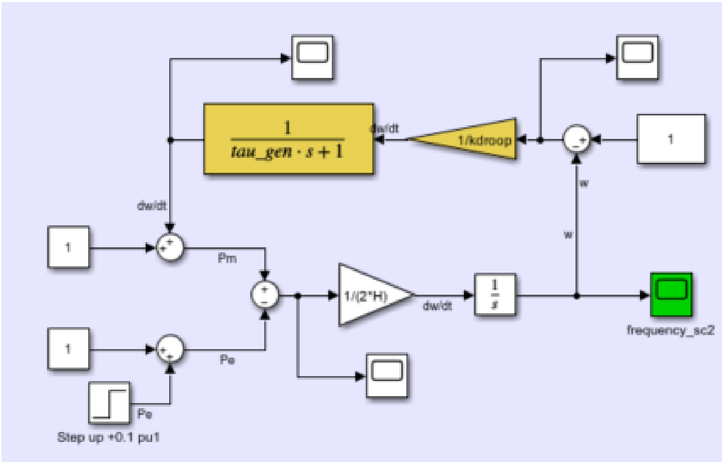


Figure 3: Simulink model, step up on load disturbance for droop controled generator (p.u)

This changes how the Generator reacts to changes in electric power demanded by the loads. The generator will now correct its own Pm to go back to a new stability point limited by Kdroop.

Different inertia values will affect on how hard is the frequency affected by the load changes (as seen in previous 1.1 section), lower Inertia values will create more violent swinging of the control response. Figure 4

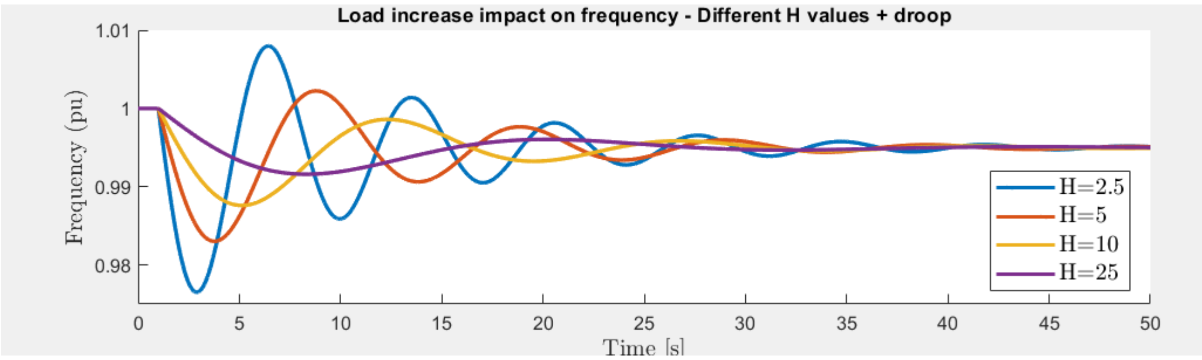


Figure 4: The droop control working to alleviate load changes effect in frequency for different inertia values

Decreasing the generator's time constant from 5 to 1, makes the controller first order response "faster", it will clear the transient state faster also reducing the swinging but increasing the frequency of the control response.Figure 5

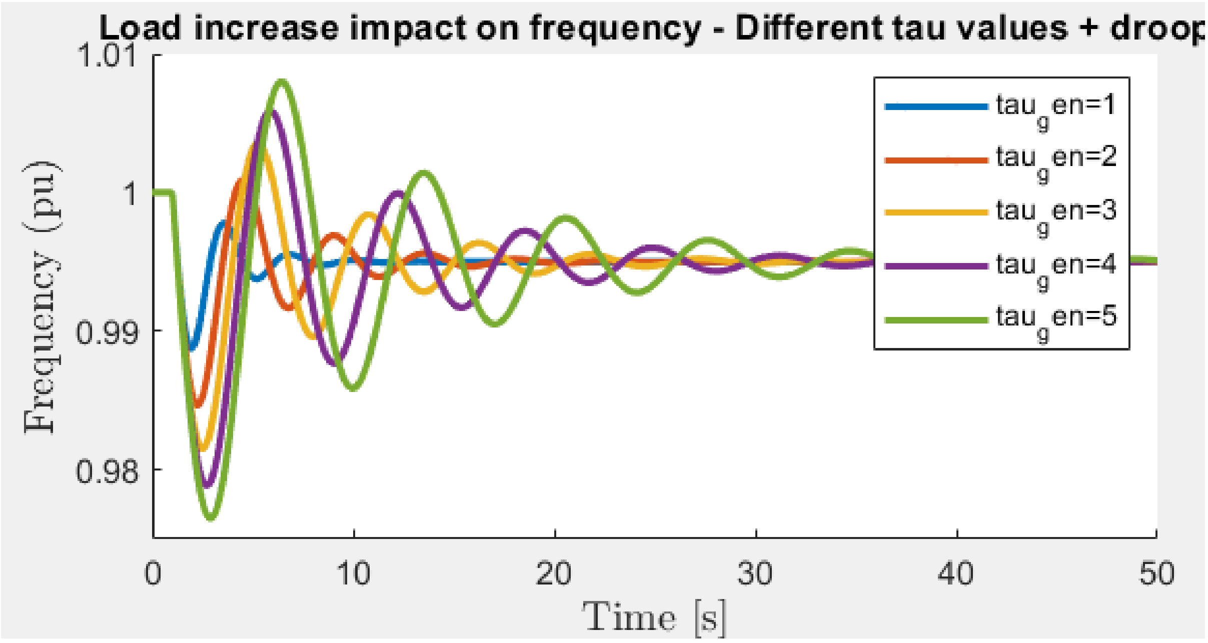


Figure 5: frequency response for different tau constants

Increasing the generator's Kdroop constant from 0.05 to 0.25 Figure 6, impacts in the steady state value, (the higher Kdroop the lower w steady response) we are decreasingly limiting the generator's P control action. As we are effectively limiting the P action of the control, the lower the P the slower the reaction and longer settling times.

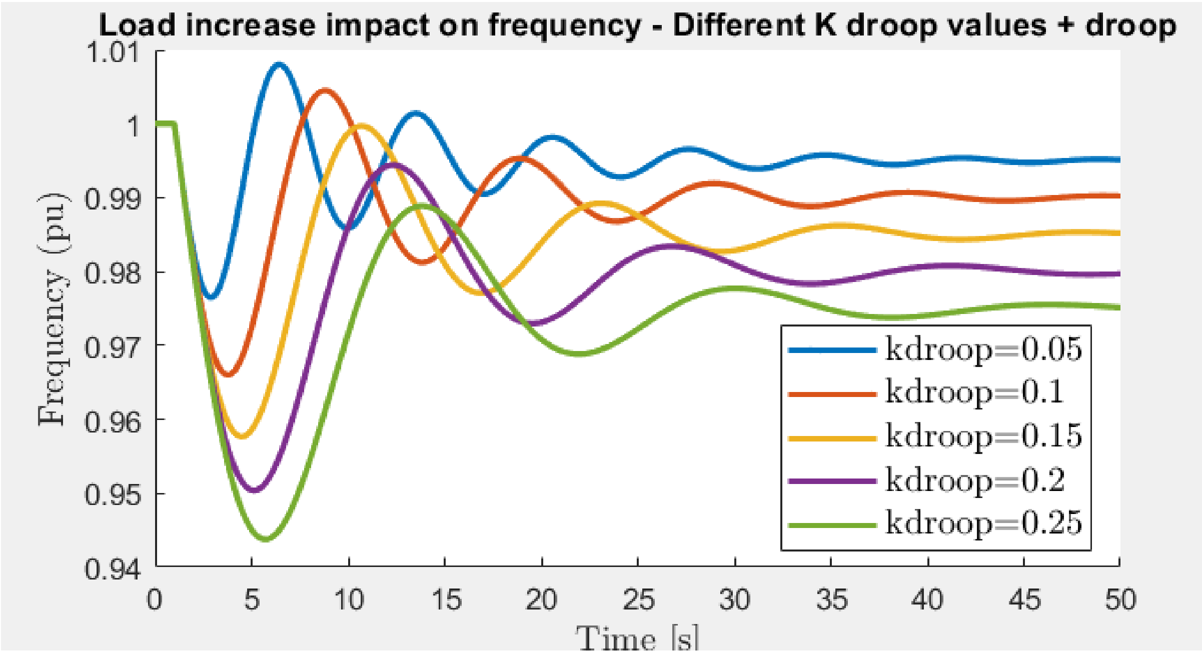


Figure 6: frequency response for different K droop constants

Looking at the same simulation module , we are also able to reduce the whole control loop into a single transfer function Figure 7, they both share identical behaviour.Figure 8

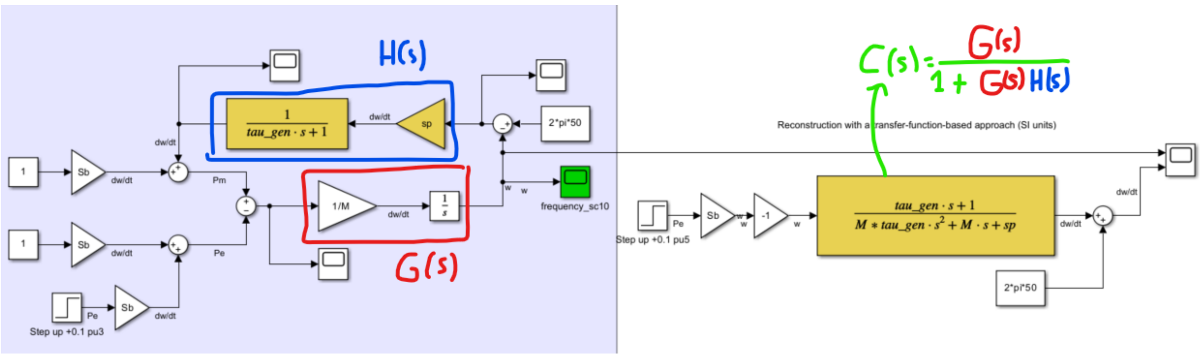


Figure 7: Whole system and transfer-functioned system

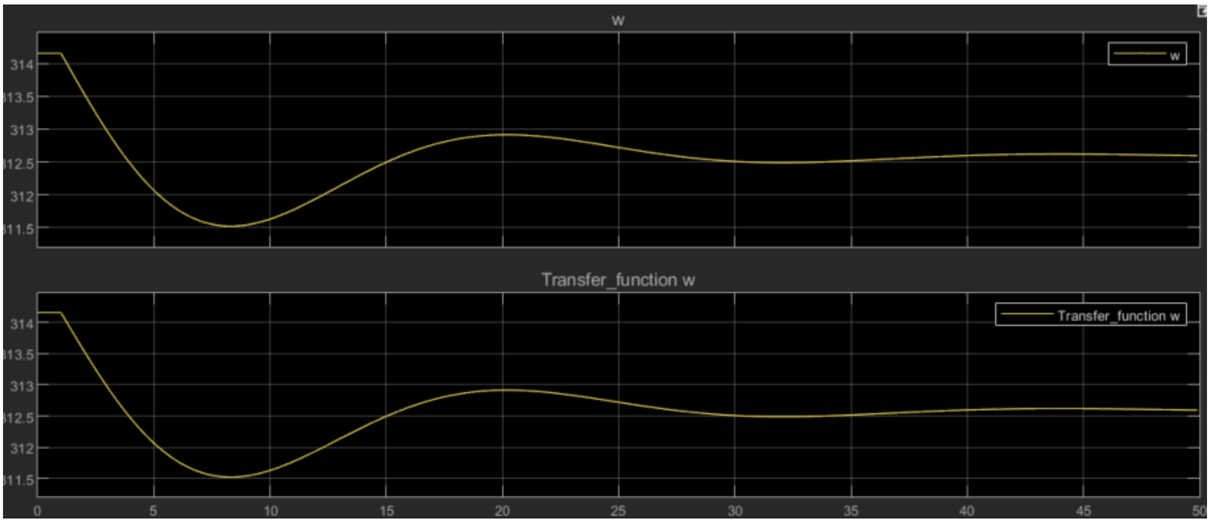


Figure 8: Exact same w response for both whole system and transfer-functioned system

1.3 Response of the 2 generator's system with droop frequency control

In order to test the droop action , two droop controlled synchronous generators are set in this simulation module.Figure 9

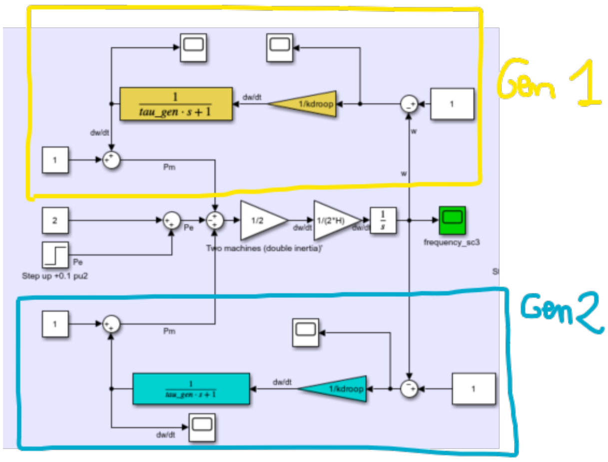


Figure 9: two generators instead of one

Both generators have identical tau (time response) and kdroop (droop constant), they will both colaborate the exact same ammount at the same time, this wont happen in real life.

Similar situation in Figure 10 to the single generation case Figure 5.

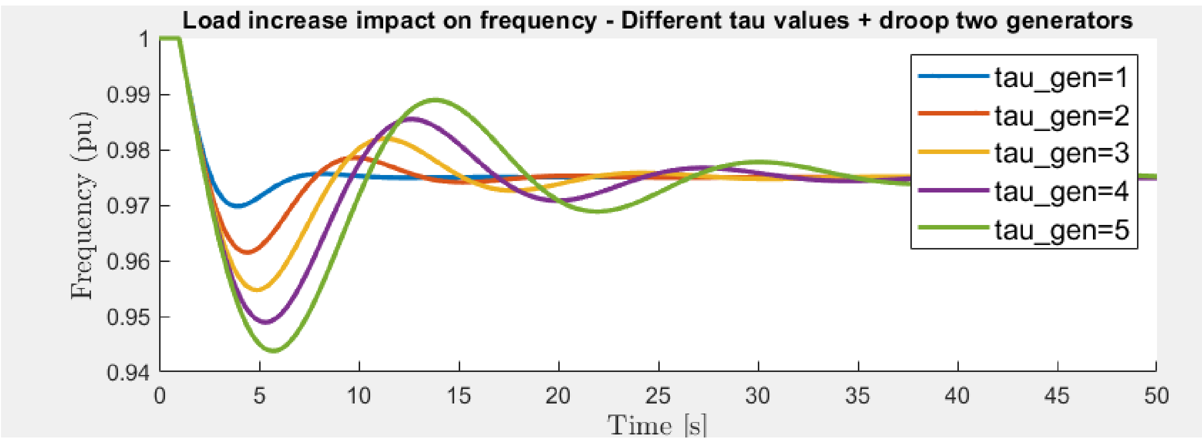


Figure 10: Effect on system frequency when varying both generator's tau constants

Similar situation in Figure 11 to the single generation case Figure 4.

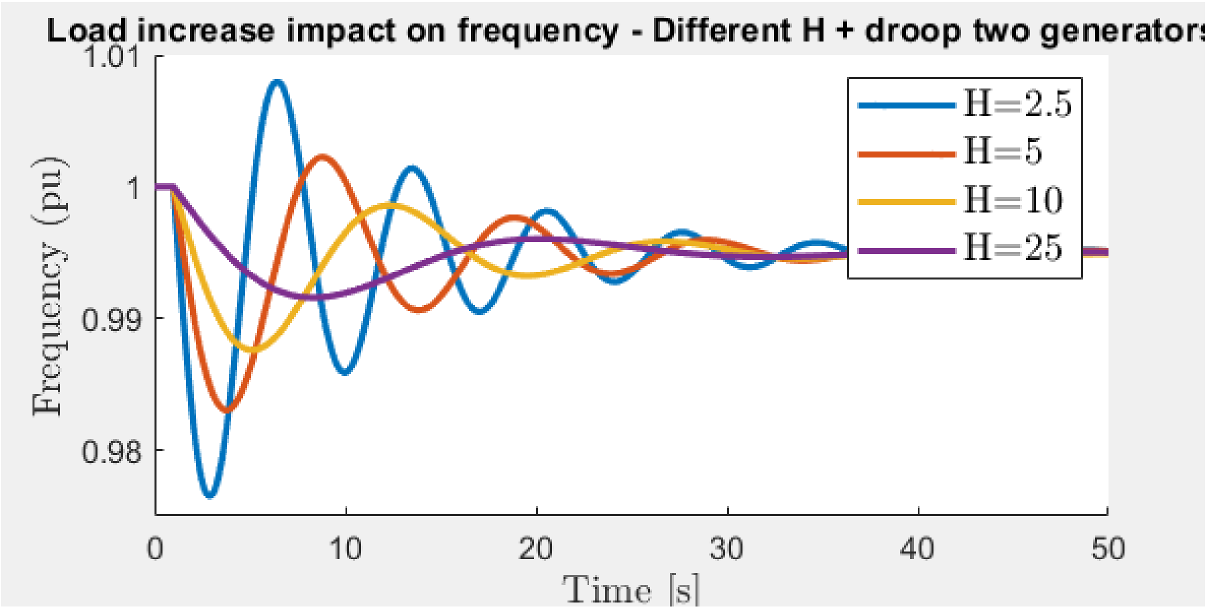


Figure 11: Effect on system frequency when varying both generator's Inertia constants

Similar situation in Figure 12 to the single generation case Figure 6.

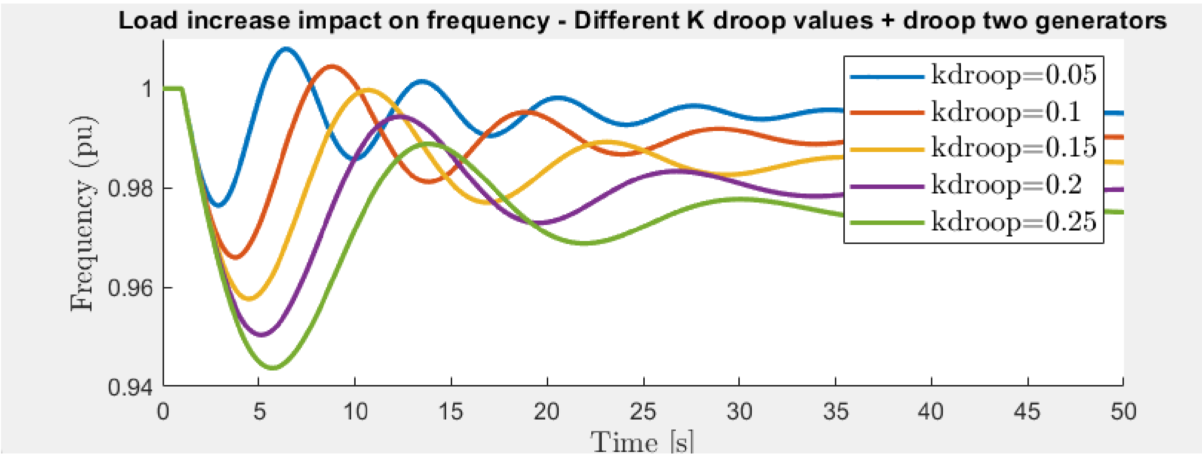


Figure 12: Effect on system frequency when varying both generator's kdroop constants

More interesting now, fixing the parameters of Generator 1, and varying the ones from generator 2 to see how they synchronise.Figure 13.

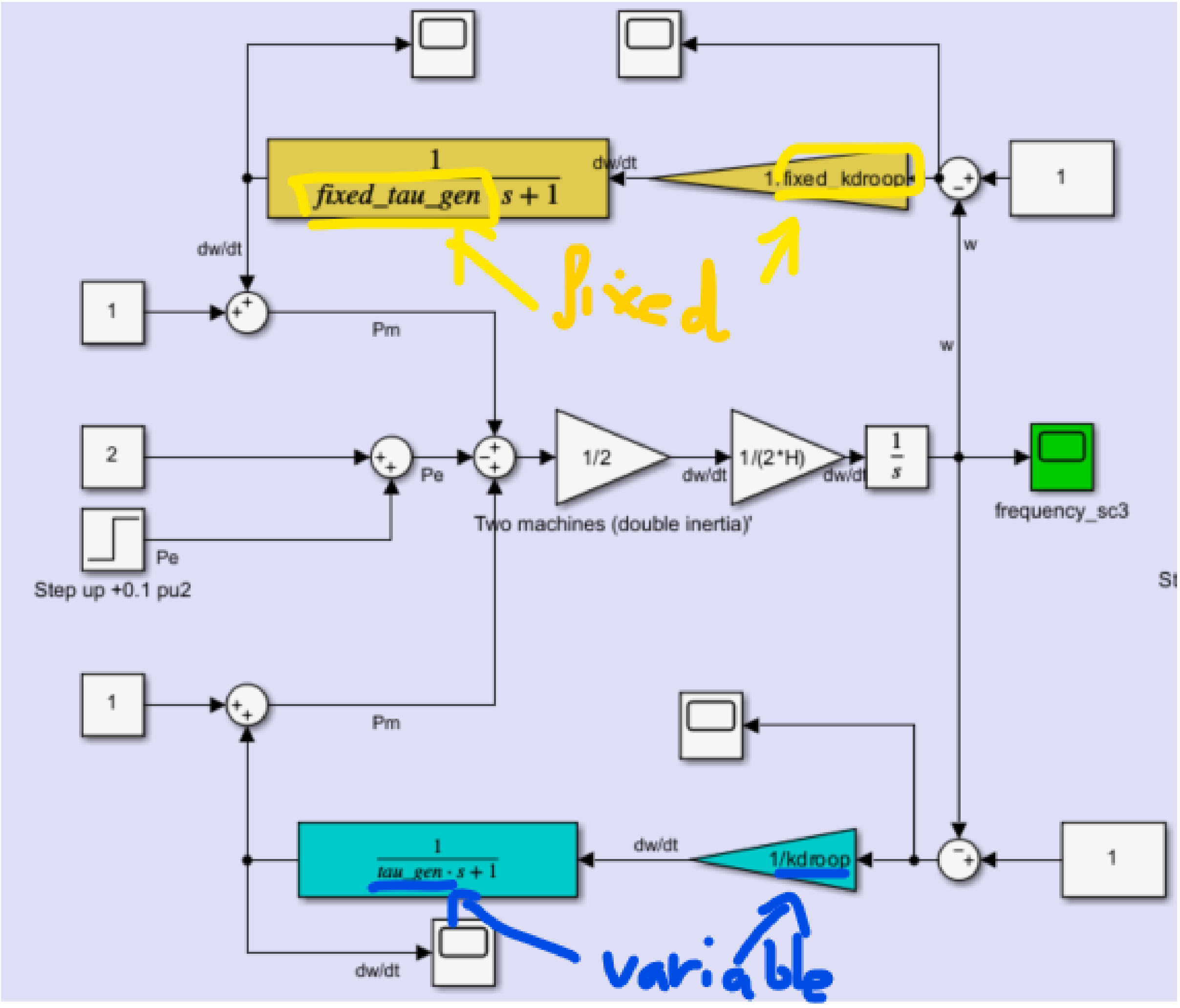


Figure 13: Simulink blocks, fixed generator1 parameteters

As seen in Figure 14 and Figure 15, both generators are still able to synchronise but slower, even if one of them has different tau or K droop. Both figures show a similar aggregated behaviour than the scenario with equal parameters, the faster generator (in this case Generator 2) doesn't take the full initial swing of the load perturbation, this validates the droop control power sharing concept.

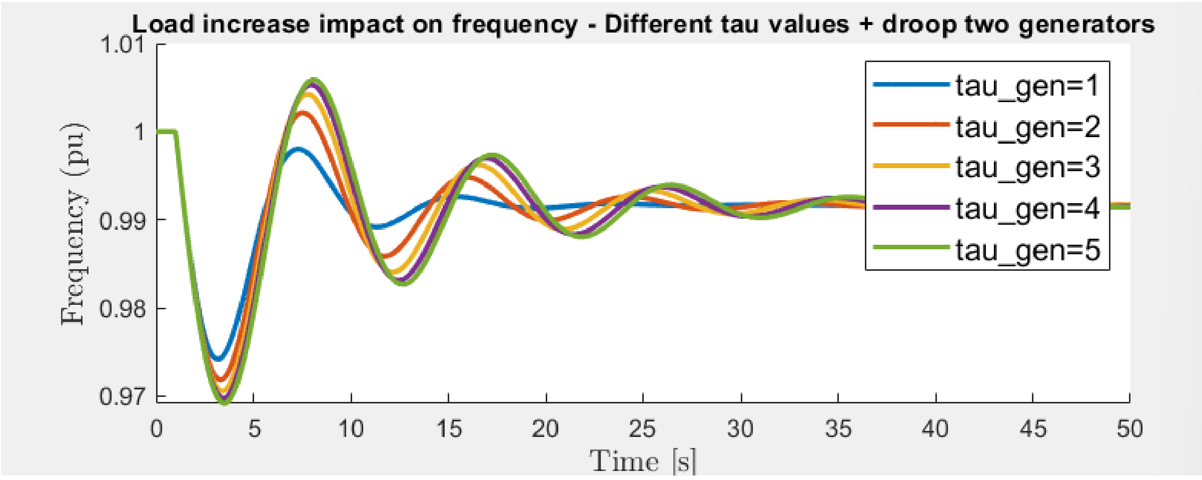


Figure 14: Frequency resulting from varying only Generator2 tau

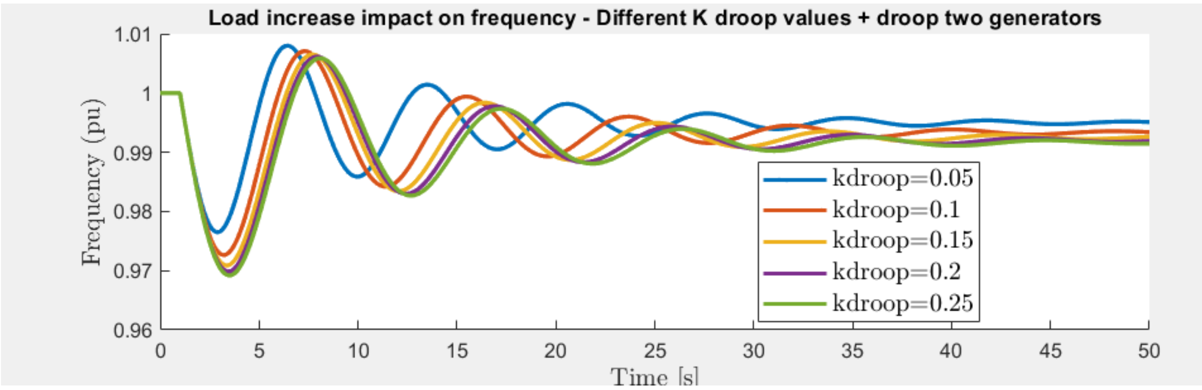


Figure 15: Frequency resulting from varying only Generator2 K

2 Grid forming VS Grid following dynamic response

Opening "VSC_GF_SG_params.m" and both simulink files "SG_GFOR_2020a" and "SG_GFOL_2020a" , to compare both control strategies for grid forming and grid following power converters respectivey.

2.1 Control structures of grid following/forming converters

Grid-forming and grid-following power converters play crucial roles in integrating renewable energy sources into power grids. Grid-forming converters are designed to establish and maintain grid voltage and frequency, operating autonomously to create a stable reference for other devices.

They utilize sophisticated control architectures such as droop control and virtual synchronous machines to mimic the behavior of traditional synchronous generators.

They are usually modelled as a amplitude and frequency(phase) controlled voltage source.Figure 16

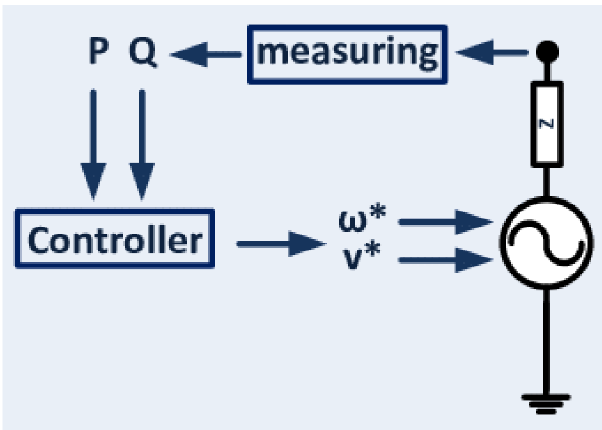


Figure 16: [1] basic control of grid forming converter.

On the other hand, grid-following converters rely on existing grid signals to synchronize and inject power accordingly. Their control architecture typically includes phase-locked loops (PLL) to track grid frequency and voltage, ensuring stable and efficient power delivery in a grid-supporting role.

Almost all power converters existing today are classified as grid followers.

They are usually modelled as an Active and reactive power controlled current source. Figure 17

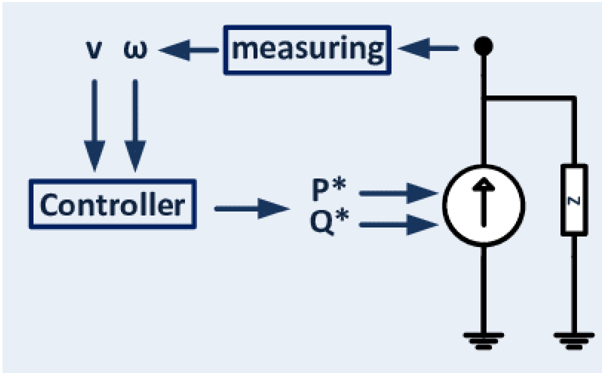


Figure 17: [1] basic control of grid following converter.

When facing the same load changes, both grid followign and grid forming type of converters will have the same stationary response (set by the identicall droop action), but their dynamic response is very different.

The grid forming power converters are able to deliver power much faster due to their voltage source behaviour Figure 18. They are also able to "heal" much better the frequency dip of the grid compared to pure grid following converters. (even with frequency support)

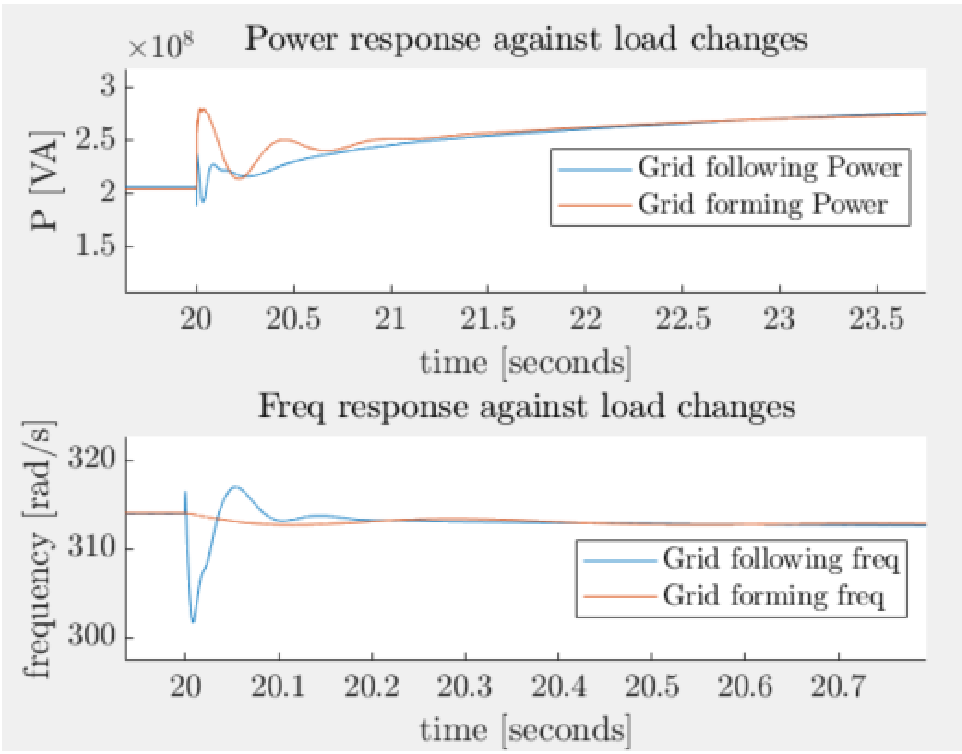


Figure 18: Power and frequency responses against load perturbations GFOL and GFOR

2.2 Grid-following control model

Simulating the effects of different inertia values for the synchronous generator, as already commented in previous points, a smaller inertia generator will be succeptible to faster changes (faster dynamics), this is why for higher inertia in Figure 19 the power and frequency reach stationary values faster, (even about to oscillate in the case of H=1).

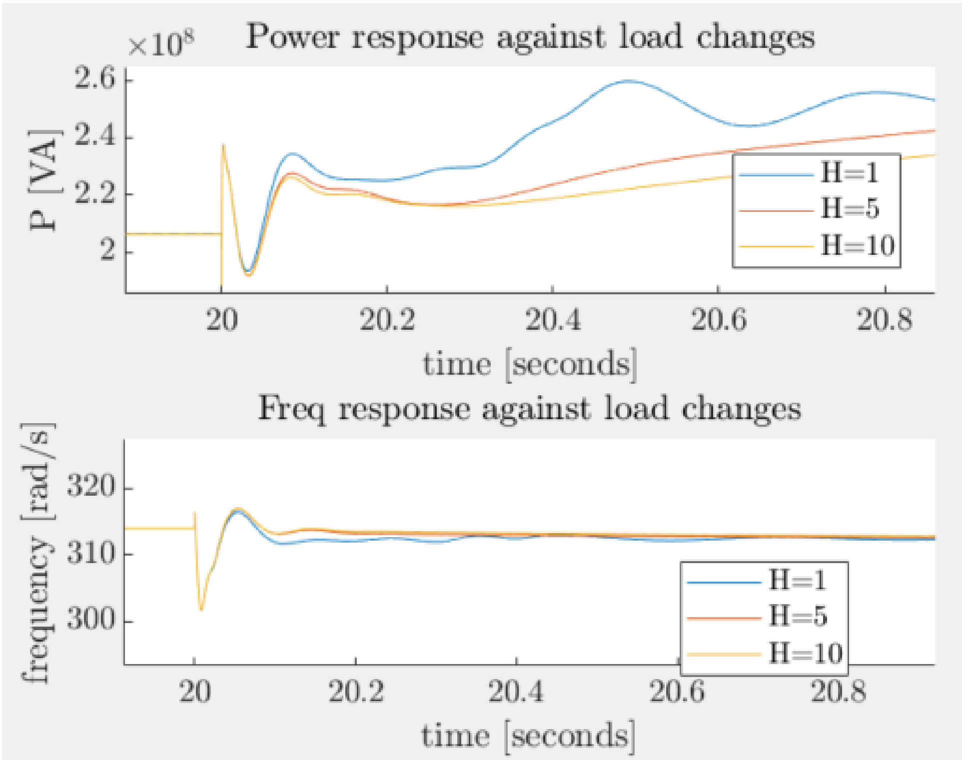


Figure 19: Power and Frequency response of a grid following converter for different SG's inertia values

The stationary working point is set by the Kdroop control, this means the simulated grid setling down for different power and frequency values for each kdroop.Figure 20 The higher the Kdroop value, the higher power and freq set points.

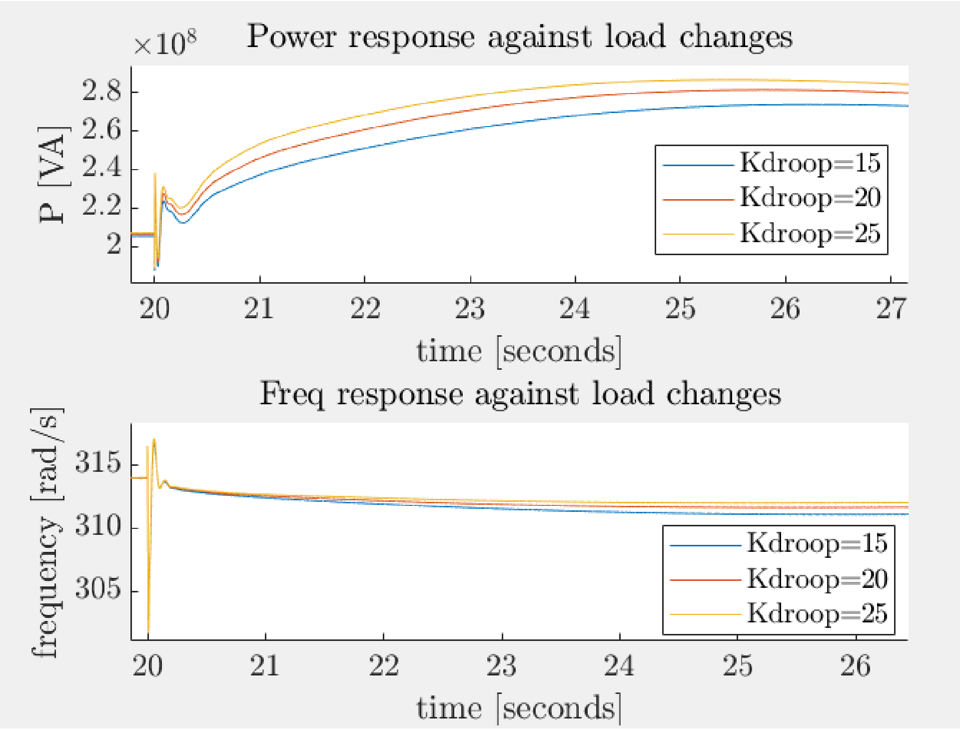


Figure 20: Power and Frequency response of a grid following converter for different Kdroop ratings 6,6% 5% and 4%

2.3 Grid-following control virtual inertia

Following the next image from the course notes to implement a virtual inertia control instead of Droop control Figure 21

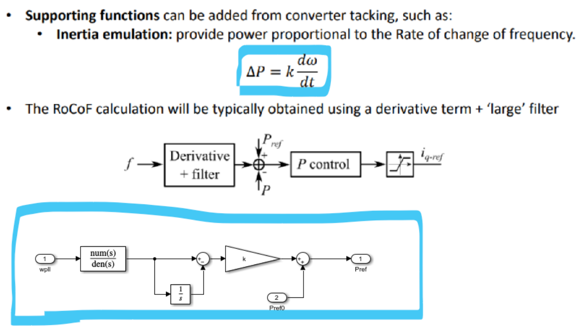


Figure 21: Enter Caption

Commenting out the droop control and introducing the Virtual inertia block instead.Figure 22

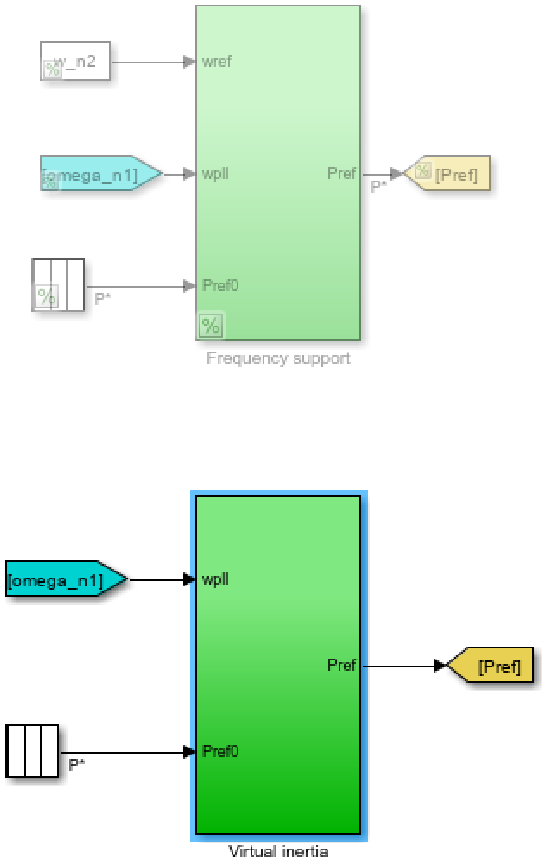


Figure 22: Using VSM instead of Droop control

Different K values creates a different virtual inertia which leads to different rocof values. For higher K , smaller virtual inertia behaviour. As i removed the droop control, there is no continuous push to recover to wref, thats why now there is a different stationary value of P and f for each K value. Figure 23

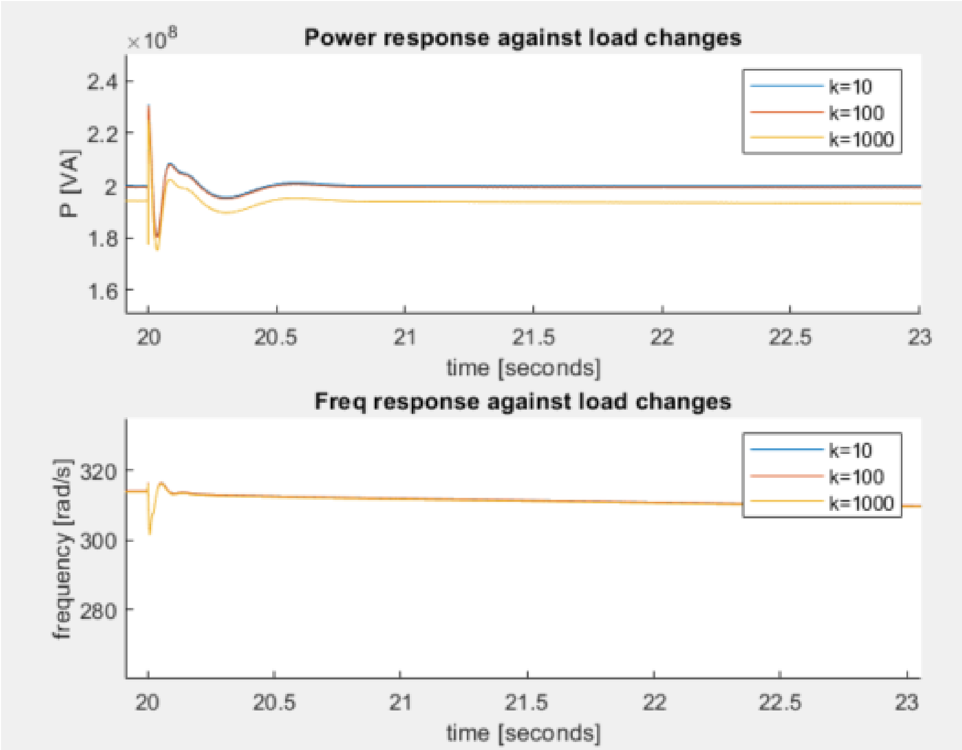


Figure 23: REsults of VSM for different inertia values

2.4 Grid-forming control model

Synchronous Generator's inertia variations have the same effect in this grid forming case, lower inertia value, uglier dynamics. Figure 24

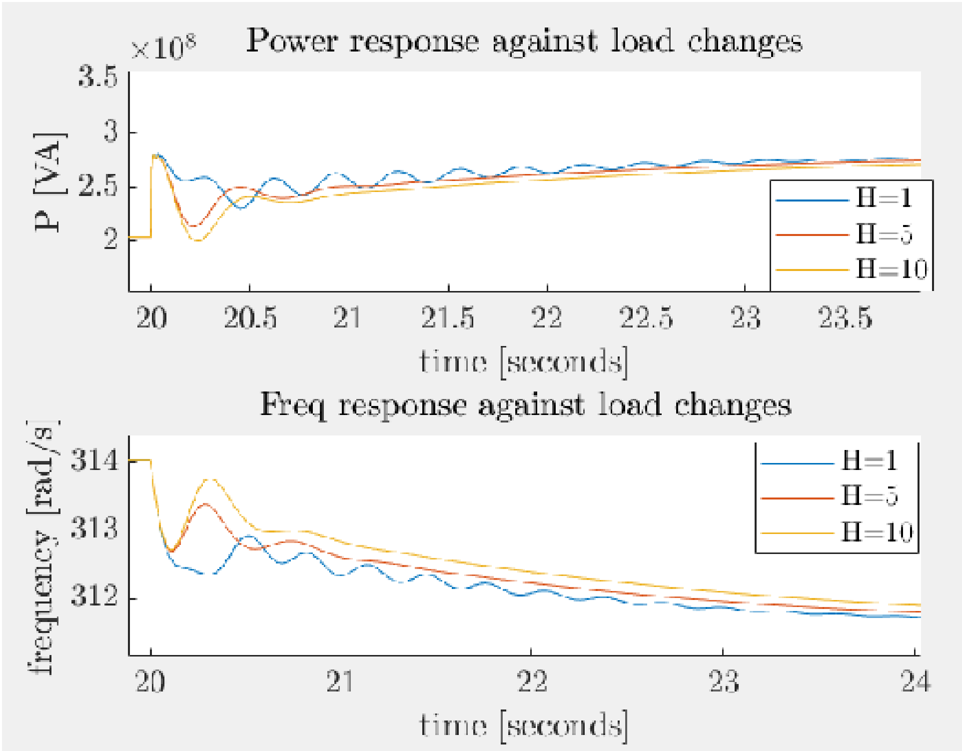


Figure 24: Power and Frequency response of a grid forming converter for different SG's inertia values

Kdroop variations have the same effect in grid forming power converters. The higher the Kdroop value, the higher power and freq set points. Figure 25

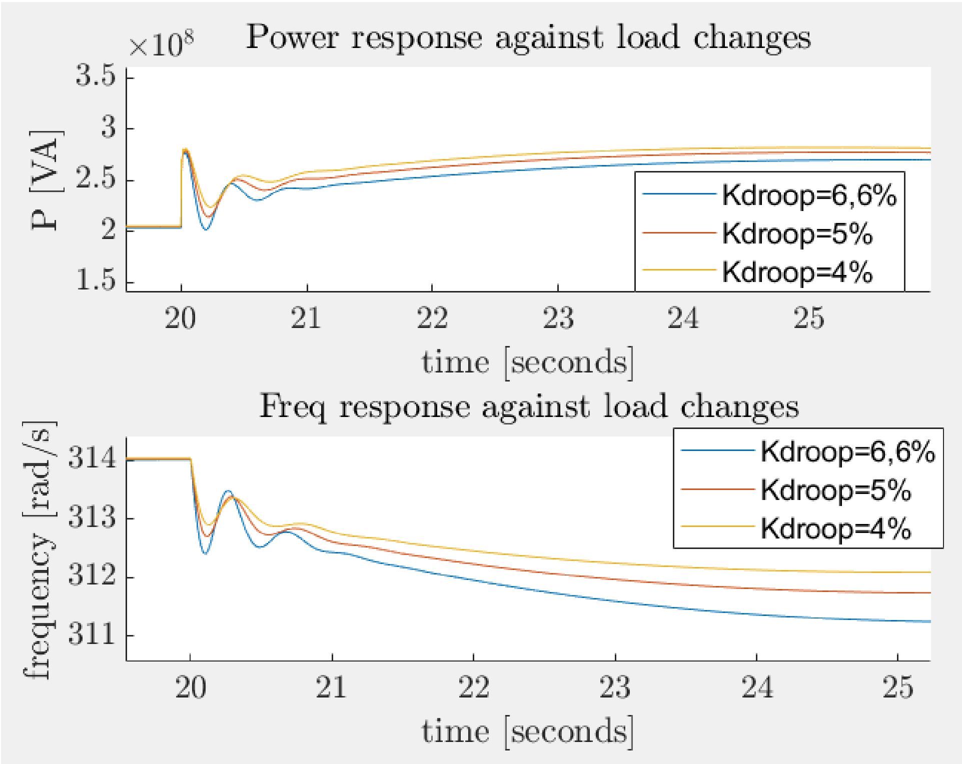


Figure 25: Power and Frequency response of a grid forming converter for different Kdroop ratings

Detuning the RLC filter Figure 26 has a small impact in the dynamic response, as the converter relies on precise and filtered Vabc for its AC voltage control block, after that, the same static values.

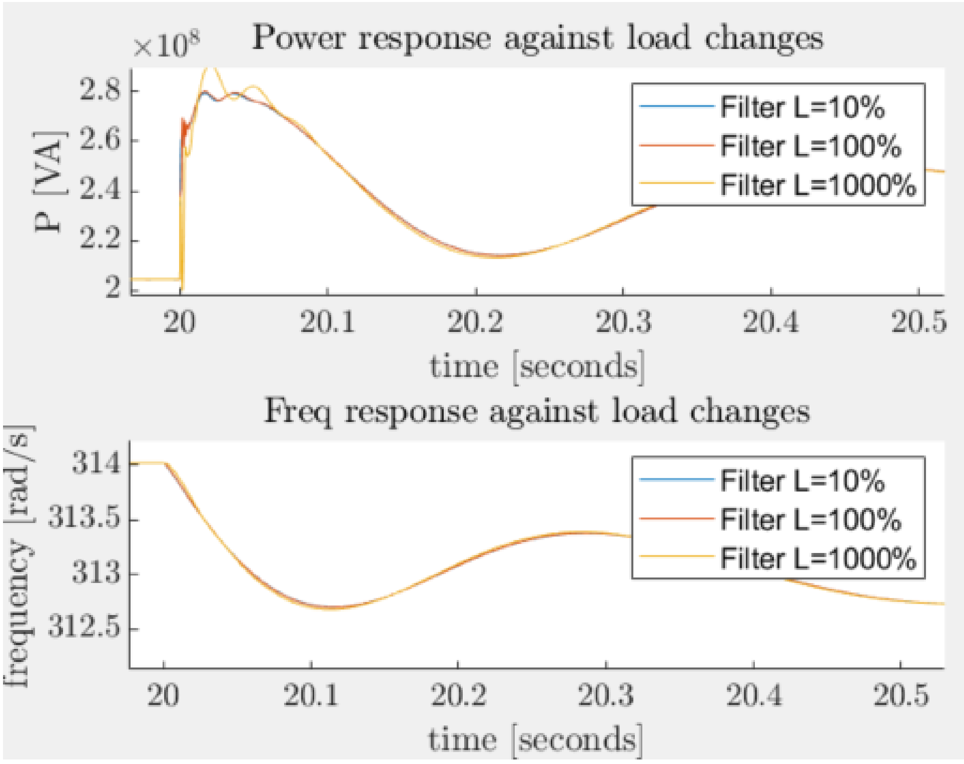


Figure 26: Power and Frequency response of a grid forming converter for different L values for its RLC filter

3 Creating my own grid forming structure

Lets try a simple Voltage control cascaded with a current loop.

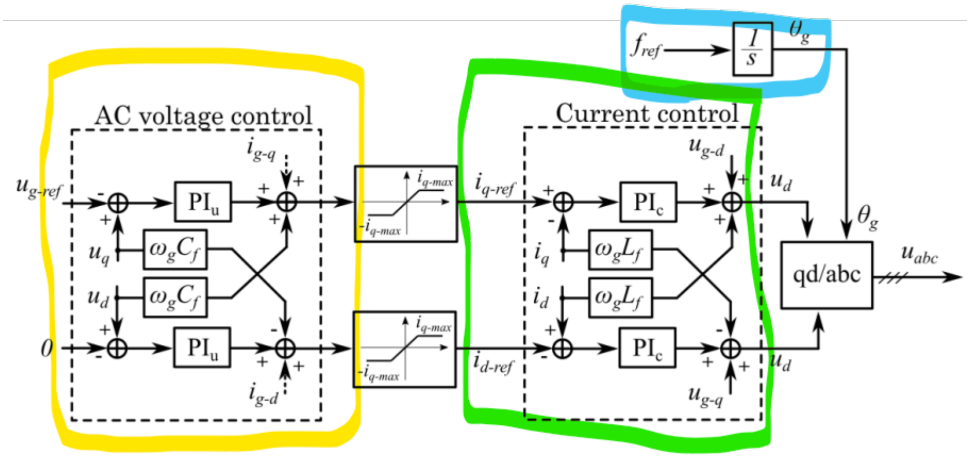


Figure 27: Cascaded control diagram, voltage control (yellow), current control (green) and angle reference (blue)

I just used the grid forming control used in previous point 2 modifying the way the angle is calculated with a PLL estimator and a virtual inertia block. The voltage abc measurements were noisy so an extra filtering stage was placed in between the volt meters and the capacitors, emulating the filtering power of a transformer. (Jaume suggestion).

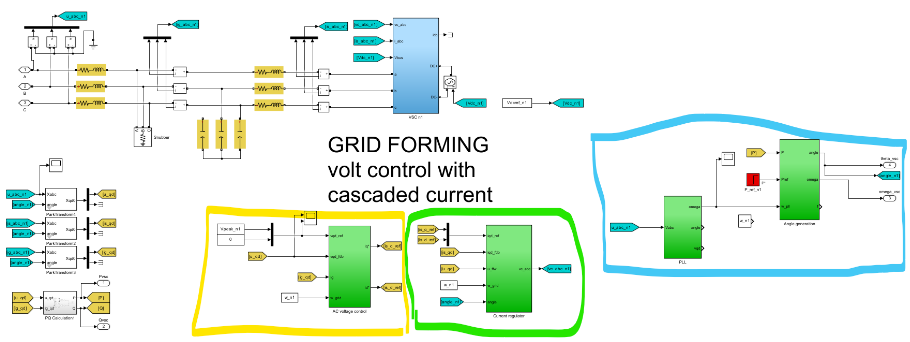


Figure 28: Cascaded control , simulink blocks with colored equivalent blocks

The virtual inertia was implemented following the formulas proposed in class.Figure 29, the control per se uses per unit magnitudes with conversion blocks in and out of the subsystem.

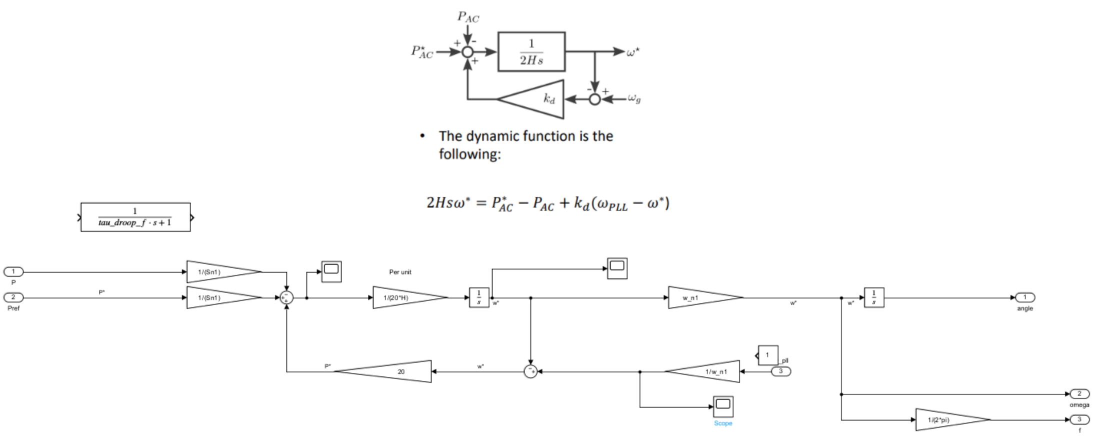


Figure 29: Detail of the virtual inertia simulink blocks

The control behaves as expected against load disturbances, the converter only provides inertia , it doesnt latch providing power even if the frequency deviated from the reference. The grid eventually stabilises back to 50Hz.(>20seconds)

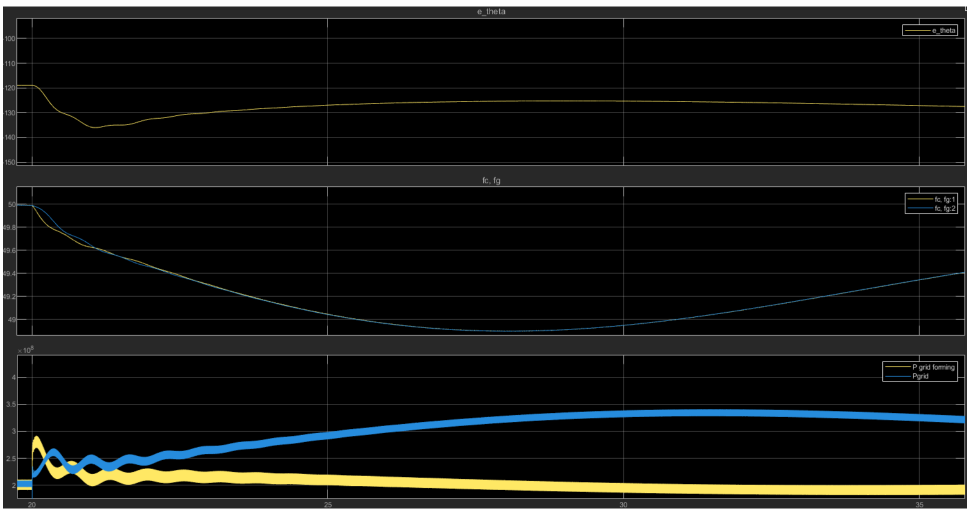


Figure 30: Cascaded control results, angle differences, local frequency and power for both Sinchronous gen and power converter

If H parameters is increased to x10 its original value, we notice the power converter dynamics being much slower, this corroborates we are able to correctly programm the power converter virtual inertia .Figure 31 The grid also eventually stabilises back to 50Hz.(»»20seconds)

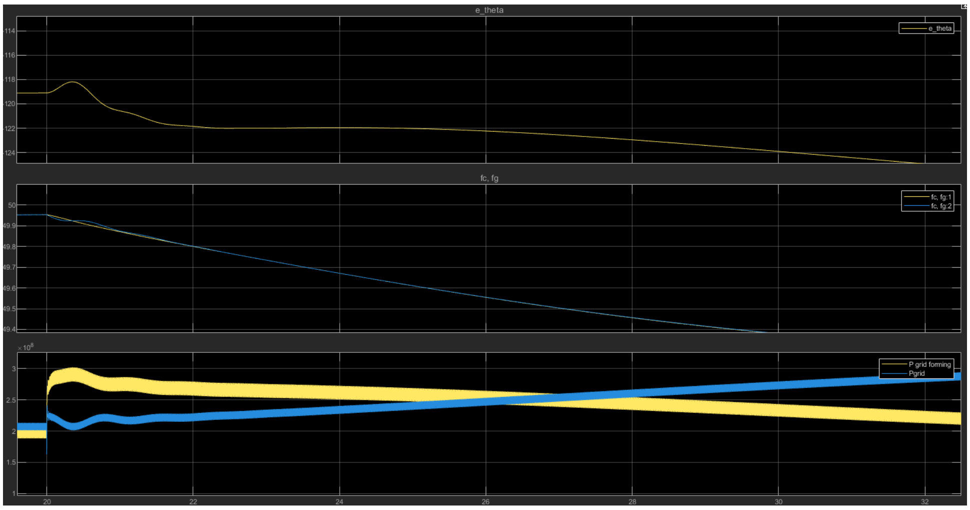


Figure 31: Cascaded control results Inertia x 10, angle differences, local frequency and power for both Sinchronous gen and power converter

4 Code

Code available in **this Github repo**

References

[1] Claudio De Persis, `Sept 2015,University of Groningen` *"A Communication-Free Master-Slave Microgrid with Power Sharing"*