ESIG FALL WORKSHOP

MIGRATE WP3 : OPERATING A SYSTEM WITH 100% POWER ELECTRONICS DEVICES

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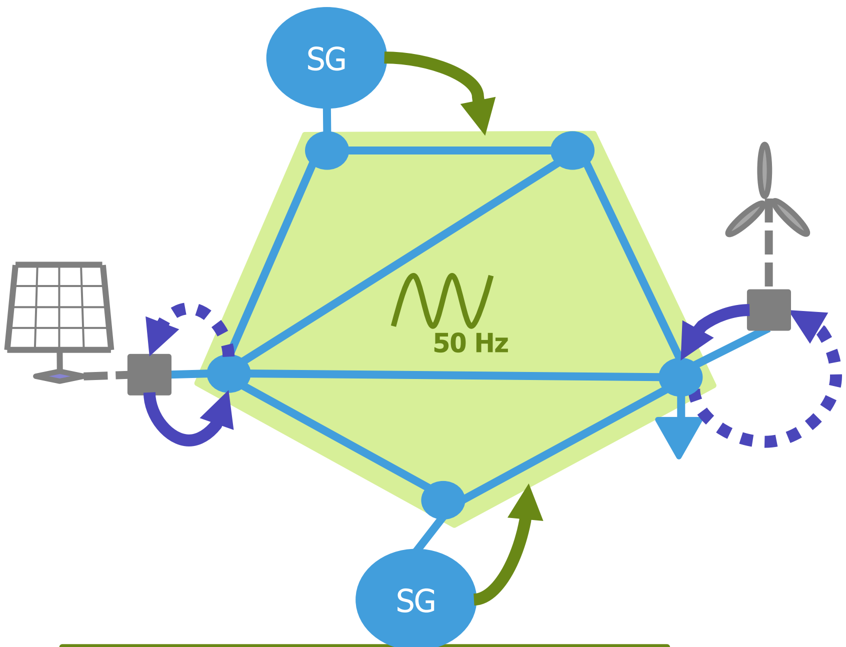
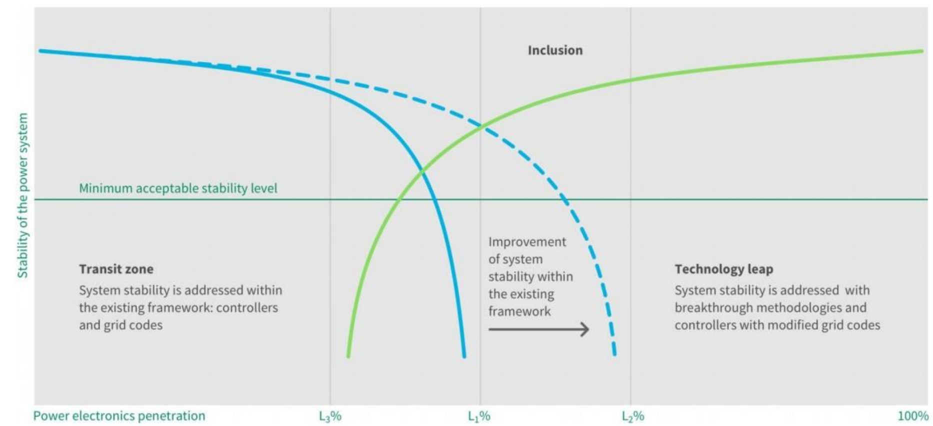
OVERVIEW OF WP3 CHALLENGE





Synchronous machines create voltage waveforms with the same frequency.

Converters measure the grid frequency.

Converters provide active and reactive power at the measured frequency.

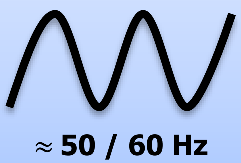
Acceptable level of stability
while keeping costs under control

Control and operation of **large transmission systems**
with **100%** converter-based devices

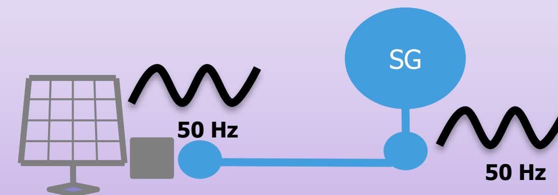
"to be forced to reset our brain"

THE GRID-FORMING FUNCTION

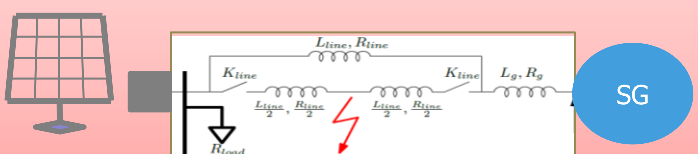
Stiff voltage source behavior



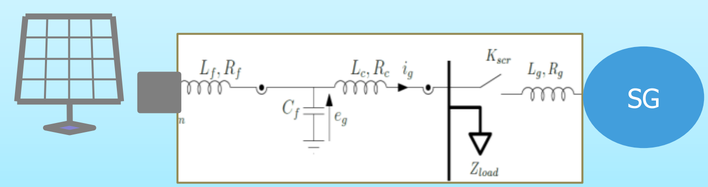
Synchronizes with other sources (RE, SM, GF)



Current-limiting strategy



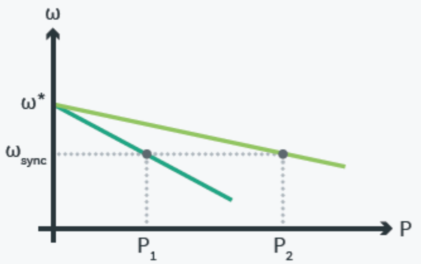
Islanding



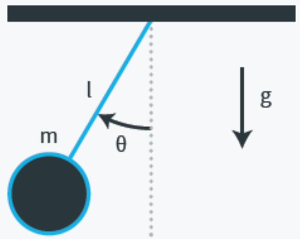
THE GF FUNCTION: MULTIPLE WAYS TO REALIZE

3 controls developed within WP3 (D3.2, D3.3) (and made open source)

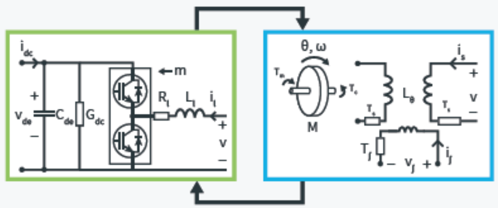
Filtered frequency droop



Dispatchable Virtual oscillator



Matching control



synchronous machine matching

Theoretical proof of stability have been achieved with basic grid assumptions. (D3.3)

Multiple other controls in the literature…

In MIGRATE, the controls were developed independently, on simple test cases

MIGRATE

THE GF FUNCTION: EXAMPLE OF TEST-CASES

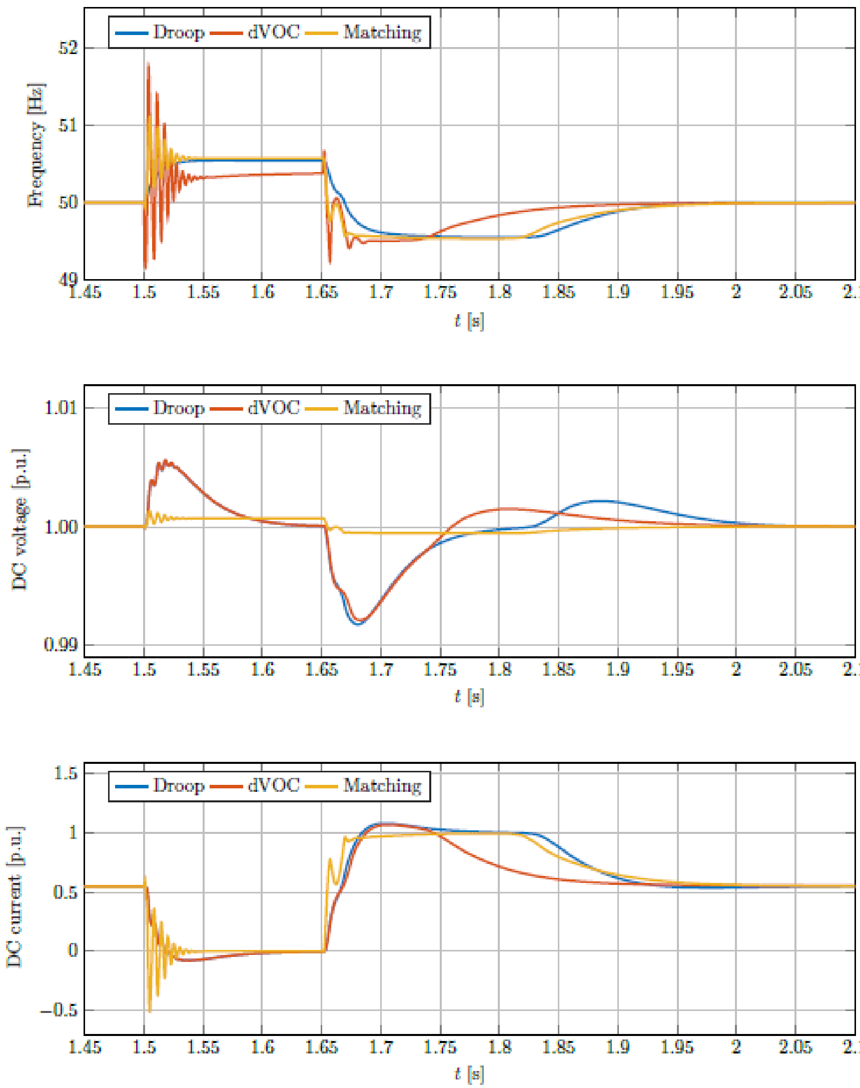


Figure 32: DC signals of a single converter during a short circuit fault and subsequent line opening. A short circuit fault occurs on one of the lines at $t = 1.5$ s and is cleared by disconnecting the line after 150 ms.

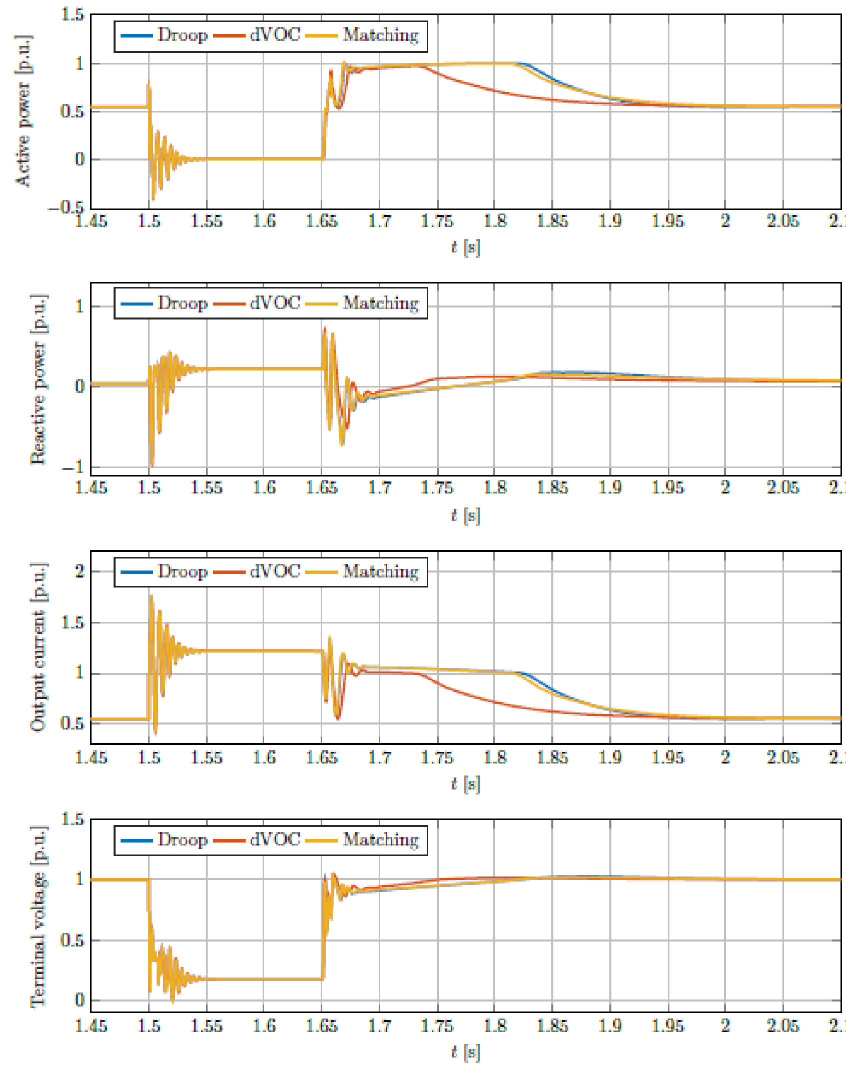
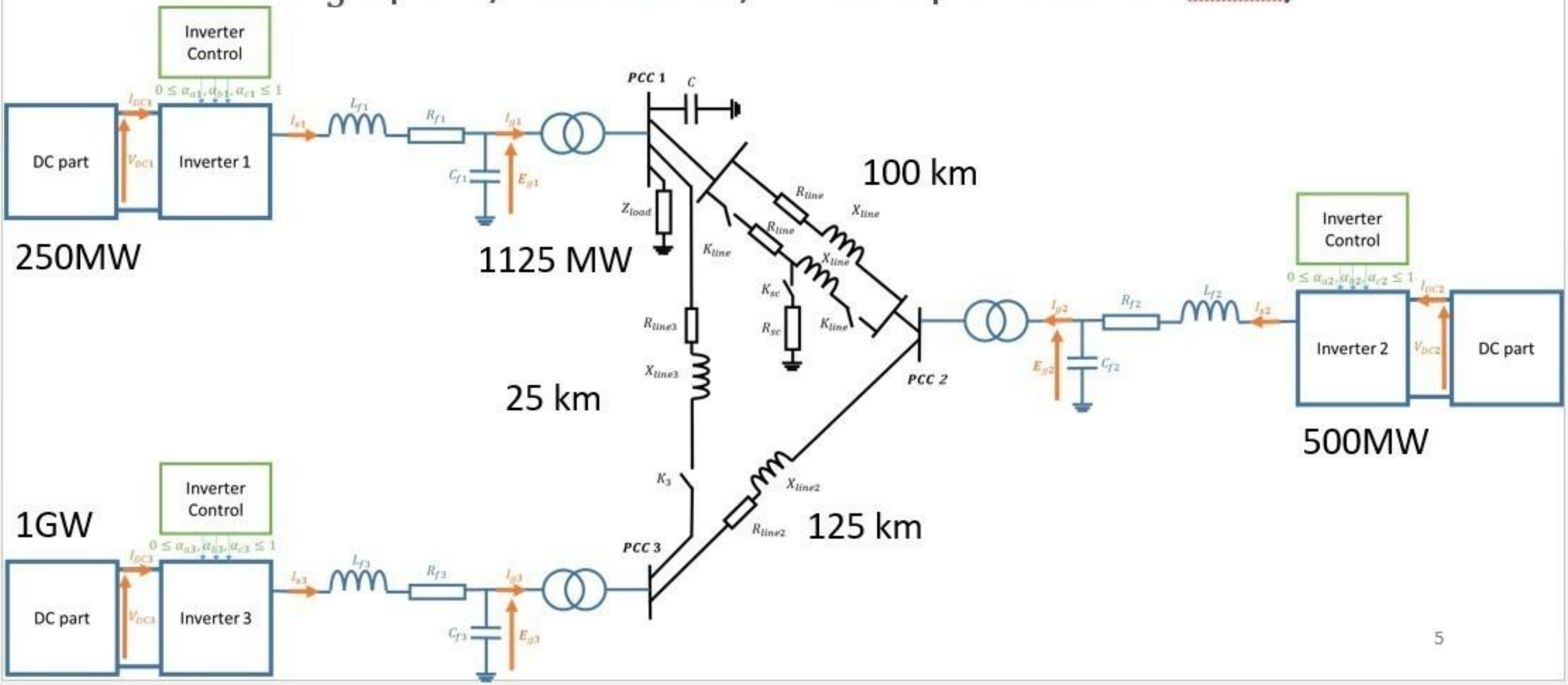


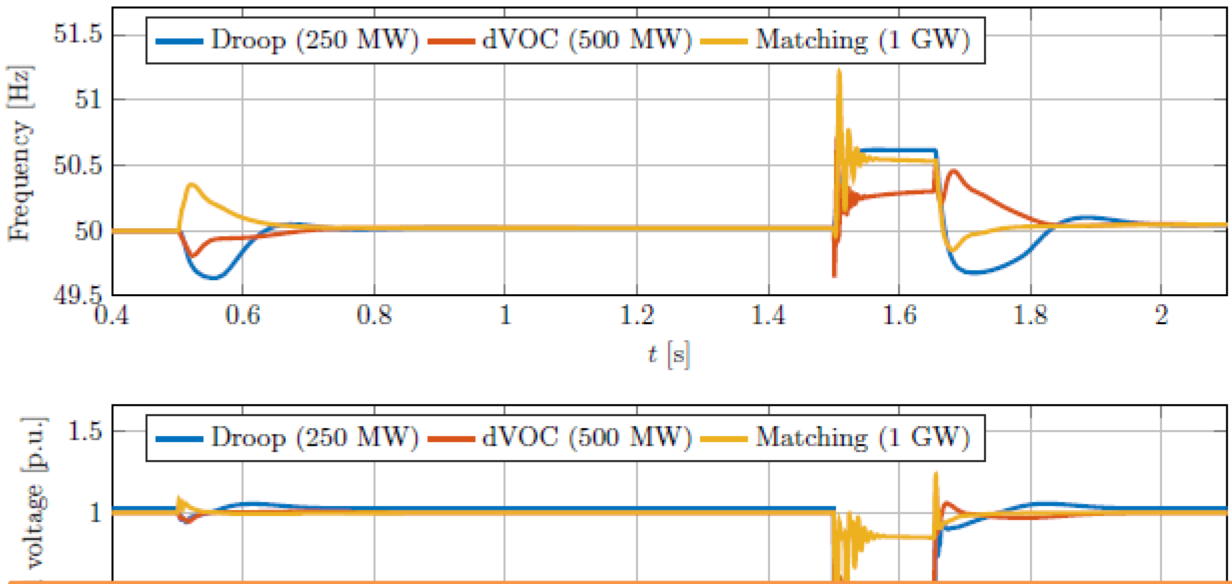
Figure 33: AC signals of a single converter during a short circuit fault and subsequent line opening. A short circuit fault occurs on one of the lines at $t = 1.5$ s and is cleared by disconnecting the line after 150 ms.

THE GF FUNCTION: EXAMPLE OF TEST-CASES

Interoperability on 3-bus Benchmark

K_3 opens, Ksc closes, $Kline$ open 150 ms after,





Events

- $t = 0.5$ s: line from PCC1 to PCC3 disconnected
- $t = 5$ s: short circuit near PCC1
- $t = 1.65$ s: short circuit is cleared

Key finding :

1. Stability and robustness are achieved if, after grid disturbance, the response of the imposed voltage magnitude and frequency is « slow enough » (D3.3)

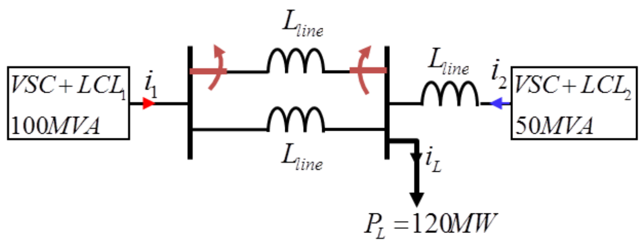
2. In small-signal, all the grid-forming control behave similarly, as seen from their output. (D3.2, D3.3)

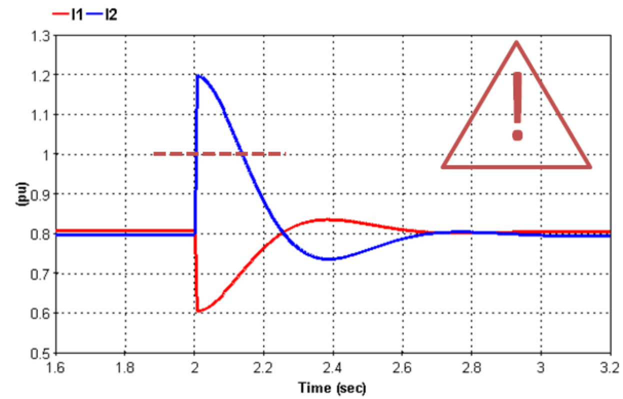
3. Interoperability of independently designed controllers (D3.2, D3.3)

PROBLEM OF GRID-SENSITIVITY OF GRID-FORMING

Slow voltage source are subject to overcurrent during stressing events

Problem :



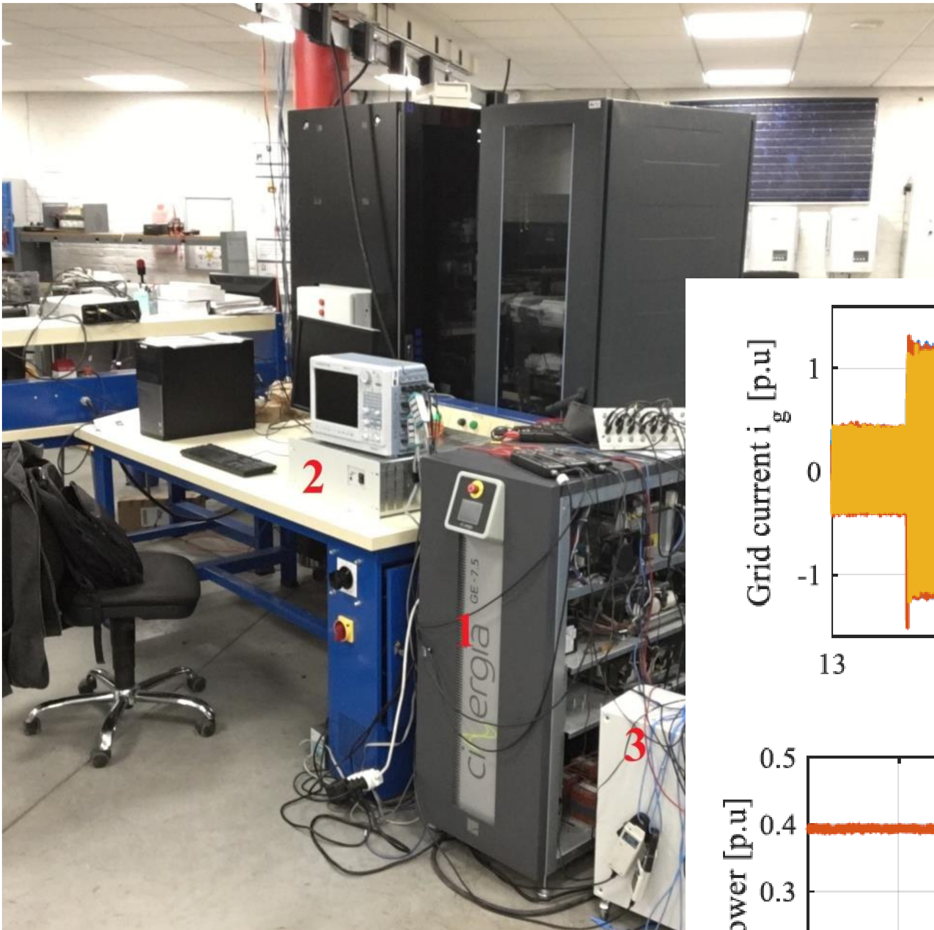


Proposed solution : Current loop saturation during first peak and virtual impedance afterwards (D3.2)

⇒ Validated concept in simulation, and on lab scale hardware.(D3.5)

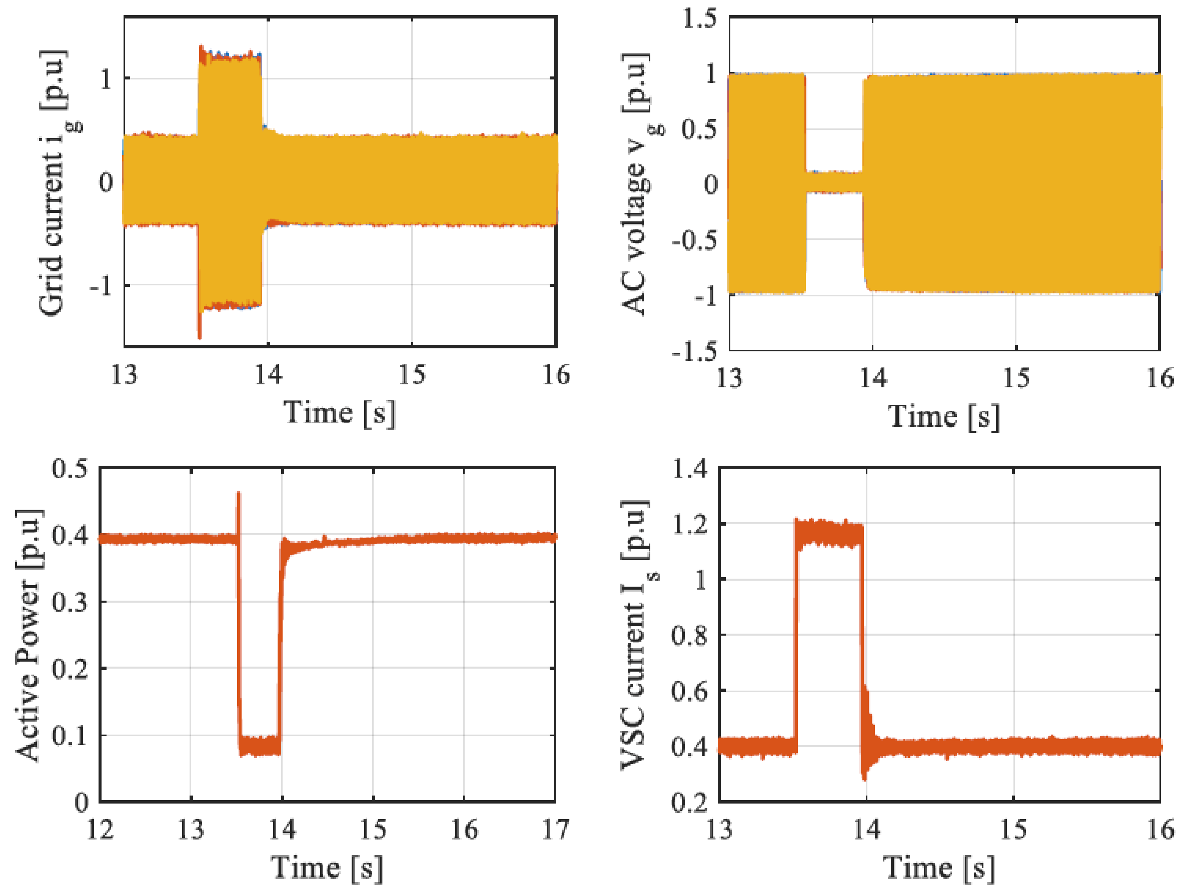
Another solution have been proposed, integrating the current limitation constraints in the voltage control loop. (D3.6)

CURRENT-LIMITING STRATEGY AND EXPERIMENTAL RESULTS



1- 2-Level voltage source converter
2- Controller dSPACE 1005
3- Transformer
4- DC supply
5- PCU-3X5000-BC amplifier

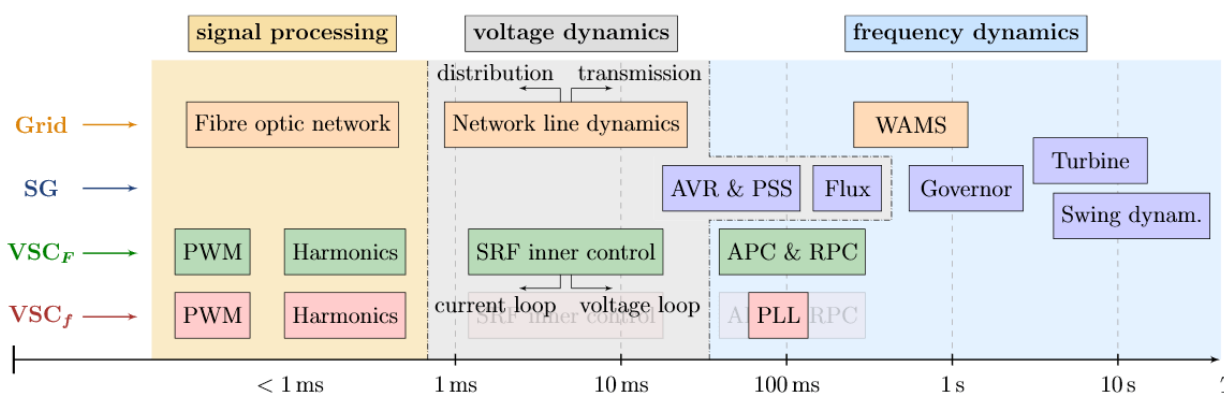
Bolted fault for 400ms



Extensive description of the hardware and the lab test results are available in D3.5

TRANSITION TO 100 %

1. **Grid forming control will release the stress put on the remaining synchronous machine.** D3.6
2. **Grid forming controls are more efficient than grid following inverters providing "similar" services.** D3.3
3. **Digital control of inverters can be seamlessly updated to have optimal allocation of new services.** D3.3
4. **When the share of inverter will be very high, (80-99%), some controls of remaining synchronous machines will need to be adapted.** D3.6



WP3 CONCLUSIONS

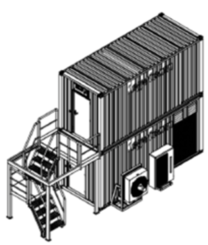
1. **Operating a grid with only Power Electronics is possible with Grid Forming inverters.** (D3.2, D3.3, D3.4)
2. **Grid-forming function performances have been unified** and defined from a system level perspective (techno-agnostic). The Grid-forming function gather the necessary conditions of a source to ensure proper and stable definition of **voltage waveform that resist to small-disturbance**, throughout a multi-sources grid. (D3.2, D3.3, D3.6)
3. **Suitable current-limiting strategy can protect sensitive power-electronics devices** during stressful event without compromising their grid-forming function and without requiring costly oversizing. (D3.2, D3.6)
4. The Grid Forming inverters are technologically feasible, and **might be cost-effective.** D6.3
5. The transition at very high penetration need specific attention and will require change in SM controllers. D3.5

OSMOSE PROJECT

– WP3 : On step beyond for Grid Forming (2 Demonstrations)

Demo 1 : Test robustness of controls developed in Migrate in real environment.

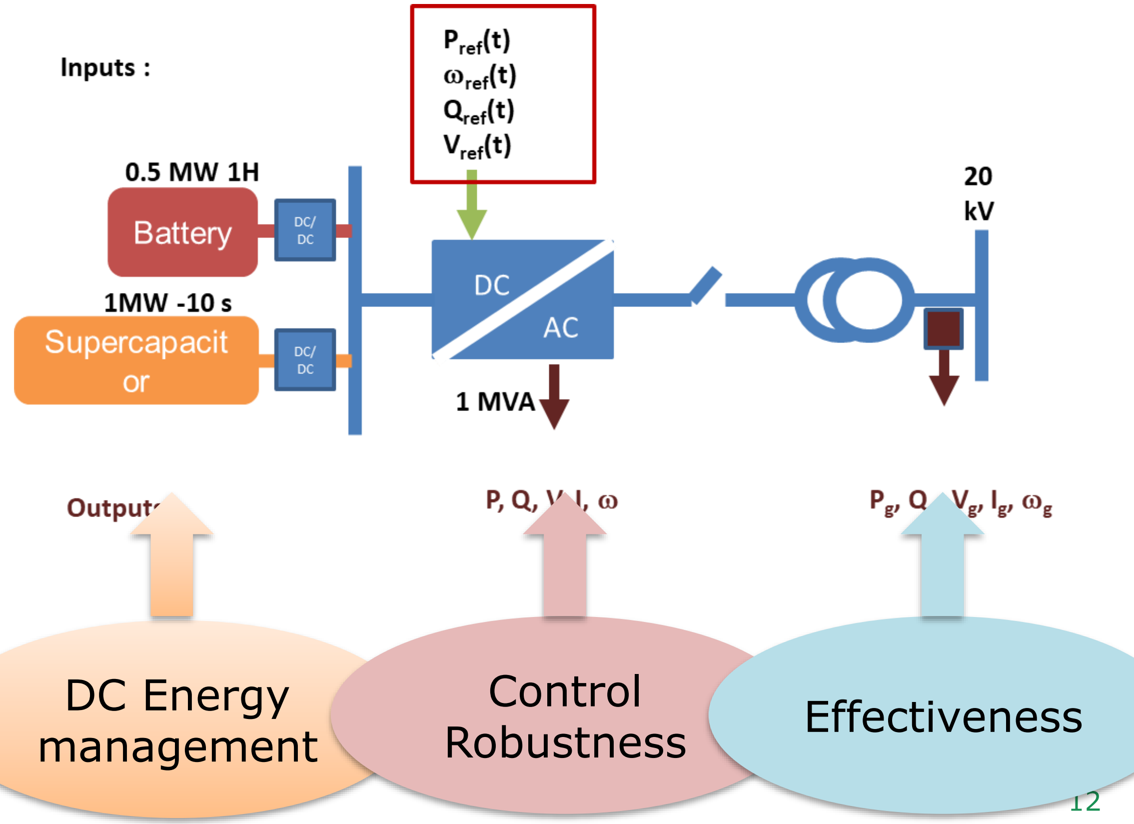
Starting summer 2020



AC/DC	1000 kVA
Battery Li-ion	500 kW – 60 min
Supercapacitors	1000 kW – 10 s
Transformer	600 V – 20 kV

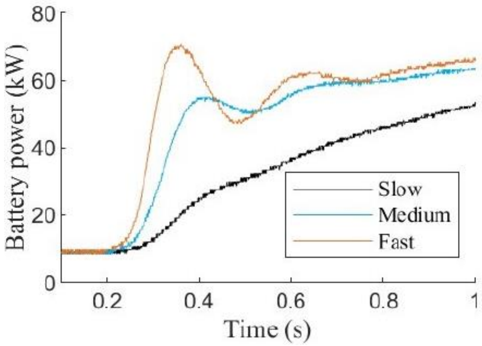
Figure 3.1: HESS layout

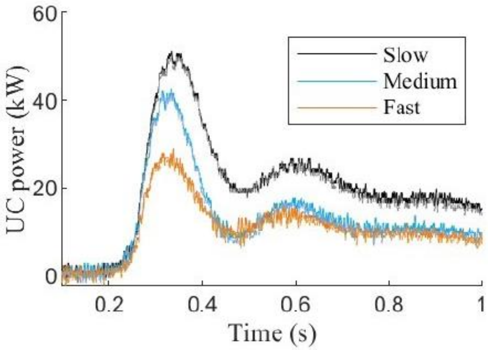
Ingeteam / Rte



OSMOSE PROJECT

- FAT have been done in July
- On site installation have been done early septembre
- SAT are ongoing





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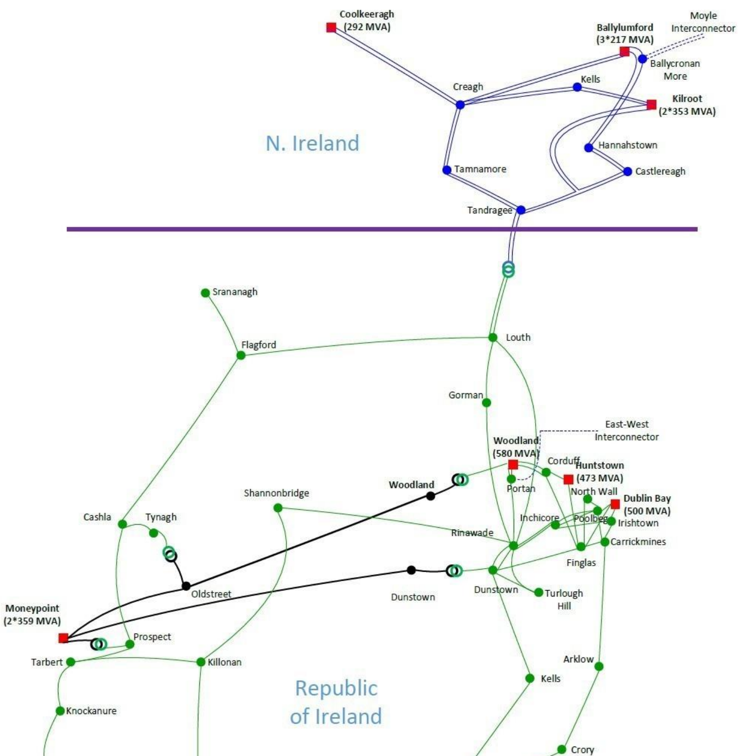
Thanks for your attention

Additional information on the MIGRATE Models can be found here:
https://doi.org/10.4121/uuid:e5497fd2-f617-4573-b6d5-1202ebae411d

IRISH SYSTEM SIMULATION WITH 100% POWER ELECTRONICS

Assessing the findings on a real case benchmark



Stability assessment for 100 ms, 3-phase faults for various distributed grid-forming / grid-following configuration

Ireland (GF %)	Ballylumf (near converter) North	Tamnam (far) North	Inchicore (near converter) Dublin	Shannonb (far) Dublin	Aghada (near converter) South	Ballyvoul (far) South
31.0	LG	LG	LG	LG	G	G
30.1	LG	LG	LG	LG	G	G
29.5	R	LG	LG	LG	G	G
28.9	R	R	R	LG	G	G
29.9	R	R	R	LG	G	G
28.8	R	R	R	LG	G	G
27.9	R	R	R	R	G	LG
26.3	R	R	R	R	R	R

Key finding :

Following an **optimal placement procedure**, the level of designed grid-forming controlled PE capacity have been found to be **satisfying above 30 %** on the Irish System (D3.4)

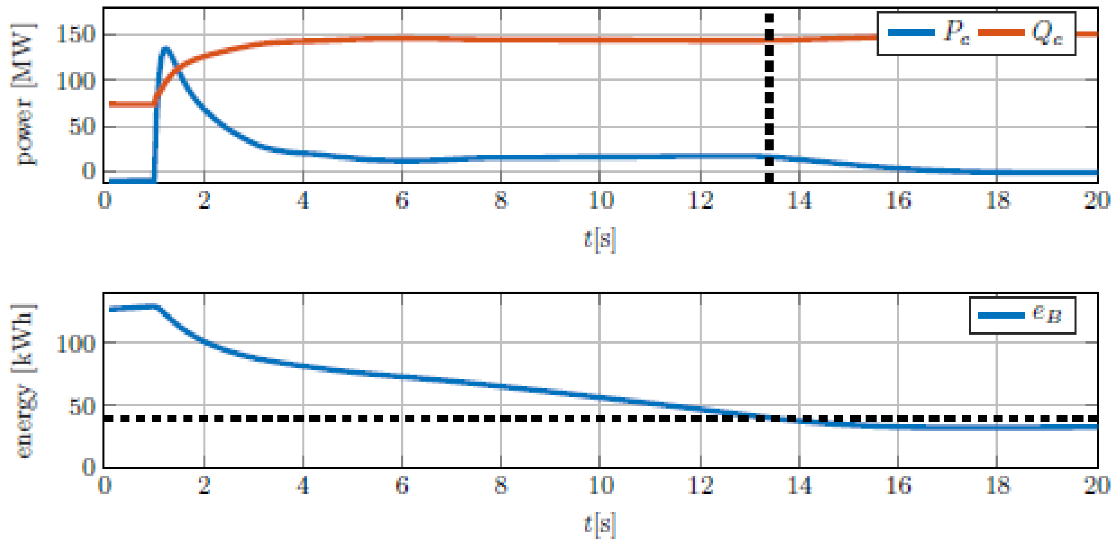
Latest work showed that with inverters providing Ancillary Services, this share can be reduced to almost 20% (D3.4)

RESULT 3: NEW ANCILLARY SERVICES

How to adjust grid-forming (GF) behavior to system needs ?

- **Proposed services**

1. GF with limited storage
2. Adaptative GF parameters

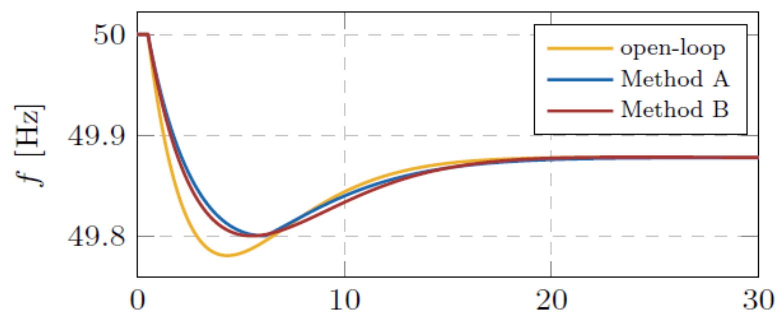


Frequency nadir and RoCoF

$$\omega_{\text{max}} = -\frac{\Delta P}{D + R_g}\left(1 + \sqrt{\frac{T(R_g - F_g)}{M}}e^{-\zeta\omega_n t_m}\right)$$

$$\dot{\omega}_{\text{max}} = -\frac{\Delta P}{M}$$

optimization constraints



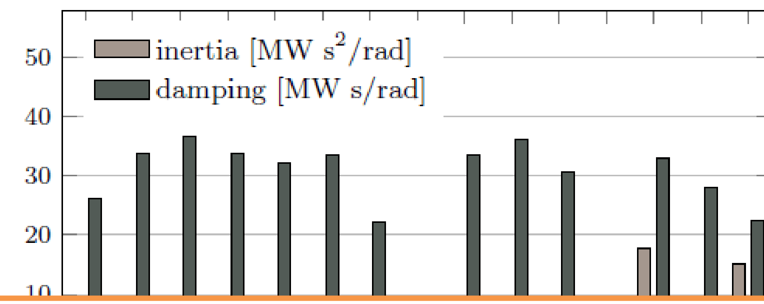
RESULT 3: NEW ANCILLARY SERVICES

How to adjust grid-forming (GF) behavior to system needs ?

- **Proposed services**

1. GF with limited storage
2. Adaptative GF parameters
3. **<u>Optimal GF placement</u>**

(a) Reinforcement with GF « electrical inertia »



Key findings :

1. Power converters fast response & Flexibility required redefinition of system services
2. Services dependent on new technical constraints, ex : P/E ratio of batteries
3. Grid-forming control reduces the control effort compared to “virtual inertia”
4. Interference of new controls & services with market paradigms

node

ADITIONAL SLIDE COMPATIBILITY AND IMPACT WITH SM

– Grid-forming VSC support low-inertia system

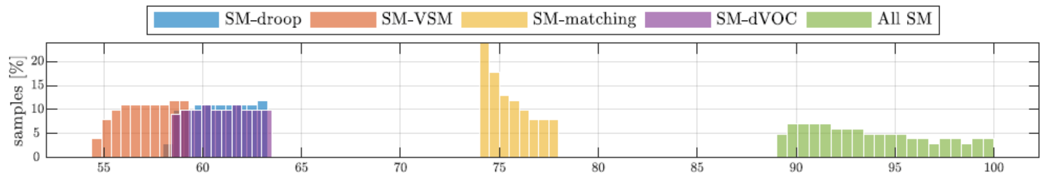


Fig. 4: Normalized distribution of the RoCoF $|\dot{\omega}_i|/|\Delta p_i|$ of the synchronous machine frequency at node 1 for load disturbances Δp_i ranging from 0.2 p.u. to 0.9 p.u. at node 7.

ROCOF at SG output

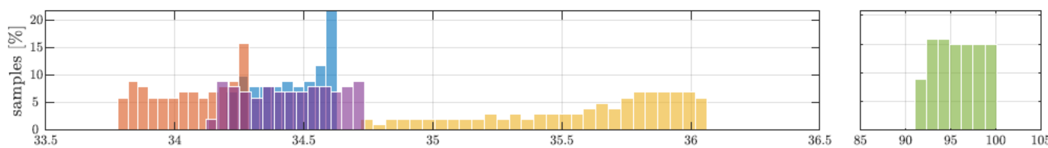


Fig. 5: Normalized distribution of the nadir $||\Delta\omega_i||_\infty/|\Delta p_i|$ of the synchronous machine frequency at node 1 for load disturbances Δp_i ranging from 0.2 p.u. to 0.9 p.u. at node 7.

NADIR at SG output

CAUSE : GF synchronize faster avoiding SG to swing

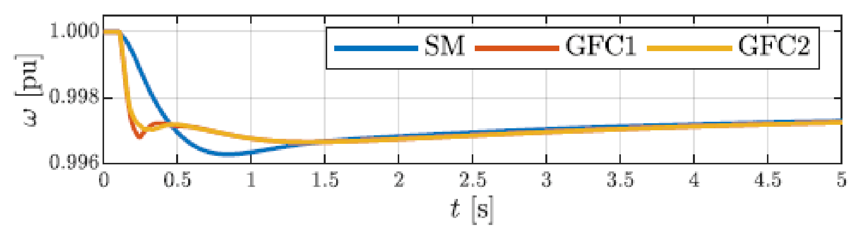


Fig. 6: Frequency of the system with two VSMs after a 0.75 pu

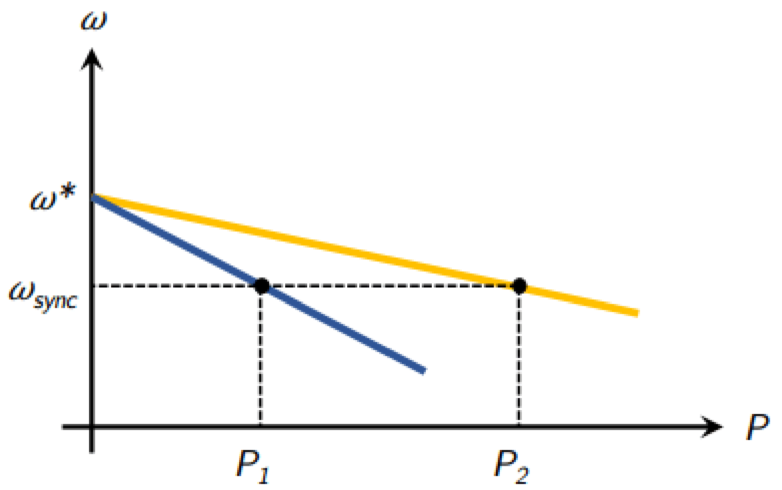
[Tayyebi, 2019] *Interactions of Grid-Forming Power Converters and Synchronous Machines – A Comparative Study*, under review

DIFFERENT APPROACHES FOR SYNCHRONIZATION

Different grid forming control have been developed/enhanced.

The droop control :

- adjust voltage frequency with active power. $\omega = \omega_{ref} + k(P - P_{ref})$



Droop control

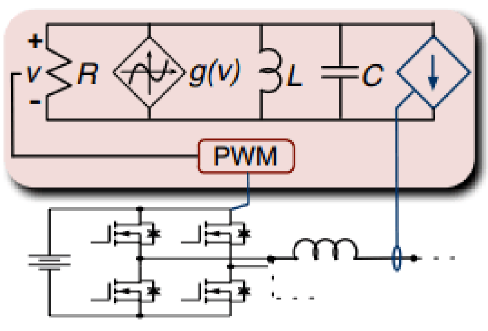
This control synchronises the sources on inductive grid. Moreover, it inherently provides frequency control.

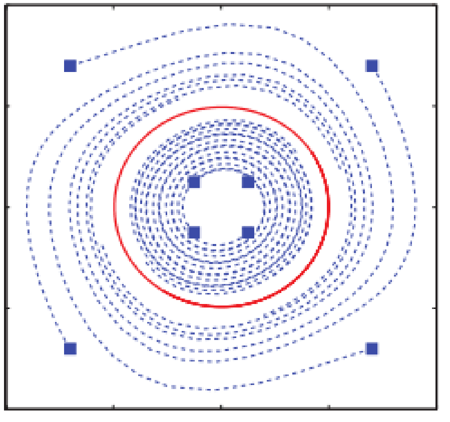
DIFFERENT APPROACHES FOR SYNCHRONIZATION

Different grid forming control have been developed/enhanced.

The dispatchable virtual oscillator:

- it uses the self synchronization property to synchronize on the grid.





In small signal, presents the same dynamic as droop control.

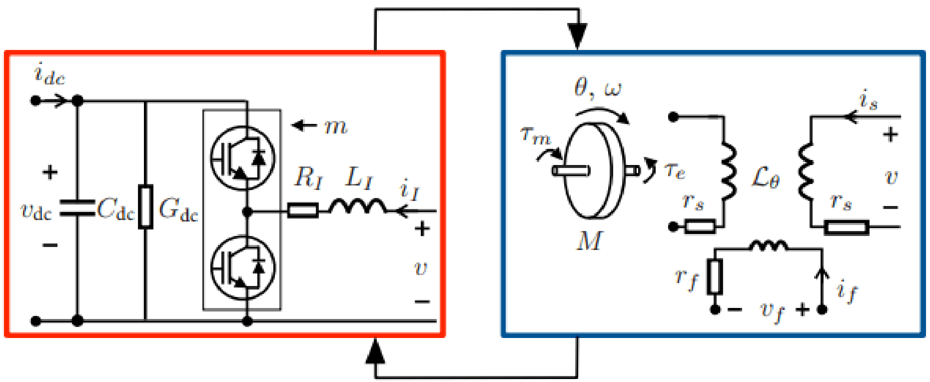
virtual oscillator control (VOC)

DIFFERENT APPROACHES FOR SYNCHRONIZATION

Different grid forming control have been developed/enhanced.

The matching control:

- matches the equation of the synchronous machine to the equation of a inverter with a DC source.



synchronous machine matching

generator	inverter	interpretation
$\frac{1}{2}M\omega^2$	$\frac{1}{2}C_{dc}v_{dc}^2$	energy stored in device
τ_m	i_{dc}	energy supply
τ_e	i_{sw}	energy flow to grid
$\omega - \omega_0$	$v_{dc} - v_{dc}^\star$	power imbalance
i_f	μ	AC voltage magnitude

Back