FICHE I18: Grid forming

Simulation results

APPLICABLE TO TYPE C, D - ELECTRICITY STORAGE MODULES

Objectives

For different operating points (within energy and current limits), and different network operating conditions the Electricity Storage Module shall demonstrate its capability to behave as Grid Forming unit. This behavior will be assessed with different events, and associated compliance criteria.

This fiche will give the necessary technical details to run the simulation for validating the Grid Forming performance of the Electricity Storage Module.

Consultation

GENERAL SYSTEM DESCRIPTION

1. Models

The model to be used for running simulations for the tests presented in this document is as such: the unit/farm is connected to a controllable infinite bus with an impedance x_{grid}.
The Power Generating Unit should be represented according to data provided in the fiche E1 relative to unit / farm technical description. (Models can be in EMT or Phasor framework, the BESS operator should state for each simulation what type of model is used, as filters such as positive sequence filter of EMT simulation introduces a delay in the measured responses.) If the storage unit state of charge has an impact on performance of the inverter seen from the AC side, therefore, this must be included in the model.

The voltage-source behavior shall be evaluated at the Power Generating Unit level by comparing its response to the response of a voltage source behind impedance as defined later in this document. The Power Generating Unit model comprises a converter, a series filter, and a transformer, providing connection to the plant's MV point of connection as seen in Figure 1. Power Generating Units with identical characteristics (tuning parameters, filter impedances, and transformer impedances) shall be tested once. Power Generating Units with differing characteristics shall each be tested separately.

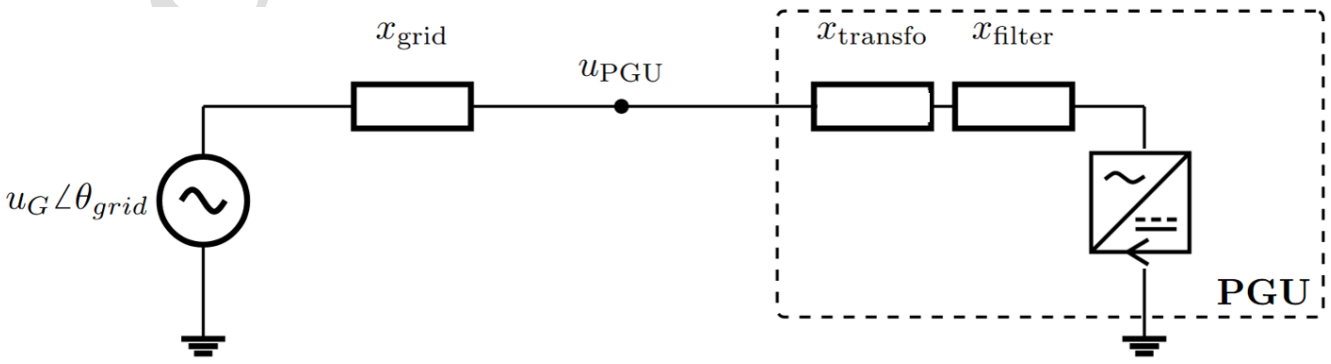


Figure 1 Power Generating Unit (PGU) representation

In this document, the ideal behavior of grid-forming converter is modelled as an ideal voltage source with a series impedance. The effective impedance x_{eff} should represent the combination of the converter's internal impedance

plus the filter and transformer impedances up to the Power Generating Unit terminals. x_{eff} thus represents the impedance of the ideal source and serves as reference behavior, see Figure 2.

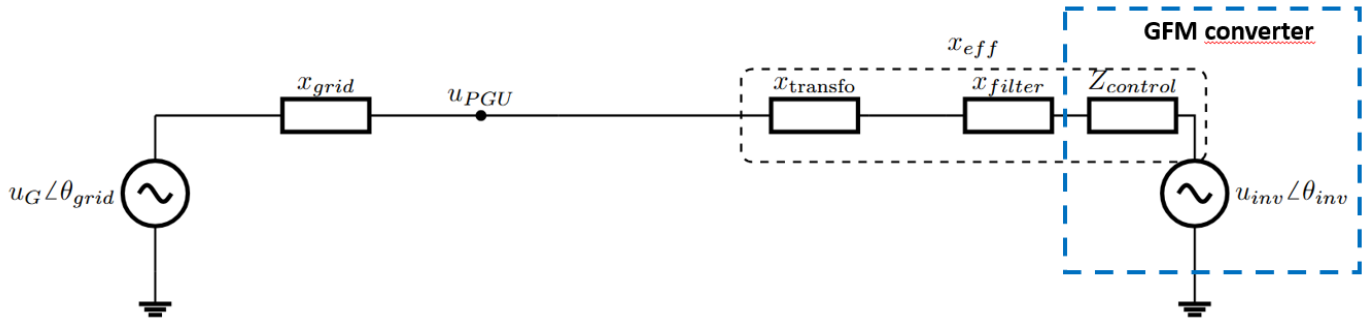


Figure 2 Effective impedance representation within a PGU

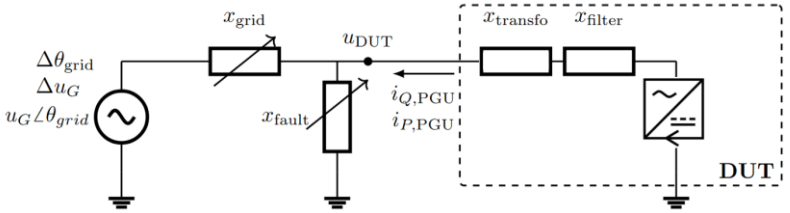
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Even if not explicitly mentioned in the requirement, all inverter behaviors are limited to the maximum current of the inverter and the available storage in the storage unit. The maximum short-term current will need to be defined from the manufacturer and used for the compliance criteria. All envelopes used for compliance testing will be limited to the maximum short-term current.

The envelopes are available here :
dyn-grid-compliance-verification/docs/GFM_envelopes_curves/Envelopes at GFM-changes · dynawo/dyn-grid-compliance-verification · GitHub

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2. Testbench summary

Testbench 1	Grid model connected to a PGU (DUT)	 • DUT (Device Under Test), represents the unit to be tested • x_{grid}, shall be adjustable to emulate weak and strong grids • u_G, denotes the grid-side voltage source and shall be varied in magnitude for test purposes. • θ_{grid}, denotes the grid phase angle and shall be modified as specified by the test procedure. • x_{fault}shall be configurable to represent different fault types

concertation

The testbench 1 must be used by the BESS operator for all the tests required in this fiche.

3. Summary of tests and compliance

	Description	Compliance criteria
Active power response following a voltage phase jump	Phase shift at the infinite bus	Envelope for active current Damping of active / reactive current and voltage.
Reactive power response following a voltage magnitude jump	Amplitude step at the infinite bus	Envelope for reactive current Damping of active / reactive current and voltage.
Active power response following a frequency variation (Rate of Change of Frequency test)	Frequency change at the infinite bus	Envelope for active current Damping of active / reactive current and voltage.
Active power response following a Short Circuit Ratio jump event	Grid impedance change (Short Circuit Ratio variation)	Envelope for active current Damping of active / reactive current and voltage.
Fault behavior	Fault behavior for different conditions	No criteria, only informative.

4. Base Values:

Tests defined in the following fiches are in per unit considering the Power Generating Unit as the base for the following parameters

S_{base}: apparent power of the Power Generating Unit

U_{base}: phase to phase RMS voltage of the Power Generating Unit

$x_{base} = \frac{U_{base}^2}{S_{base}}$: base impedance

5. Operating conditions

In this draft version, all tests will be carried out at PGU terminal.

SCR_{min}=2

SCR_{max}=10

x_{eff} = 0.27 pu

$T_{R,\,PPM}$ =10 s (corresponding to H = 5 s)

For avoidance of doubt $x_{grid} = \frac{1}{SCR}$

Operating conditions	Active power	Reactive power	Energy available (State of Charge)	Voltage
OC1	0	0	50%	1

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OC2	0.5 Pn	0	50%	1
OC3	-0.5 Pn	0	50%	1
OC4	0.95 Pn	0	50%	1
OC5	-0.95 Pn	0	50%	1
OC6	0	-Qmax = -0.3 Pn	50%	1
OC7	0	Qmax = 0.3 Pn	50%	1

6. Ancillary services deactivation

All ancillary services modes must be deactivated during the GFM performance assessment as the aim is to assess the voltage source behavior on short-term, and to avoid any interaction with additional control loops.

For avoidance of doubt, these are the controls that should be deactivated.

Description	Enable
Voltage control	No
Frequency sensitivity mode	No
Limited frequency sensitivity mode (under)	No
Limited frequency sensitivity mode (over)	No

TEST 1: <u>Voltage angle steps:</u>

Test system: TestBench1

Simulation:

An angle step at the infinite bus (Thevenin equivalent) of $\Delta\theta_{grid}$ should occur in the system. The simulation should last at least until the steady state is reached.

Specific conditions:

The tests should be done with two different values of x_{grid} corresponding to SCR_{min} $\left(x_{grid,\,min}\right)$ and SCR_{max} $\left(x_{grid,\,max}\right)$ and for four different voltage angle jumps corresponding to +/- $0.3 \cdot \left(x_{eff} + x_{grid}\right)$ and $0.6 \cdot \left(x_{eff} + x_{grid}\right)$.

The tests should be done for OC 2 and 3 to demonstrate adequate behavior, and for OC 4 and 5 to demonstrate a correct saturation of the installation (no trip).

Scenario	Voltage angle step $\Delta\theta_{grid}$	SCR

concertation

S_VolAngStep 1	6.36°	SCR_{max}
S_VolAngStep 2	-6.36°	SCR_{max}
S_VolAngStep 3	13.24°	SCR_{min}
S_VolAngStep 4	-13.24°	SCR_{min}
S_VolAngStep 5	12.72°	SCR_{max}
S_VolAngStep 6	-12.72°	SCR_{max}
S_VolAngStep 7	26.47°	SCR_{min}
S_VolAngStep 8	-26.47°	SCR_{min}

Test Matrix:

The tests must be done for the following operating points and scenarios:

Test	Scenario	Operating Conditions
S_VolAngStep1OC2	S_VolAngStep1	OC2
S_VolAngStep1OC3	S_VolAngStep1	OC3
S_VolAngStep2OC2	S_VolAngStep2	OC2
S_VolAngStep2OC3	S_VolAngStep2	OC3
S_VolAngStep3OC2	S_VolAngStep3	OC2
S_VolAngStep3OC3	S_VolAngStep3	OC3
S_VolAngStep4OC2	S_VolAngStep4	OC2
S_VolAngStep4OC3	S_VolAngStep4	OC3
S_VolAngStep1OC4	S_VolAngStep1	OC4
S_VolAngStep1OC5	S_VolAngStep1	OC5
S_VolAngStep2OC4	S_VolAngStep2	OC4
S_VolAngStep2OC5	S_VolAngStep2	OC5
S_VolAngStep3OC4	S_VolAngStep3	OC4
S_VolAngStep3OC5	S_VolAngStep3	OC5
S_VolAngStep4OC4	S_VolAngStep4	OC4
S_VolAngStep4OC5	S_VolAngStep4	OC5

Test	Scenario	Operating Conditions
S_VolAngStep5OC2	S_VolAngStep5	OC2
S_VolAngStep5OC3	S_VolAngStep5	OC3
S_VolAngStep6OC2	S_VolAngStep6	OC2
S_VolAngStep6OC3	S_VolAngStep6	OC3
S_VolAngStep7OC2	S_VolAngStep7	OC2
S_VolAngStep7OC3	S_VolAngStep7	OC3
S_VolAngStep8OC2	S_VolAngStep8	OC2
S_VolAngStep8OC3	S_VolAngStep8	OC3
S_VolAngStep5OC4	S_VolAngStep5	OC4

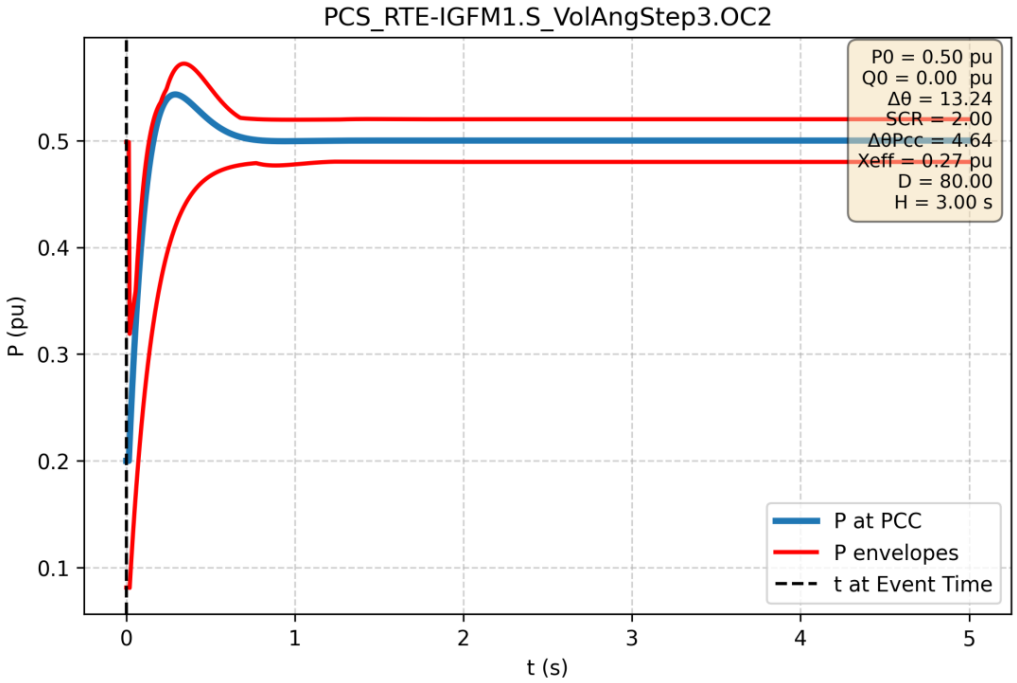
orientation

S_VolAngStep5OC5	S_VolAngStep5	OC5
S_VolAngStep6OC4	S_VolAngStep6	OC4
S_VolAngStep6OC5	S_VolAngStep6	OC5
S_VolAngStep7OC4	S_VolAngStep7	OC4
S_VolAngStep7OC5	S_VolAngStep7	OC5
S_VolAngStep8OC4	S_VolAngStep8	OC4
S_VolAngStep8OC5	S_VolAngStep8	OC5

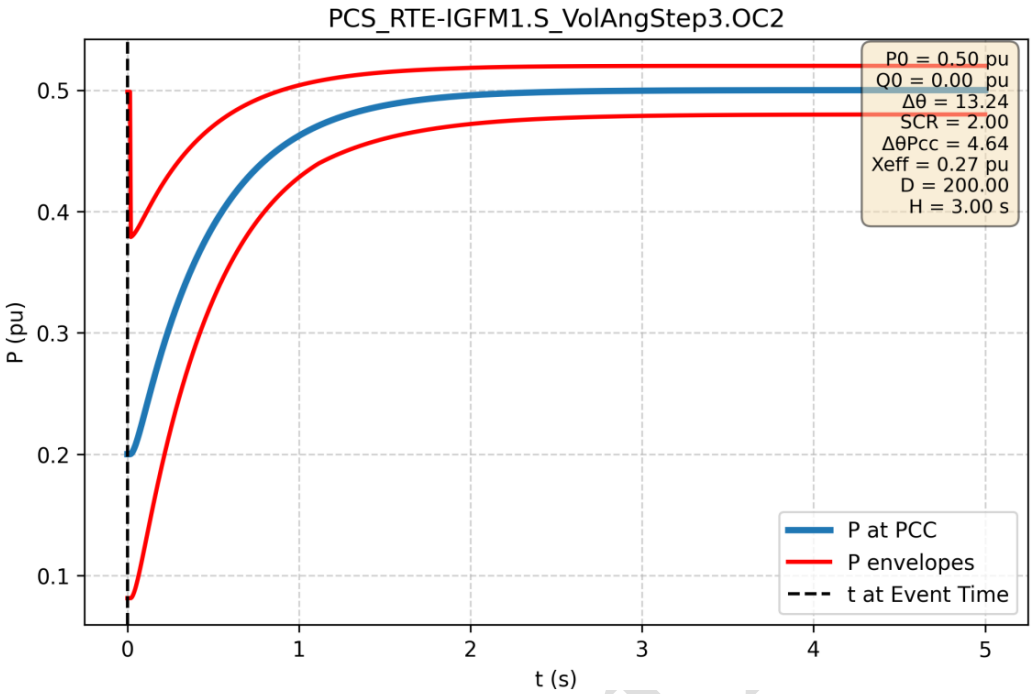
Performance will be assessed using envelopes:

As an example for the test **S_VolAngStep3OC2** the envelope is:

- For an underdamped response:



- For an overdamped response:



TEST 2: <u>Voltage amplitude steps:</u>

Test system: TestBench1

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Simulation:

An amplitude step Δu_G at the infinite bus should occur. The simulation should last at least until the steady state is reached.

Specific conditions:

The tests should be done with two different values of x_{grid} corresponding to $SCR_{min}(x_{grid,\,min})$ and $SCR_{max}(x_{grid,\,max})$ and for four different voltage magnitude jumps +/- 0.15 $(x_{eff} + x_{grid})$

Scenario	Voltage Magnitude Jump (Δu_G)	SCR
S_VolAmpStep1	0.116 pu	SCR_{min}
S_VolAmpStep2	-0.116 pu	SCR_{min}
S_VolAmpStep3	0.056 pu	SCR_{max}
S_VolAmpStep4	-0.056 pu	SCR_{max}

Test Matrix:

The tests must be done for the following operating points and scenarios:

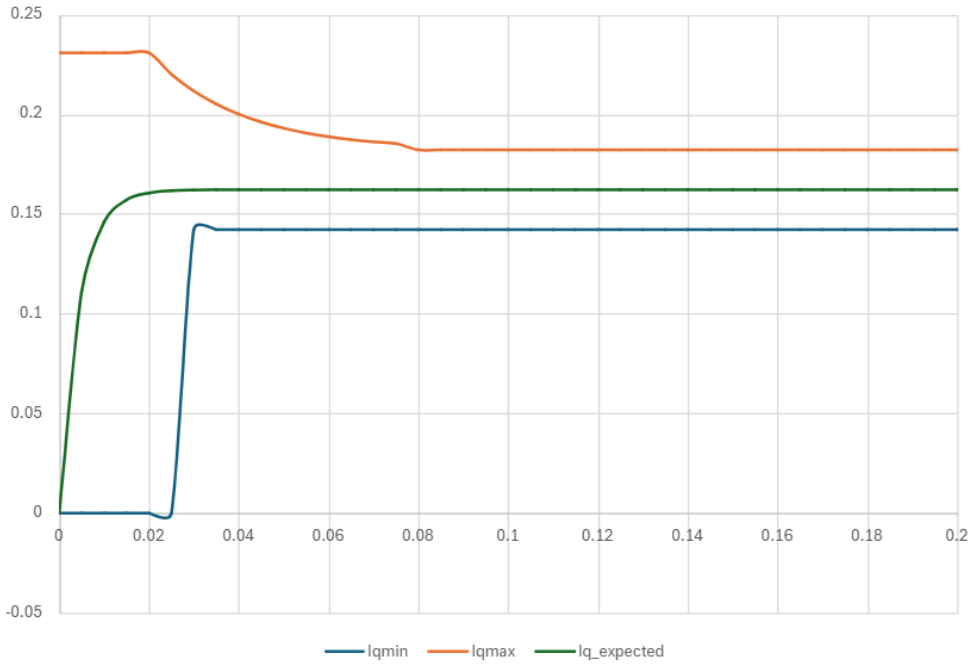
Test	Scenario	Operating Conditions
S_VolAmpStep1_OC1	S_VolAmpStep1	OC1
S_VolAmpStep1_OC2	S_VolAmpStep1	OC2
S_VolAmpStep1_OC3	S_VolAmpStep1	OC3
S_VolAmpStep1_OC4	S_VolAmpStep1	OC4

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S_VolAmpStep1_OC5	S_VolAmpStep1	OC5
S_VolAmpStep1_OC6	S_VolAmpStep1	OC6
S_VolAmpStep1_OC7	S_VolAmpStep1	OC7
S_VolAmpStep2_OC1	S_VolAmpStep2	OC1
S_VolAmpStep2_OC2	S_VolAmpStep2	OC2
S_VolAmpStep2_OC3	S_VolAmpStep2	OC3
S_VolAmpStep2_OC4	S_VolAmpStep2	OC4
S_VolAmpStep2_OC5	S_VolAmpStep2	OC5
S_VolAmpStep2_OC6	S_VolAmpStep2	OC6
S_VolAmpStep2_OC7	S_VolAmpStep2	OC7
S_VolAmpStep3_OC1	S_VolAmpStep3	OC1
S_VolAmpStep3_OC2	S_VolAmpStep3	OC2
S_VolAmpStep3_OC3	S_VolAmpStep3	OC3
S_VolAmpStep3_OC4	S_VolAmpStep3	OC4
S_VolAmpStep3_OC5	S_VolAmpStep3	OC5
S_VolAmpStep3_OC6	S_VolAmpStep3	OC6
S_VolAmpStep3_OC7	S_VolAmpStep3	OC7
S_VolAmpStep4_OC1	S_VolAmpStep4	OC1
S_VolAmpStep4_OC2	S_VolAmpStep4	OC2
S_VolAmpStep4_OC3	S_VolAmpStep4	OC3
S_VolAmpStep4_OC4	S_VolAmpStep4	OC4
S_VolAmpStep4_OC5	S_VolAmpStep4	OC5
S_VolAmpStep4_OC6	S_VolAmpStep4	OC6
S_VolAmpStep4_OC7	S_VolAmpStep4	OC7

Performance will be assessed using envelopes:

As an exemple for the test **S_VolAmpStep1_OC2** the envelope will be:



Cancellation

TEST 3: <u>Short Circuit Ratio variations:</u>

Test System: Testbench 1

Simulation:

A variation in the Short Circuit Ratio occurs in the grid and is done by a change in the grid impedance switching from an initial value -$x_{grid,\,initial} = \frac{1}{SCR_{initial}}$.- to a final value - $x_{grid,\,final} = \frac{1}{SCR_{final}}$ -. The simulation should last at least until the steady state is reached.

Specific conditions:

There are two different scenarios to consider:

Scenario	$SCR_{initial}$	SCR_{final}
S_SCRup1	2	10
S_SCRdown1	10	2

Test Matrix:

The tests must be done for the following operating points and scenarios:

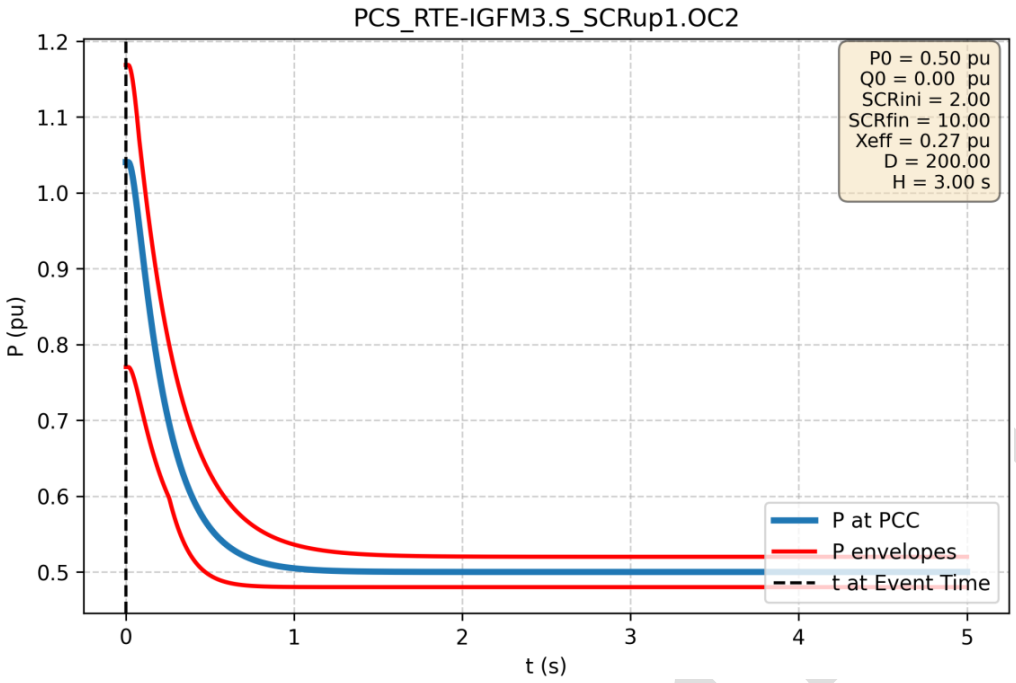
Test	Scenario	Operating Conditions
S_SCRup1_OC1	S_SCRup1	OC1
S_SCRup1_OC2		OC2
S_SCRup1_OC3		OC3
S_SCRup1_OC4		OC4
S_SCRup1_OC5		OC5
S_SCRdown1_OC1	S_SCRdown1	OC1
S_SCRdown1_OC2		OC2
S_SCRdown1_OC3		OC3
S_SCRdown1_OC4		OC4
S_SCRdown1_OC5		OC5

concertation

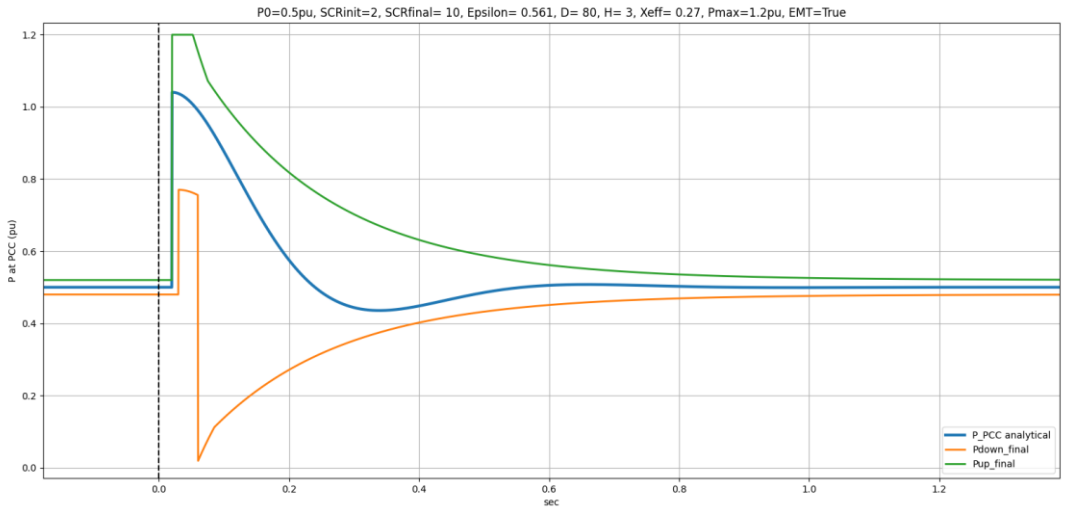
Performance will be assessed using envelopes:

As an exemple for the test S_SCRup1_OC2 the envelope will be:

- For an overdamped response:



- For an underdamped response:



TEST 4: <u>Frequency ramp:</u>

Test system: Testbench1

Simulation:

The frequency of the infinite bus will be modified, and the simulation should last at least until steady state is reached.

Specific conditions:

The tests should be done with two different values of x_{grid} corresponding to $SCR_{min}(x_{grid,\,min})$ and $SCR_{max}(x_{grid,\,max})$ and for four different profiles of frequency variations:

1. Profile 1 - Starting at 49.5 Hz (initial frequency) + 0.5Hz/sec for 3 s (Rate of Change of Frequency)
2. Profile 2 - Starting at 50.5 Hz (initial frequency) - 0.5Hz/sec for 3 s (Rate of Change of Frequency)
3. Profile 3 - Starting at 49.5 Hz (initial frequency) + 2 Hz/sec for 500 ms (Rate of Change of Frequency)
4. Profile 4 - Starting at 50.5 Hz (initial frequency) - 2 Hz/sec for 500 ms (Rate of Change of Frequency)

Exclusion area: in case of state of charge above 95% (resp. below 5%), inertia provision for decreasing (resp. increasing) frequency is not required.

Scenario	Frequency Profile	SCR
S_Rocof1	Profile 1	SCR_{min}
S_Rocof2	Profile 2	SCR_{min}
S_Rocof3	Profile 3	SCR_{min}
S_Rocof4	Profile 4	SCR_{min}
S_Rocof5	Profile 1	SCR_{max}
S_Rocof6	Profile 2	SCR_{max}
S_Rocof7	Profile 3	SCR_{max}
S_Rocof8	Profile 4	SCR_{max}

Test Matrix:

The tests must be done for the following operating points and scenarios:

Test	Scenario	Operating Conditions
S_Rocof1_OC1	S_Rocof1	OC1
S_Rocof1_OC2	S_Rocof1	OC2
S_Rocof1_OC3	S_Rocof1	OC3
S_Rocof2_OC1	S_Rocof2	OC1
S_Rocof2_OC2	S_Rocof2	OC2
S_Rocof2_OC3	S_Rocof2	OC3
S_Rocof3_OC1	S_Rocof3	OC1
S_Rocof3_OC2	S_Rocof3	OC2
S_Rocof3_OC3	S_Rocof3	OC3
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S_Rocof4_OC3	S_Rocof4	OC3
S_Rocof5_OC1	S_Rocof5	OC1
S_Rocof5_OC2	S_Rocof5	OC2
S_Rocof5_OC3	S_Rocof5	OC3
S_Rocof6_OC1	S_Rocof3	OC1
S_Rocof6_OC2	S_Rocof3	OC2

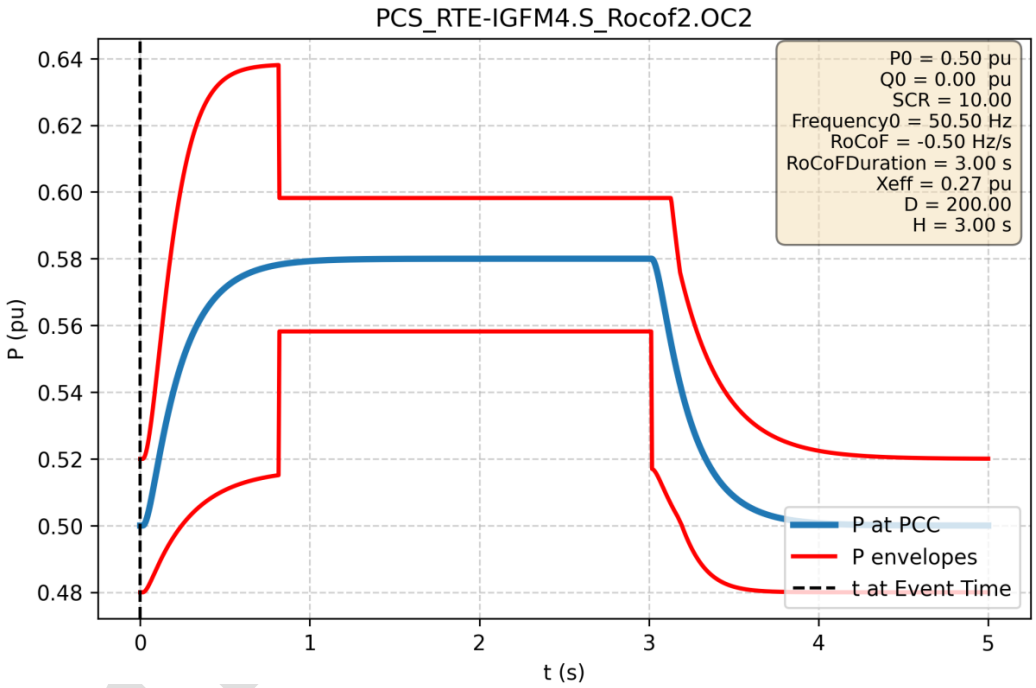
Concertation

S_Rocof6_OC3	S_Rocof6	OC3
S_Rocof7_OC1	S_Rocof7	OC1
S_Rocof7_OC2	S_Rocof7	OC2
S_Rocof7_OC3	S_Rocof7	OC3
S_Rocof8_OC1	S_Rocof8	OC1
S_Rocof8_OC2	S_Rocof8	OC2
S_Rocof8_OC3	S_Rocof8	OC3

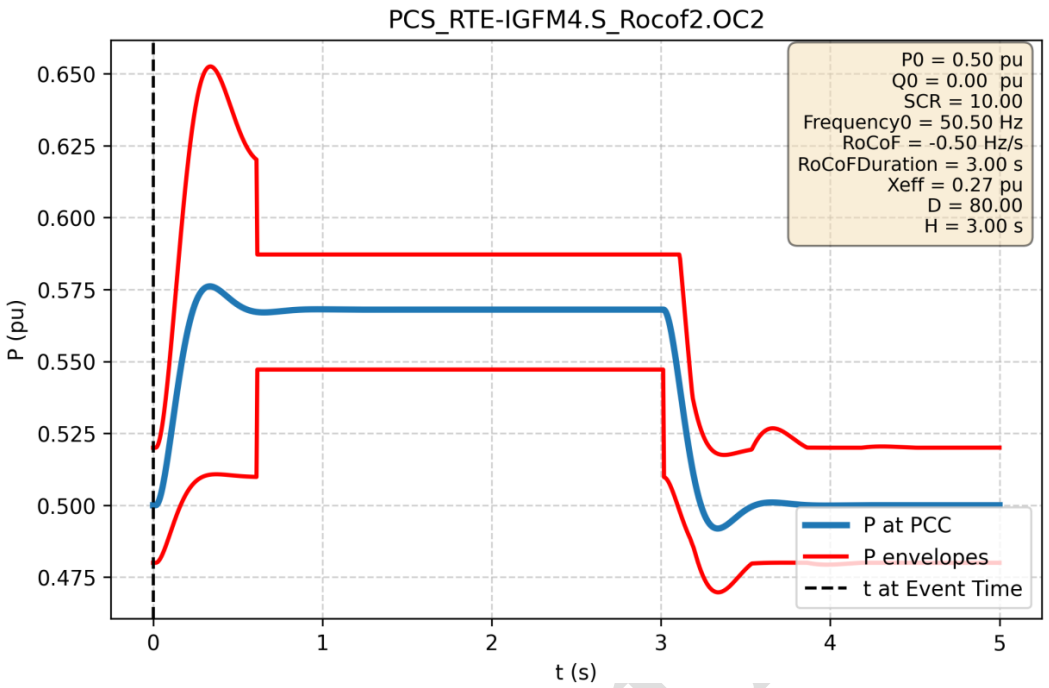
Performance will be assessed using envelopes:

As an exemple for the test S_Rocof2_OC2 the envelope will be:

- For an overdamped response



- For an underdamped response



TEST 5: Fault behavior

Test system: Testbench1

Simulation:

Different faults will be simulated. For each fault, the simulation should at least last until steady state is reached.

Specific conditions :

The tests should be done with two different values of x_{grid} corresponding to $SCR_{min}(x_{grid,min})$ and $SCR_{max}(x_{grid,max})$ and for the different faults described below:

Phase to ground 0Ω	Fault 1
Phase to ground 10Ω	Fault 2
Phase to phase 0Ω	Fault 3
Phase to Phase to ground 0Ω	Fault 4
Phase to Phase to ground 10Ω	Fault 5
3 phases 0Ω	Fault 6
3 phases 10Ω	Fault 7

They should last 150 ms.

Test Matrix:

concertation

The tests must be done for the following operating points and scenarios.
[i] goes from 1 to 7

Test	Scenario	Operating Conditions
S1_Fault[i]_OC1	S1_Fault[i]	OC1
S1_Fault[i]_OC2	S1_Fault[i]	OC2
S1_Fault[i]_OC3	S1_Fault[i]	OC3
S1_Fault[i]_OC4	S1_Fault[i]	OC4
S1_Fault[i]_OC5	S1_Fault[i]	OC5
S2_Fault[i]_OC1	S2_Fault[i]	OC1
S2_Fault[i]_OC2	S2_Fault[i]	OC2
S2_Fault[i]_OC3	S2_Fault[i]	OC3
S2_Fault[i]_OC4	S2_Fault[i]	OC4
S2_Fault[i]_OC5	S2_Fault[i]	OC5

Data to be transmitted to BESS operator by RTE

The envelopes for active current for Test 1, 3 and 4 and each test of the test matrix.
The envelopes for reactive current for Test 2 and each test of the test matrix.

Detailed shape of the envelope will be provided in csv format to the client for each test from the test matrix.

Results to be transmitted by the BESS operator to RTE

The curve of the RMS value of active and reactive current should be delivered for all simulations with the different operating points and will be compared to envelope.
The curve of the RMS value of the voltage at the Power Generating Unit testing point.

The requested time-domain signals should be exported in CSV or COMTRADE format, with a sampling interval less than 1 ms across the entire simulation. The simulation record shall cover the period from the event initiation until steady state is reached.

Conformity check

The tests should be deemed passed if the value of the active and reactive current for all tests stays within the envelopes.
The active and reactive current will be analyzed using pencil matrix method[1] to determine the oscillatory mode and their damping: the damping must be above 50%. (The method has been implemented and can be tested here.)
The unit must stay connected and stable for all the tests.

concertation

[1] ***Pencil Matrix : Open Access article Fernández Rodríguez, A., de Santiago Rodrigo, L., López Guillén, E. et al., "Coding Prony's method in MATLAB and applying it to biomedical signal filtering", BMC Bioinformatics 19, 451 (2018), https://doi.org/10.1186/s12859-018-2473-y.***