100% POWER ELECTRONICS, A CHANGE OF PARADIGM IN POWER SYSTEMS

THE EU MIGRATE PROJECT
FOCUS ON WP3

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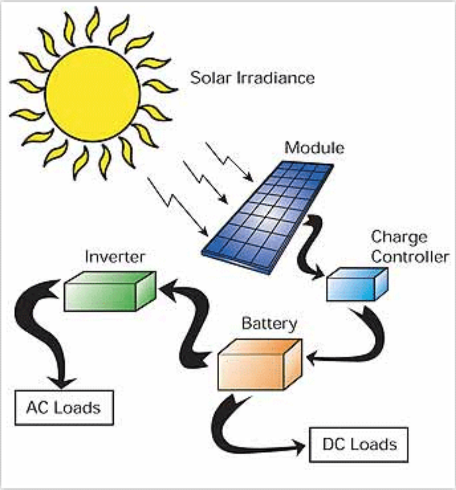
INTRODUCTION



A system with 100% renewable is "easy" to operate (Icelandic system)

But A system with 100% power electronic based renewable is very challenging.

Is inertia a real need? And what is inertia?

Emulating synchronous machine is only one possible solution!

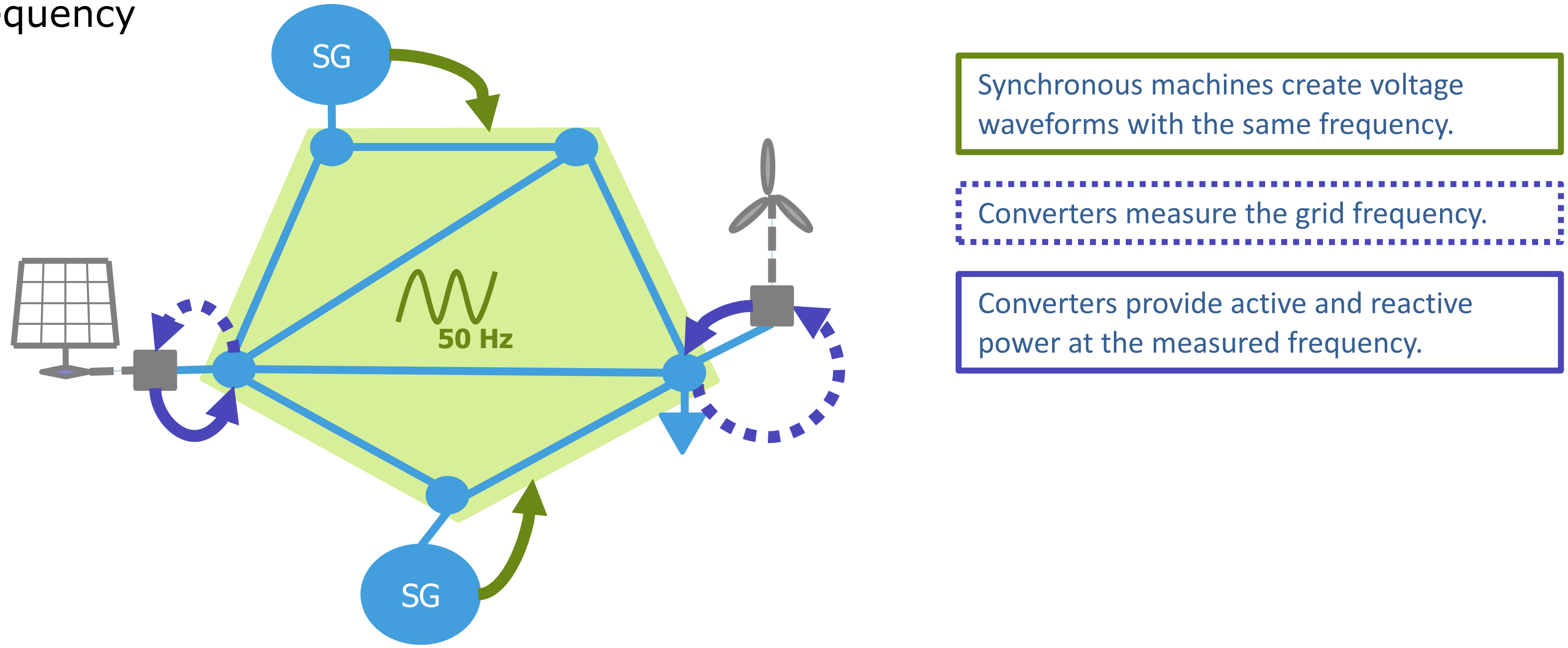
- Today's system inertia is the consequence of the existence of large synchronous generators.
- Emulating "synchronous generators with identical inertia" with PE devices is technically possible but requires over-sized inverters

Requirement: stability at an acceptable cost

- Acceptable level of stability for large transmission system while keeping costs under control
- Stable operation of large transmission system should not depend on telecommunication system: we must keep something like "frequency" to synchronize inverters

THE INITIAL QUESTION

Today inverters connected to the grid are "grid-following": they measure the frequency and adapt their current injection to provide active/reactive power with the same frequency



What if there is nothing to "follow"?

Inverters (at least some of them) need to be "grid forming", they have to create the voltage waveform on their own.

RESULT 1: GRID-FORMING CONTROLS

Some inverters need to be "grid forming", they have to create the voltage waveform on their own.

Definition in the MIGRATE project

Such an inverter needs :
- to behave as a **voltage source**
- to be **synchronized** with other voltage source (if any)
- to behave properly **in islanded mode** (do not rely on direct frequency measurement)
- to take care of **overcurrent limitation** (be a voltage source as much as possible)
- to be compatible with **synchronous machines and grid following**

RESULT 1: GRID-FORMING CONTROLS

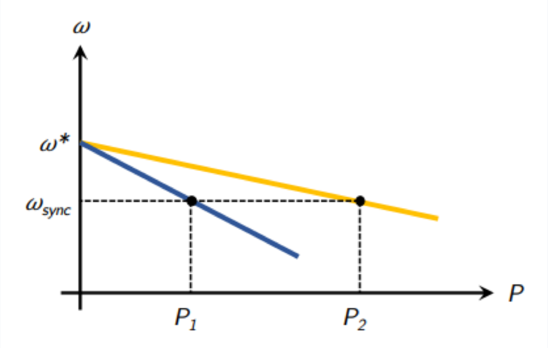
Three-different controls independently tuned on defined test-cases for robustness

L2EP

ETH zürich

Filtered frequency droop

- $\omega = \omega_{ref} + m_p \frac{(P_{ref} - P)}{T_p s + 1}$

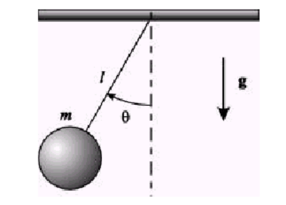


Dispatchable Virtual oscillator

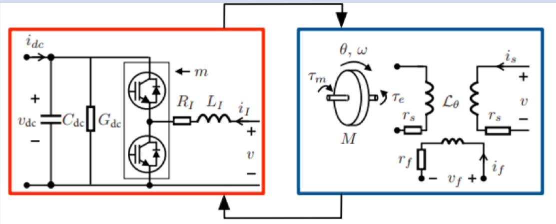
- Under transmission system assumption :

$$\frac{\mathrm{d}}{\mathrm{d}t}\theta_k = \frac{\eta}{v_k^{\star 2}}(p_k^\star - p_k),$$

$$\|v_k\| = v_k^\star + \frac{\eta}{\alpha v_k^\star}(q_k^\star - q_k).$$



Matching control



synchronous machine matching

$$\mu = \mu^* + K_{ac}(P - P^*)$$

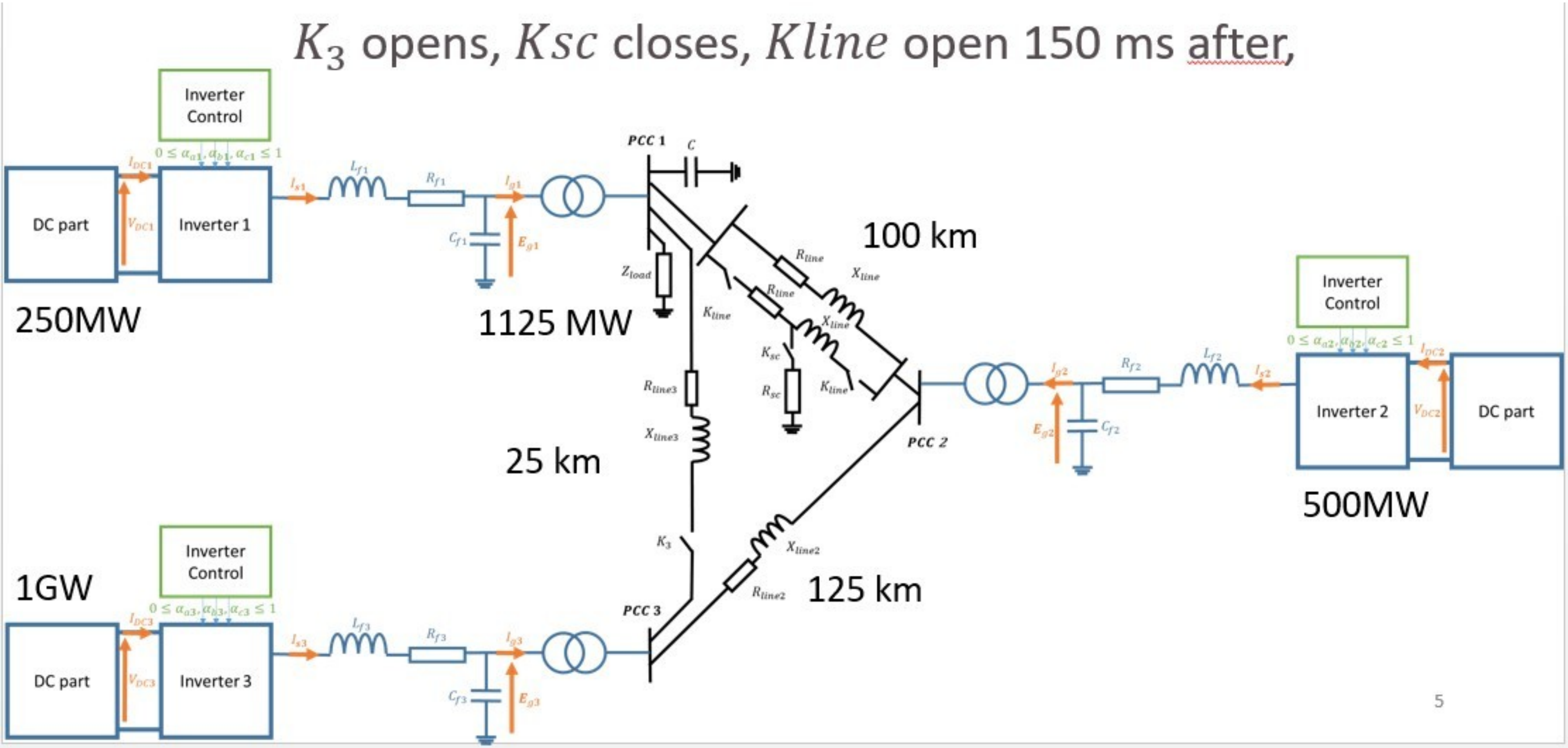
$$\mu^* = \frac{2V^*}{v_{dc}^*}$$

All the controls have been made open source.

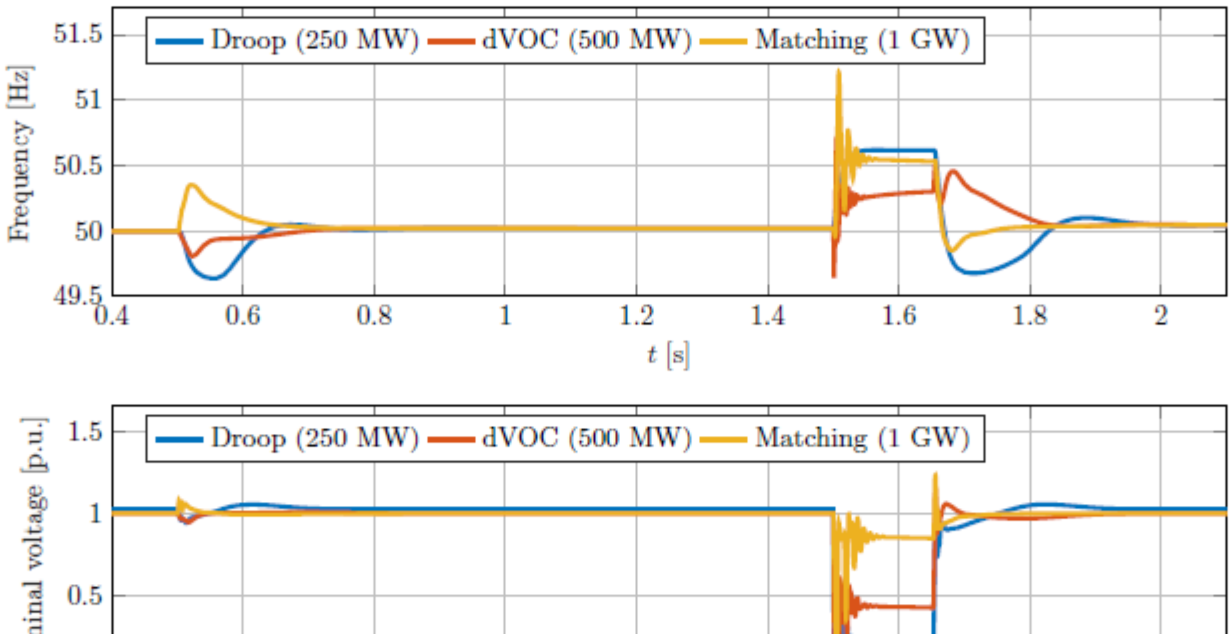
https://doi.org/10.4121/uuid:e5497fd2-f617-4573-b6d5-1202ebae411d

RESULT 1: GRID-FORMING CONTROLS

They turned out to be interoperable on 3-bus Benchmark



These test cases are open source.



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 »

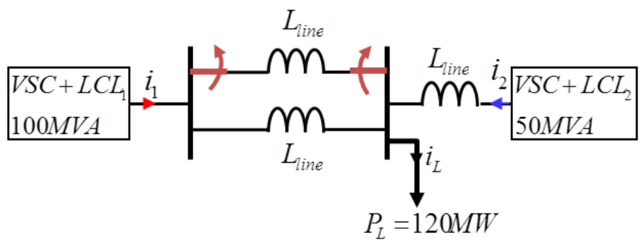
2. In small-signal, all the grid-forming control behave similarly, as seen from their output.

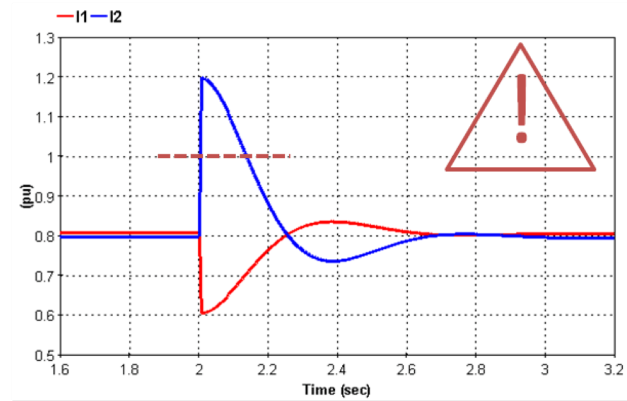
3. Interoperability of independently designed controllers

RESULT 2 : CURRENT-LIMITING STRATEGY

Slow voltage source are subject to overcurrent during stressing events

Problem :





Proposed solution :

- Current loop saturation during first peak, to act fast
- Virtual impedance afterwards, to keep voltage source behavior during the event

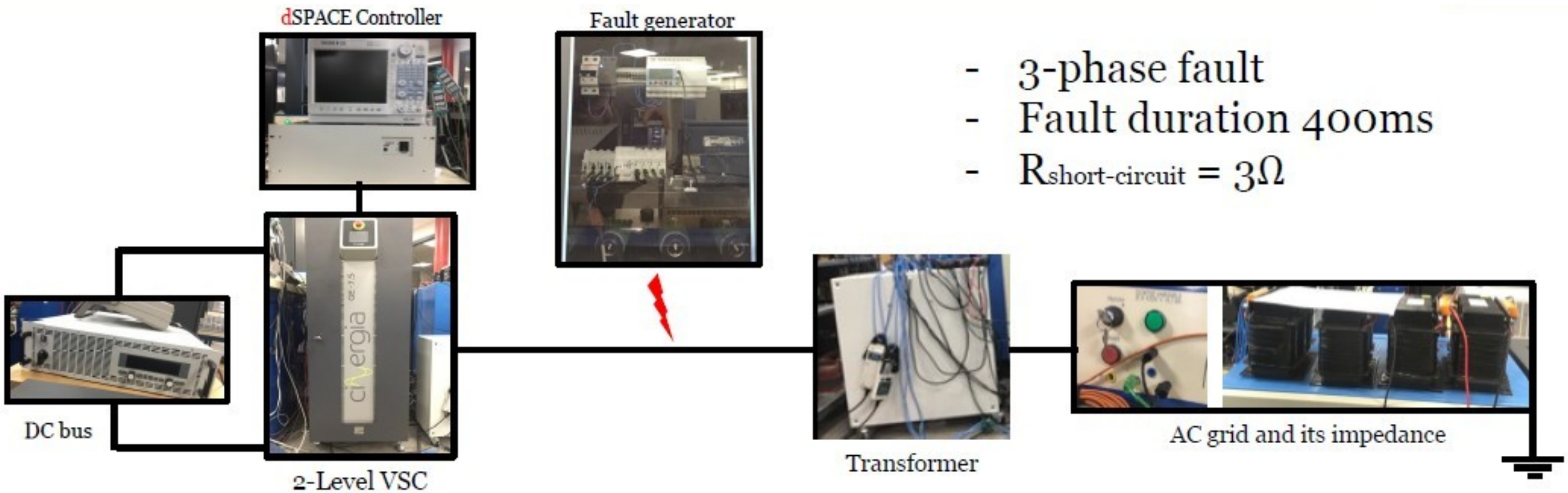
⇒ Validated concept in simulation, currently tested experimentaly

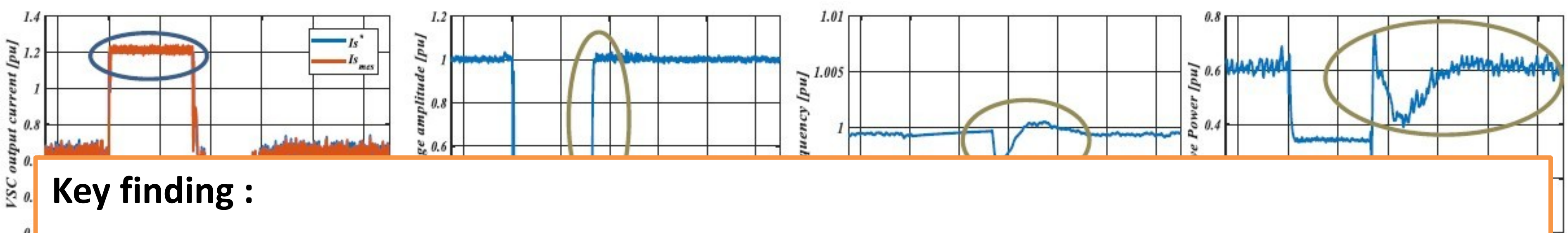
⇒ Will be integrated in the open source model

RESULT 2 : CURRENT-LIMITING STRATEGY

Slow voltage source are subject to overcurrent during stressing but daily events

- 3-phase fault
- Fault duration 400ms
- $R_{short\text{-}circuit} = 3\Omega$





Key finding :

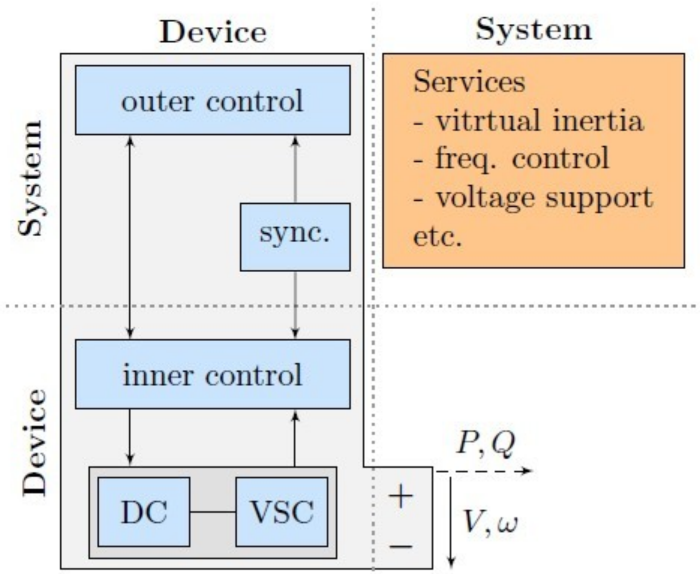
The developed current-limiting strategy is compatible with all three grid-forming controllers and real reduced size inverters.

RESULT 3: NEW ANCILLARY SERVICES

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

Level of implementation

Level of expressed needs



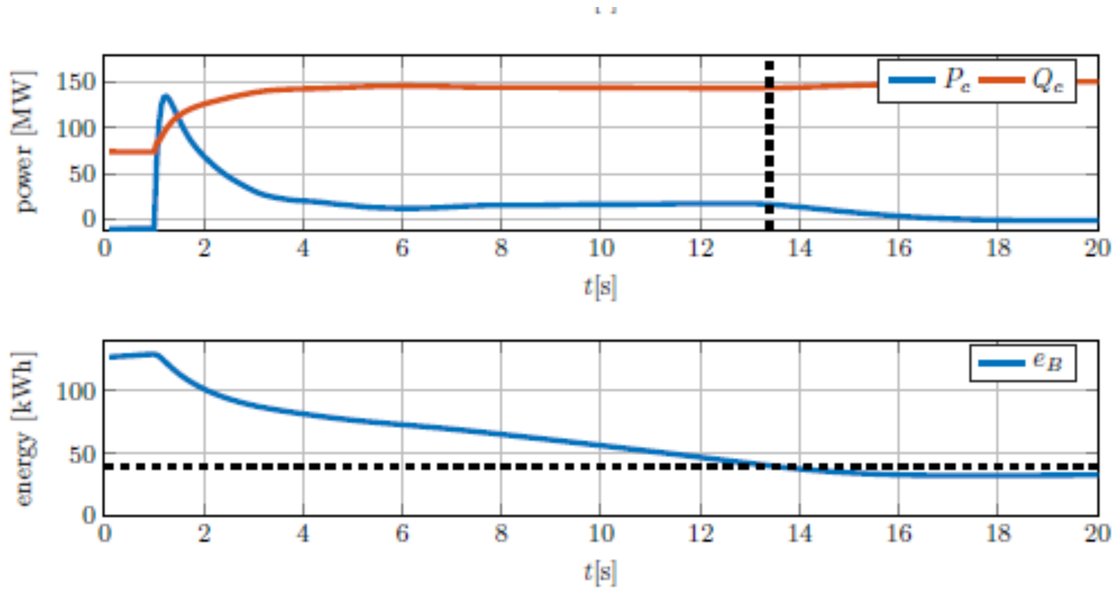
=> Efforts on abstraction and categorization of system-level behaviours to distinguish system vital needs and system possible optimization

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

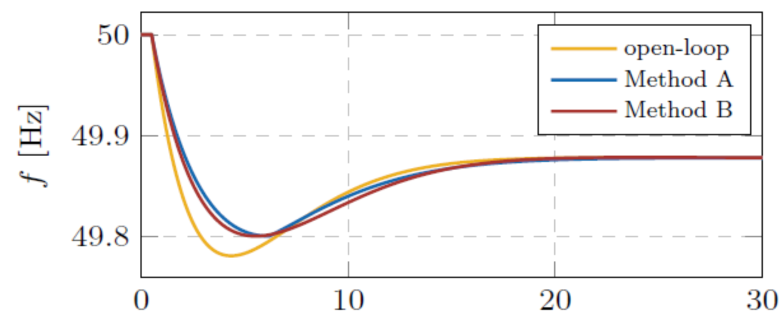


Frequency nadir and RoCoF

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

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

optimization constraints



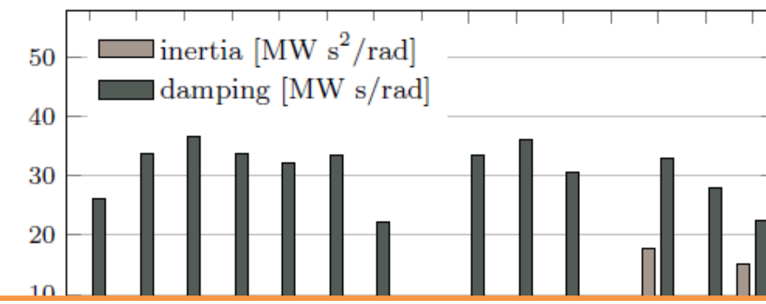
RESULT 3: NEW ANCILLARY SERVICES

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

- **Proposed services**

1. GF with limited storage
2. Adaptative GF parameters
3. Optimal GF placement

(a) Reinforcement with GF « electrical inertia »

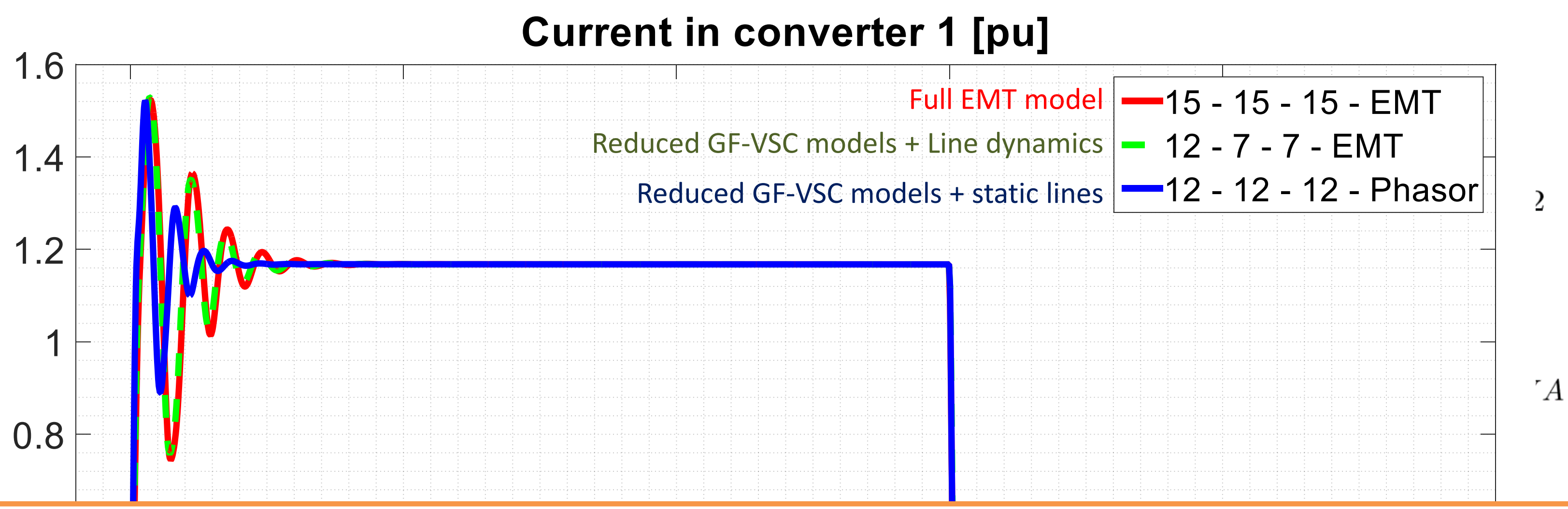


Key findings :

1. Power converters fast response & Flexibility require 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

RESULT 4: NEW LARGE SCALE MODELS

How to simulation large power system without synchronous machine ?



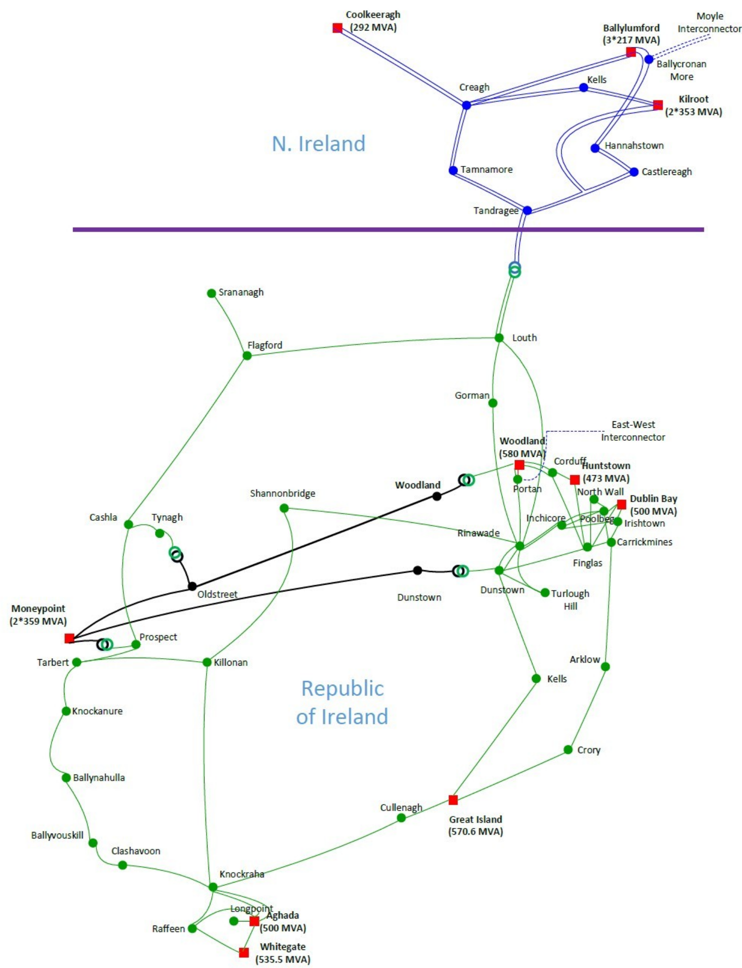
Key findings :

1. Not full EMT but lines dynamics along with some VSC controller states must be modelled

2. Depending on the transient event and localisation, accurate reduced models can still be used

RESULT 5: IRISH SYSTEM SIMULATION WITH 100 % POWER ELECTRONICS

Assessing the findings on a real case benchmark



RESULT 5: IRISH SYSTEM SIMULATION WITH 100 % POWER ELECTRONICS

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

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

CONCLUSIONS

1. **Grid-forming function performances have been unified** and defined from a system level perspective (techno-agnostic). Suitable **current-limiting strategy can protect sensible power-electronics devices** during stressful event without compromising their grid-forming function and without requiring costly oversizing.
2. These controls have been made open source to have a higher impact on future research and development.
3. **The Large inertia** historically provided by Synch. Gen. **is not a goal itself**. But still, a minimum "electrical inertia" level is needed, probably three to ten times lower.
4. **Low inertia/faster systems** and Grid-forming converters open the path to **new services** to share the regulation efforts amongst capable sources. These services can improve the stability starting from today
5. By simulation of the **large scale Irish system**, a real case illustrated how all synchronous generation can be **replaced by a limited capacity of the proposed Grid-forming algorithm** for power-electronics based converters

NEXT STEP

OSMOSE
OPTIMAL SYSTEM-MIX OF FLEXIBILITY SOLUTIONS FOR EUROPEAN ELECTRICITY

MIGRATE

In WP3

~1MVA Grid forming inverter connected to the transmission grid (in France)

~1MW 500kWh Battery + ~1MW ultracaps for a few seconds.

- It will be connected to a node with both generation (SM) and industrial load.
- It will allow to validate the compatibility of such a control with the present grid and measure the positive impact on the grid.
- The current saturation strategy will also be validated on field.
- The concept will be to do the grid forming control using the ultracaps while using the battery for other type of ancillary service. (virtual line, peak shaving, …)

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Thank you for your attention

Any questions ?

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ADITIONAL SLIDE IF TIME AVAILABLE

– Grid-forming VSC support low-inertia system

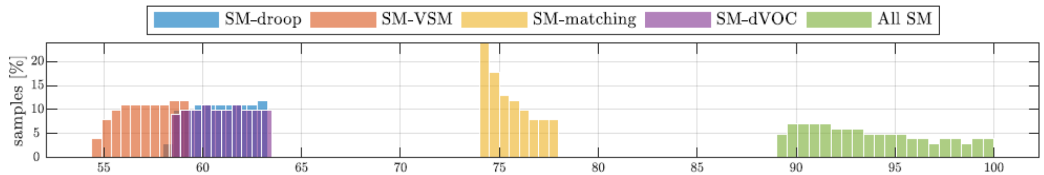

Fig. 4: Normalized distribution of the RoCoF $|\dot{\omega}_i|/|\Delta p_i|$ of the synchronous machine frequency at node 1 for load disturbances Δp_i ranging from 0.2 p.u. to 0.9 p.u. at node 7.

ROCOF at SG output

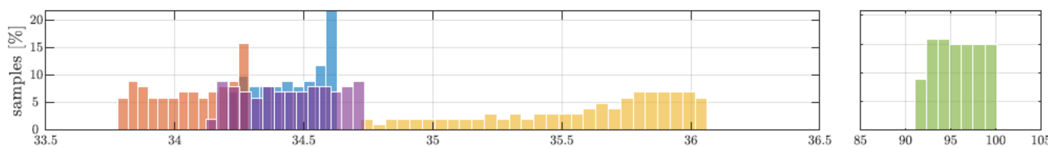

Fig. 5: Normalized distribution of the nadir $||\Delta\omega_i||_\infty/|\Delta p_i|$ of the synchronous machine frequency at node 1 for load disturbances Δp_i ranging from 0.2 p.u. to 0.9 p.u. at node 7.

NADIR at SG output

CAUSE : GF synchronize faster avoiding SG to swing

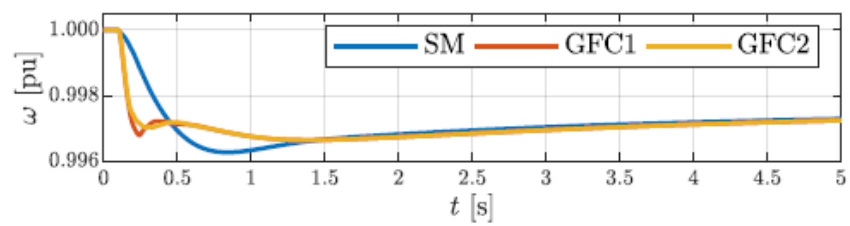

Fig. 6: Frequency of the system with two VSMs after a 0.75 pu

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