Soirée-débat « virtuelle »

Services système du futur

Du grid-forming à l'ajustement

Les services système permettent d'assurer la stabilité du réseau en fréquence et en tension. Avec le développement des énergies renouvelables, on retrouve davantage de production interfacée par électronique de puissance et cela a un impact significatif sur le fonctionnement du système électrique. Plusieurs études ont analysé les besoins futurs de services système et le bureau du chapitre français de l'IEEE PES vous convie à une soirée-débat pour faire le point sur trois de ces projets.

Dans un premier temps, Marie-Ann Evans (EDF R&D), Directrice Technique du Projet H2020 EU-SysFlex, introduira les enjeux sur l'intégration d'une part importante d'énergies renouvelables variables dans le système électrique européen, notamment les simulations réalisées sur la stabilité du réseau, ainsi que les analyses économiques associées, et présentera les projets-démonstrateurs de solutions techniques testées dans ce cadre pour y répondre.

Vera Silva, CTO de GE Grid Solutions, et Xavier Guillaud, professeur au L2EP, présenteront des résultats issus du projet MIGRATE (Massive InteGRATion of power Electronic devices). Comment gérer le support de fréquence dans un réseau avec un fort taux de pénétration de convertisseurs d'électronique de puissance ?

Enfin, William Phung, chef du projet OSMOSE, présentera le démonstrateur grid forming et les multi-services développés dans le cadre du projet et fera un focus sur les mix de flexibilités optimaux.

Organisation et Parrainage

- Chapitre français de l'IEEE PES (Power & Energy Society)
- Avec l'appui de la SEE (Société de l'Electricité, de l'Electronique et des Technologies de l'Information et de la Communication) – Club technique « Systèmes électriques » Plan : https://bit.ly/2ABYAox

17 Décembre 2020
de 18h à 20h
Microsoft Teams

18h	***Accueil et introduction*** Yannick Jacquemart, *RTE,* *Président du bureau français de l'IEEE PES*
18h10	***Projet H2020 EU-SysFlex*** Marie-Ann Evans, EDF R&D *Directrice Technique du projet*
18h40	***Enseignements tirés du projet européen MIGRATE*** Vera Silva, CTO GE Grid Solutions Xavier Guillaud, professeur au L2EP
19h10	***Projet OSMOSE*** William Phung, RTE, *chef du projet*

Inscription et Renseignements

Inscription en ligne gratuite : http://bit.ly/1gNuQWb

Après la soirée, les présentations sont disponibles sur http://ewh.ieee.org/r8/france/pes/

Details de Connexion

Rejoindre la réunion Microsoft Teams

Cliquez ici pour participer à la réunion

EU-SysFlex

System operation and flexibility solutions to meet 50% renewables in Europe by 2030

IEEE Webinar – 17/12/2020

Marie-Ann EVANS (EDF R&D), Technical Manager

Disclaimer: This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 773505.

EU-SysFlex H2020 Project

A demonstration project involving 34 power system players

Nov 2017- Oct 2021 20M€ H2020 funding

Eu-sysflex.com

🟥 TSO

EIRGRID SONI elering

PSE AST

🟧 DSO

edp distribuição innogy HELEN

e-distribuzione elektrilevi

Technology providers, consultants

SIEMENS ENERCON ENERGY FOR THE WORLD EURACTIV AKKA

enoco PÖYRY CYBERNETICA

zabala innovation consulting ESADE guardtime

🟩 Generation, retail and aggregato

EDF upside

Research institutes, universities

Imperial College London INESCTEC VTT

Fraunhofer KU LEUVEN UCD DUBLIN

UNIKASSEL VERSITÄT RSE UNIVERSITY OF TARTU

vito Energy Ville NEW ENERGY WORLD NATIONAL CENTRE FOR NUCLEAR RESEARCH ŚWIERK

★ Demonstrators

Real time simulator

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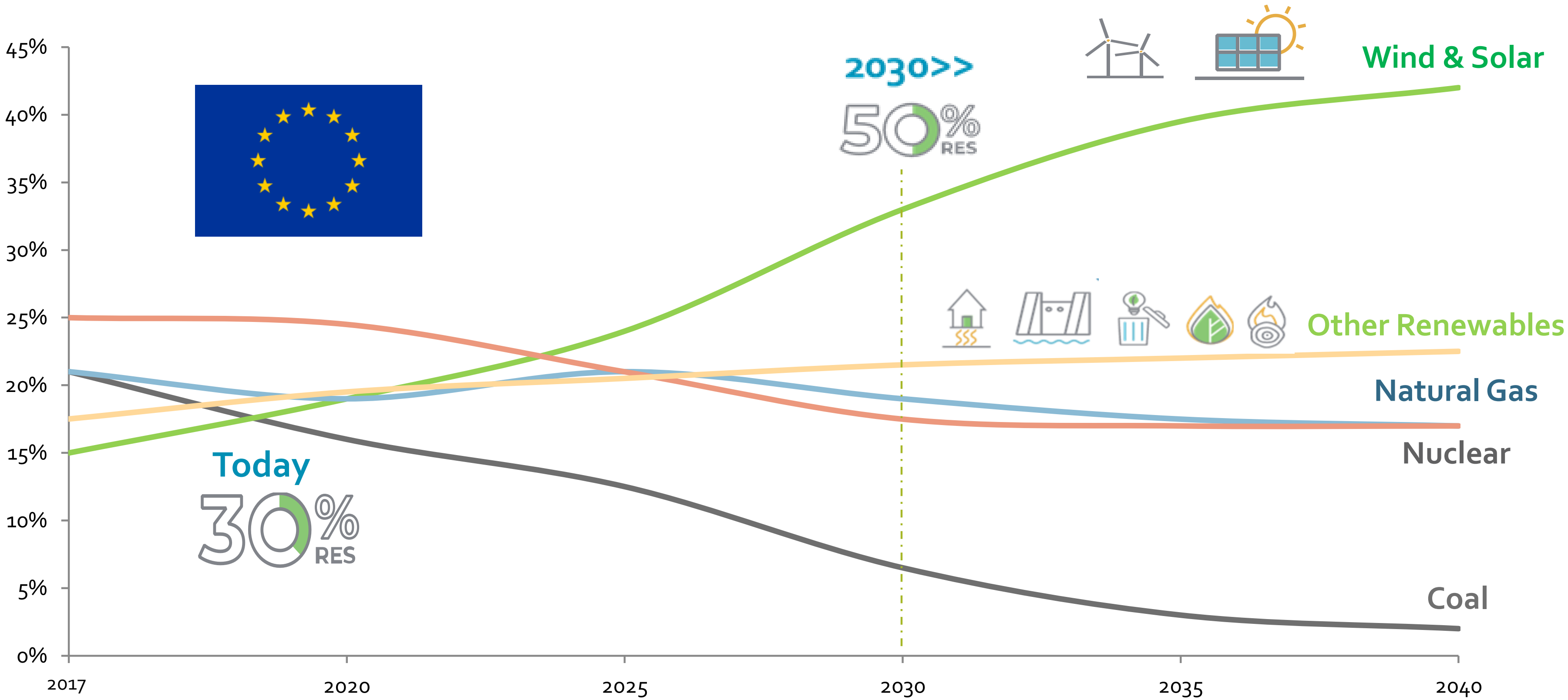
EU-SysFlex

Energy transition : A future system increasingly reliant on **renewables**, especially on **variable** sources of electricity (vRES)



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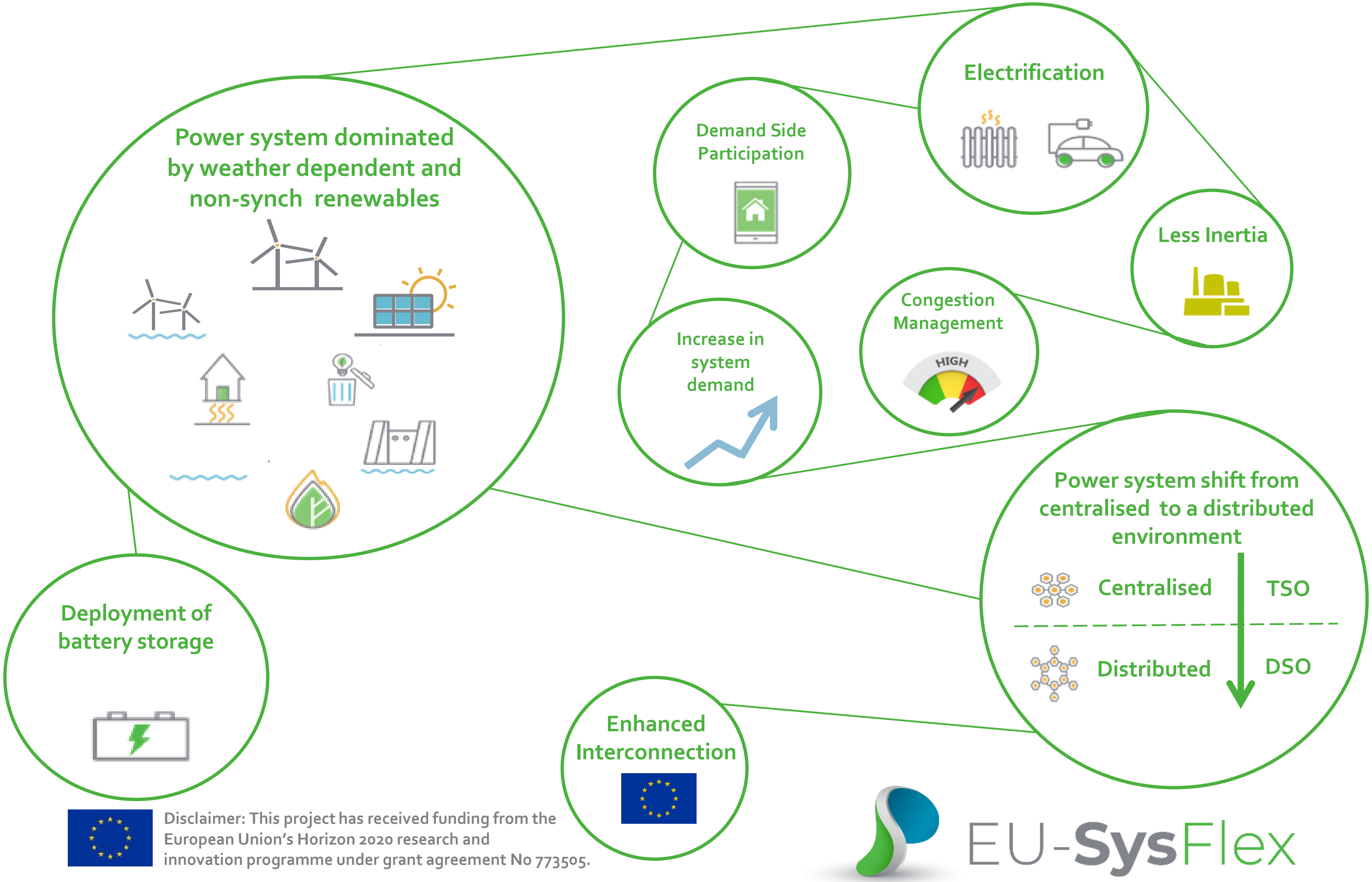
EU-SysFlex

Significant changes on the power **generation** side, not only **variable** but also **non synchronous and distributed**, and additional changes on the **demand** side.

2030>>
50% RES



Power system dominated by weather dependent and non-synch renewables

Demand Side Participation

Electrification

Less Inertia

Increase in system demand

Congestion Management

Power system shift from centralised to a distributed environment

Centralised	TSO
Distributed	DSO

Deployment of battery storage

Enhanced Interconnection

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EU-SysFlex

Avec des taux d'ENRV importants, la gestion de l'équilibre et de la stabilité du système doit évoluer

Energy Transition

aligned with EU REF 2030

52% RES-E for Europe

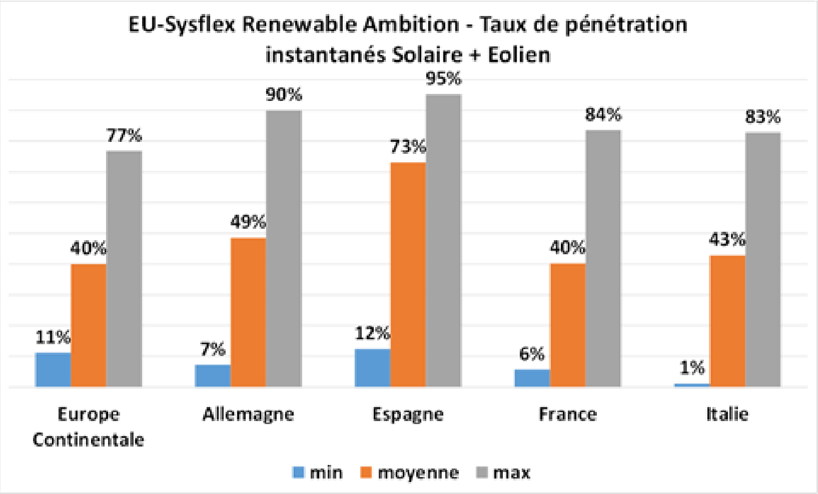
Renewable Ambition

aligned with EU REF 2050

66% RES-E for Europe

% of RES-E

0% 100%



EU-Sysflex Renewable Ambition - Taux de pénétration instantanés Solaire + Eolien

EU-SysFlex scenarios for RES penetration in Europe (D2.2, 2018)

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EU-SysFlex

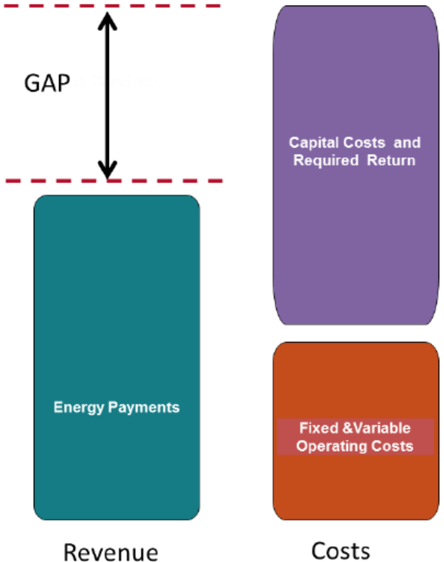
Les indicateurs mesurés confirment des enjeux techniques importants

Scarcity	Europe	Ireland	Nordic
RoCoF (dimensioning incident)	Localised concern	Inertia Scarcity	No scarcity seen (hydro)
RoCoF (System Split)	Global concern	N/A	Not analysed
Frequency Containment (dimensioning incident)	Evolving Characteristic	Evolving Characteristic	Evolving Characteristic
Frequency Containment (System Split)	Global concern	N/A	Not analysed
Steady State Voltage Regulation	SS Reactive power scarcity	SS Reactive power scarcity	
Fault Level	Not conclusive	Dynamic reactive scarcity	
Dynamic Voltage Regulation	Not conclusive	Dynamic reactive scarcity	
Critical Clearing times	Evolving Characteristic	Evolving Characteristic	
Rotor Angle Margin	Not analysed	Localised concern	
Oscillation Damping	Damping Scarcity	Damping Scarcity	
System Congestion	Global Concern	Transmission capacity scarcity	
System Restoration	Not analysed	Evolving Characteristic	

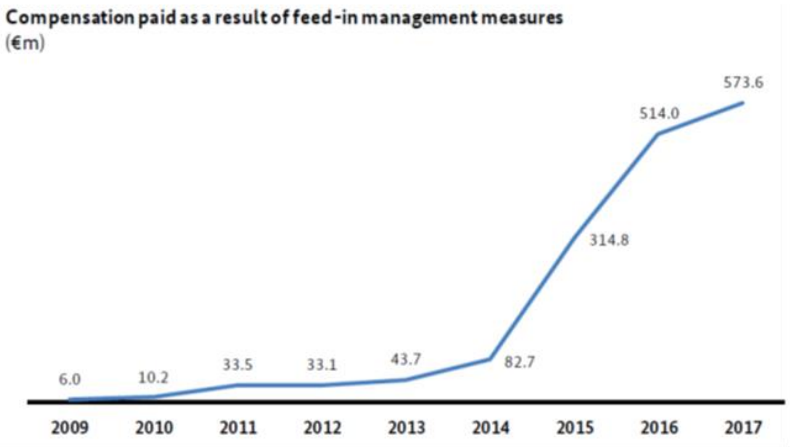
- Balancing and stability issues at high RES/SNSP are experienced in the Island of Ireland and are appearing in CE, especially when systems split.
- Congestions in all grids increase, as well as cross-borders unscheduled flows, and need inter-SO coordination: TSO-TSO and TSO-DSO
- Rethinking system operation and restoration process

EU-SysFlex

Des enjeux économiques pour la production et l'ensemble du système qui challengent les mécanismes actuels



Source : Eirgrid 2019



Source : Germany, Innogy 2019

- Structure of costs changes: capital and fixed costs make up the overwhelming share, as in addition of RES, OCGT are still needed as flexible generation for adequacy.
- Revenues for all sources of power generation drop: with zero marginal costs for vRES, gap in revenues increases for all generation plants, and even more with larger share of vRES (cannibalization) → investment risk
- Curtailment is a flexible but costly solution needed to manage increasing congestions, with compensation payments and re-dispatch costs increasing, on top of grid reinforcement → Increasing costs for SO
- Present market designs are not sufficient to support the clean energy target. Energy and flexibility prices are low and decreasing, challenging investment but also decarbonisation.

Disclaimer: This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 773505.

EU-SysFlex

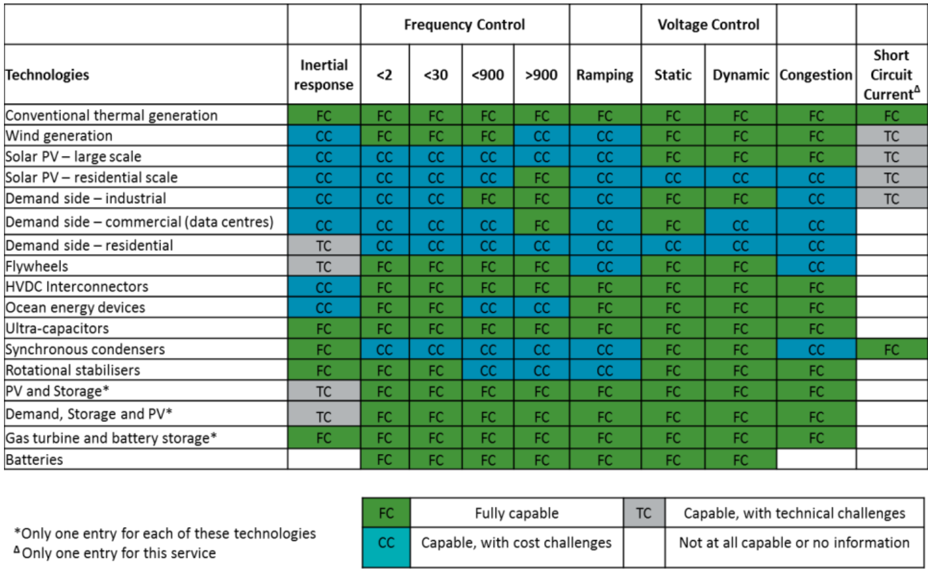
Les Services au Système évoluent et doivent être supportés par l’ensemble des acteurs

- Changes in the power system imply more flexibility from remaining conventionals, and new flexibility providers. New needs are appearing: faster frequency reserves, larger volumes of reserves, shared across countries, closer to real-time …

- To include decentralized generation and flexibility, data exchange and coordination is crucial between TSO / DSO / all energy and flexibility providers (local/global). Services will be needed and also provided at DSO level. Boundaries, processes and roles are reevaluated.

- Investments in new generation and flexibilities (storage), but also in networks' reinforcements, new components (FACTS, protections), and smart devices in the demand side, need to be secured as soon as possible by clear and stable signals → if short-term markets cannot procure these signals, long term capacity products can foster investment in flexibility.

Products and System Services vs technologies in D3.1



		Frequency Control					Voltage Control			
Technologies	Inertial response	<2	<30	<900	>900	Ramping	Static	Dynamic	Congestion	Short Circuit Current$^{\Delta}$
Conventional thermal generation	FC	FC	FC	FC	FC	FC	FC	FC	FC	FC
Wind generation	CC	FC	FC	FC	CC	CC	FC	FC	FC	TC
Solar PV – large scale	CC	CC	CC	CC	CC	CC	FC	FC	FC	TC
Solar PV – residential scale	CC	CC	CC	CC	FC	CC	CC	CC	CC	TC
Demand side – industrial	CC	CC	CC	FC	FC	CC	FC	FC	CC	TC
Demand side – commercial (data centres)	CC	CC	CC	CC	FC	CC	FC	CC	CC	
Demand side – residential	TC	CC	CC	CC	CC	CC	CC	CC	CC	
Flywheels	TC	FC	FC	FC	FC	CC	FC	FC	CC	
HVDC Interconnectors	CC	FC	FC	FC	FC	FC	FC	FC	FC	
Ocean energy devices	CC	FC	FC	CC	CC	FC	FC	FC	FC	
Ultra-capacitors	FC	FC	FC	FC	FC	FC	FC	FC	FC	
Synchronous condensers	FC	CC	CC	CC	CC	CC	FC	FC	CC	FC
Rotational stabilisers	FC	FC	FC	CC	CC	CC	FC	FC	FC	
PV and Storage*	TC	FC	FC	FC	FC	FC	FC	FC	FC	
Demand, Storage and PV*	TC	FC	FC	FC	FC	FC	FC	FC	FC	
Gas turbine and battery storage*	FC	FC	FC	FC	FC	FC	FC	FC	FC	
Batteries		FC	FC	FC	FC	FC	FC	FC		

*Only one entry for each of these technologies
$^{\Delta}$Only one entry for this service

FC	Fully capable	TC	Capable, with technical challenges
CC	Capable, with cost challenges		Not at all capable or no information

Market and regulatory design
- Simultaneous vs. sequential market clearing
- Technology bias vs. neutrality
- Temporal aspects

Market behaviour
- Decision-making in multi-service markets
- Potential for strategic behaviour

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Geographical aspects
- Locality of system services
- Interconnections and cross-border exchange of products
- Cross-border coordination and congestion management

Investment effects
- Long-term investment signals of short-term system services
- Cost-benefit analysis of cross-border coordination and investment allocation

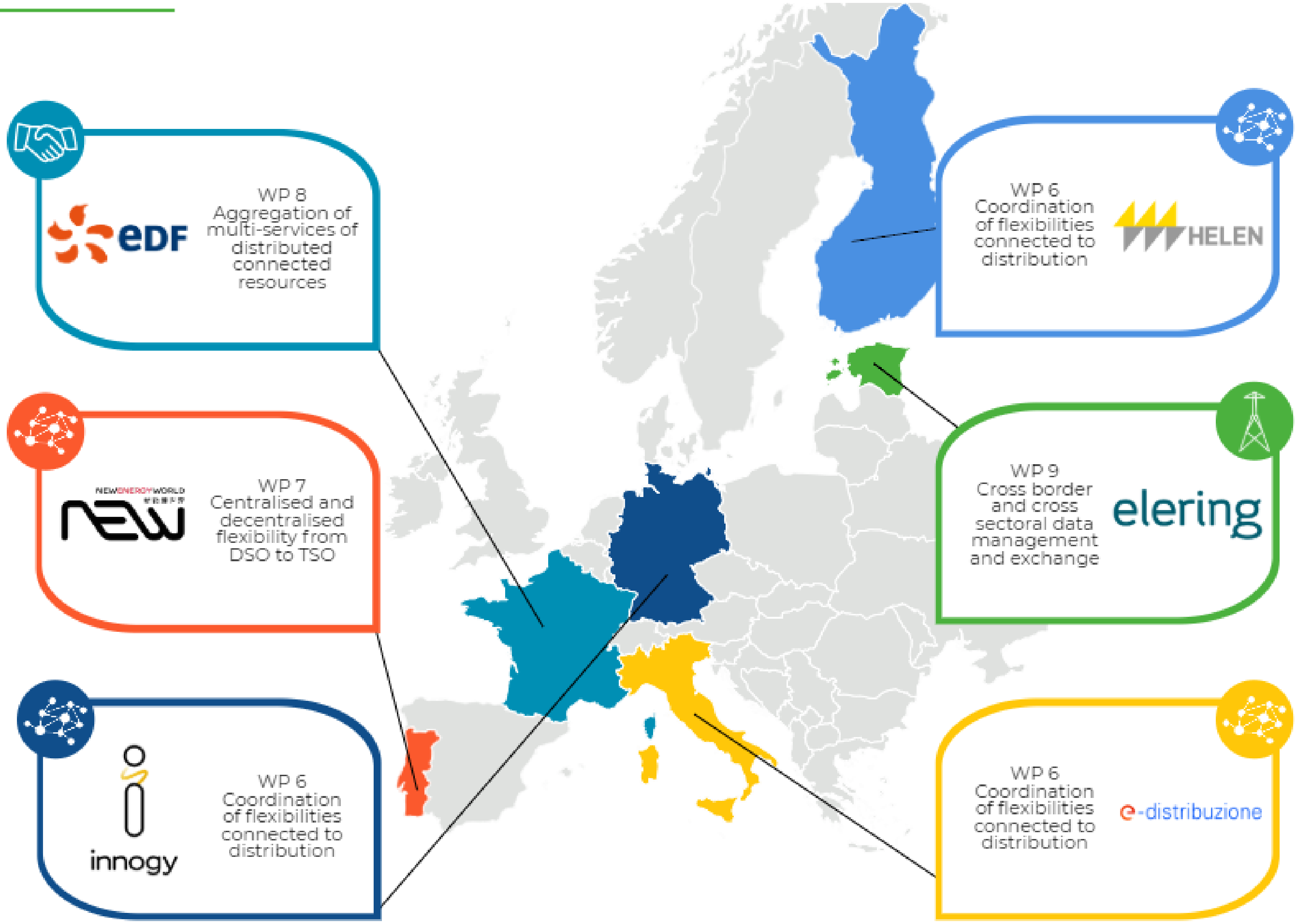
Disclaimer: This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 773505.

Plusieurs démonstrateurs et acteurs impliqués en Europe

SONI

IRE & N IRE

WP 4 – Trial process for technologies capability to provide innovative system services to the TSO



EDF

WP 8
Aggregation of multi-services of distributed connected resources

NEW

WP 7
Centralised and decentralised flexibility from DSO to TSO

innogy

WP 6
Coordination of flexibilities connected to distribution

HELEN

WP 6
Coordination of flexibilities connected to distribution

elering

WP 9
Cross border and cross sectoral data management and exchange

e-distribuzione

WP 6
Coordination of flexibilities connected to distribution

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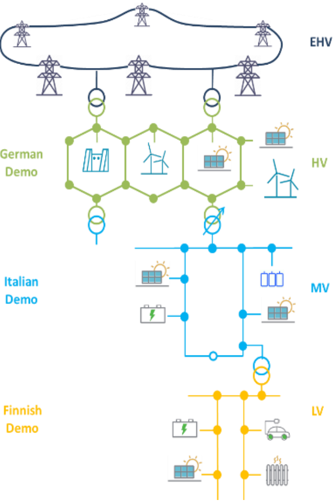
Des solutions testées à l'échelle industrielle pour répondre aux enjeux techniques de variabilité, de décentralisation et de digitalisation

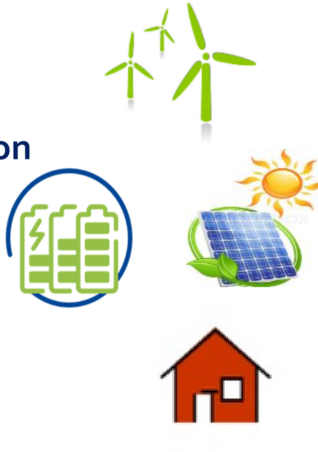


Flexibility and Stability Challenges

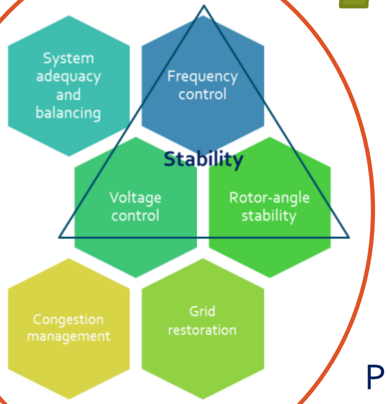
dRES participation in system services

TSO and DSO can activate flexibilities

vRES and DSR participation in system services



Individual capability of vRES and storage



3 TSO/DSO demos

Performance enhanced for flexibility and congestion

TSO-DSO Coordination

Performance enhanced for energy and flexibility services

3 aggregation demos

Operational gain increased as an aggregation

DX set of demos
Standardisation
Interoperability
Security...

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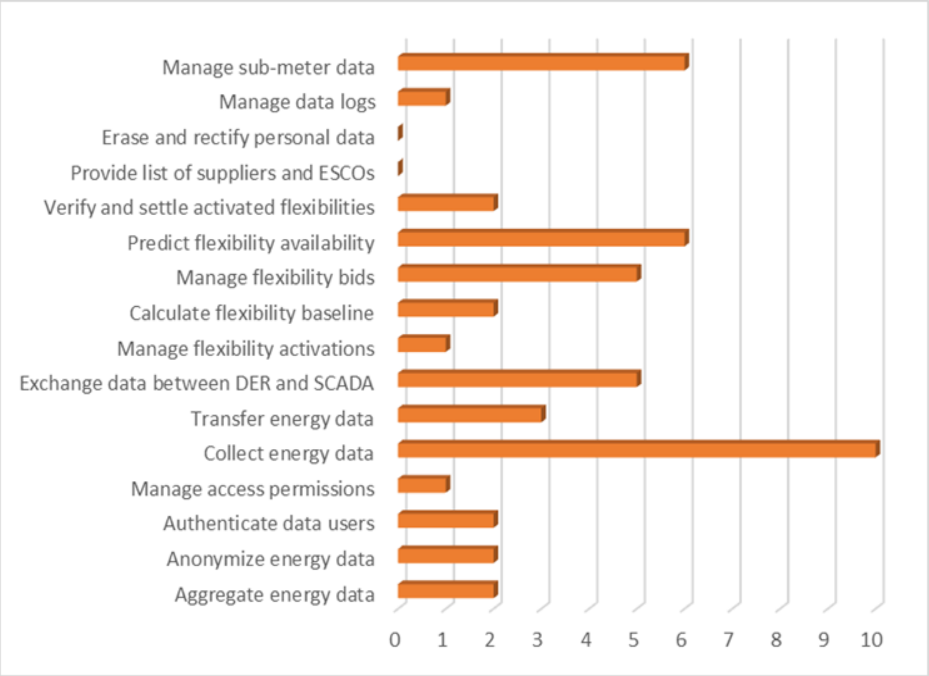
EU-SysFlex

La réplicabilité, la fiabilité et l’interopérabilité des solutions sont nécessaires à leur développement



Source : T5.3 SUMMARY OF NUMBER OF BIG DATA REQUIREMENTS PER USE CASE

- Solutions are demonstrated in their field-testing environment with specific requirements → how <u>replicable and qualified in other SO environments?</u> (WP4)
- Flexibility challenge relies on <u>Digitalization</u> : what data, property, security, standards, interoperability of tools and platforms, etc. (WP5)
- Analysis of <u>Scalability, replicability and reliability</u> of flexibility solutions started (T10.1), as well as business potential (T11.7).

Source : Germany, Innogy 2019

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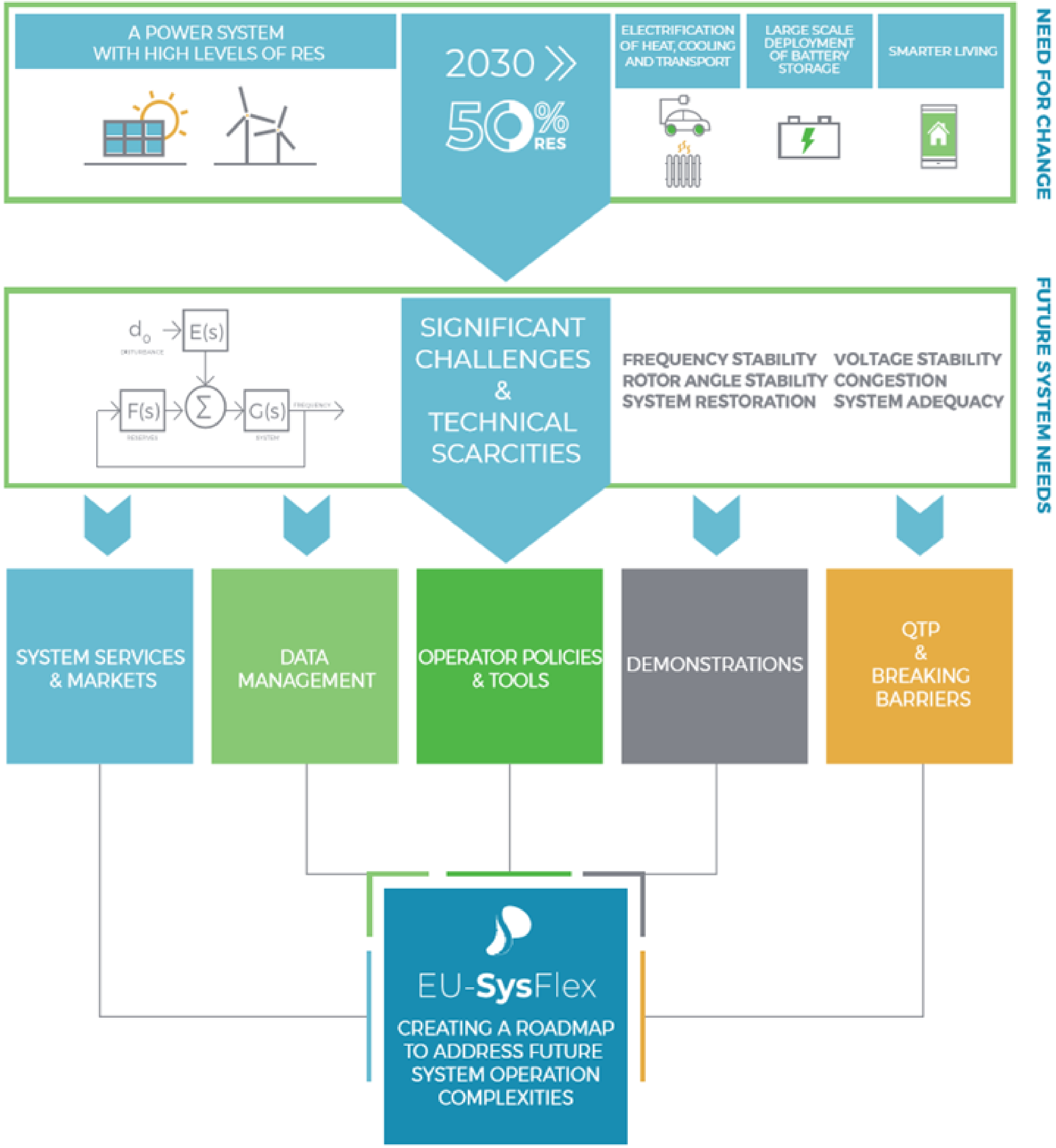
EU-SysFlex

Dernière étape du projet:
EU-SysFlex Roadmap to a flexible, low-carbon and resilient power system



NEED FOR CHANGE

A POWER SYSTEM WITH HIGH LEVELS OF RES

2030 »
50% RES

ELECTRIFICATION OF HEAT, COOLING AND TRANSPORT

LARGE SCALE DEPLOYMENT OF BATTERY STORAGE

SMARTER LIVING

FUTURE SYSTEM NEEDS

SIGNIFICANT CHALLENGES & TECHNICAL SCARCITIES

FREQUENCY STABILITY
ROTOR ANGLE STABILITY
SYSTEM RESTORATION

VOLTAGE STABILITY
CONGESTION
SYSTEM ADEQUACY

SYSTEM SERVICES & MARKETS

DATA MANAGEMENT

OPERATOR POLICIES & TOOLS

DEMONSTRATIONS

QTP & BREAKING BARRIERS

EU-SysFlex

CREATING A ROADMAP TO ADDRESS FUTURE SYSTEM OPERATION COMPLEXITIES

ET DISSEMINER !

EU renewable electricity hopes get welcome jolt

By Sam Morgan | EURACTIV.com 21. 5. 2019 (updated: 22. 5. 2019)

urope's power grid of the future needs to be upgraded in order to deal with new demands. [Photo: Shutterstock]

nguages: Slovak

fty percent of the EU's electricity will have to come from renewable energy sources by 2030 ut the issue is more than just a matter of building more solar panels and wind turbines. The ructure of Europe's power grid will have to change.

cording to new EU rules for the next decade, the bloc will have to get 32% of total energy from newable energy by 2030 and make sure 14% of transport's needs are from clean energy sources.

e EU is currently on track to hit a 20% overall target set for next year and despite a slowdown in obal renewable investments, the amount of clean electricity behind the plug is likely to top 50% by 30.

t the European power grid cannot handle that much power in its current form and major work, th structural and administrative, will have to be completed in the coming years if the targets are to met.

ng Horizon 2020-funded project EU-SysFlex set out to address those challenges, of €26.5 million to identify the future energy system's needs by building seven jects across Europe.

of various projects met in Brussels to share how their work is progressing and ned so far, as the programme nears its midway point.

EU-SysFlex

Newsletter no. 3, October 2019

System operation & flexibility solutions required to meet the ambition of 50% renewables on the European electricity grid by 2030

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eu-sysflex.com

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Thank you for your attention!

Q&A

This project has received funding from the European Union’s Horizon 2020 research and innovation program under grant agreement No 773505.

DIGITAL ENERGY

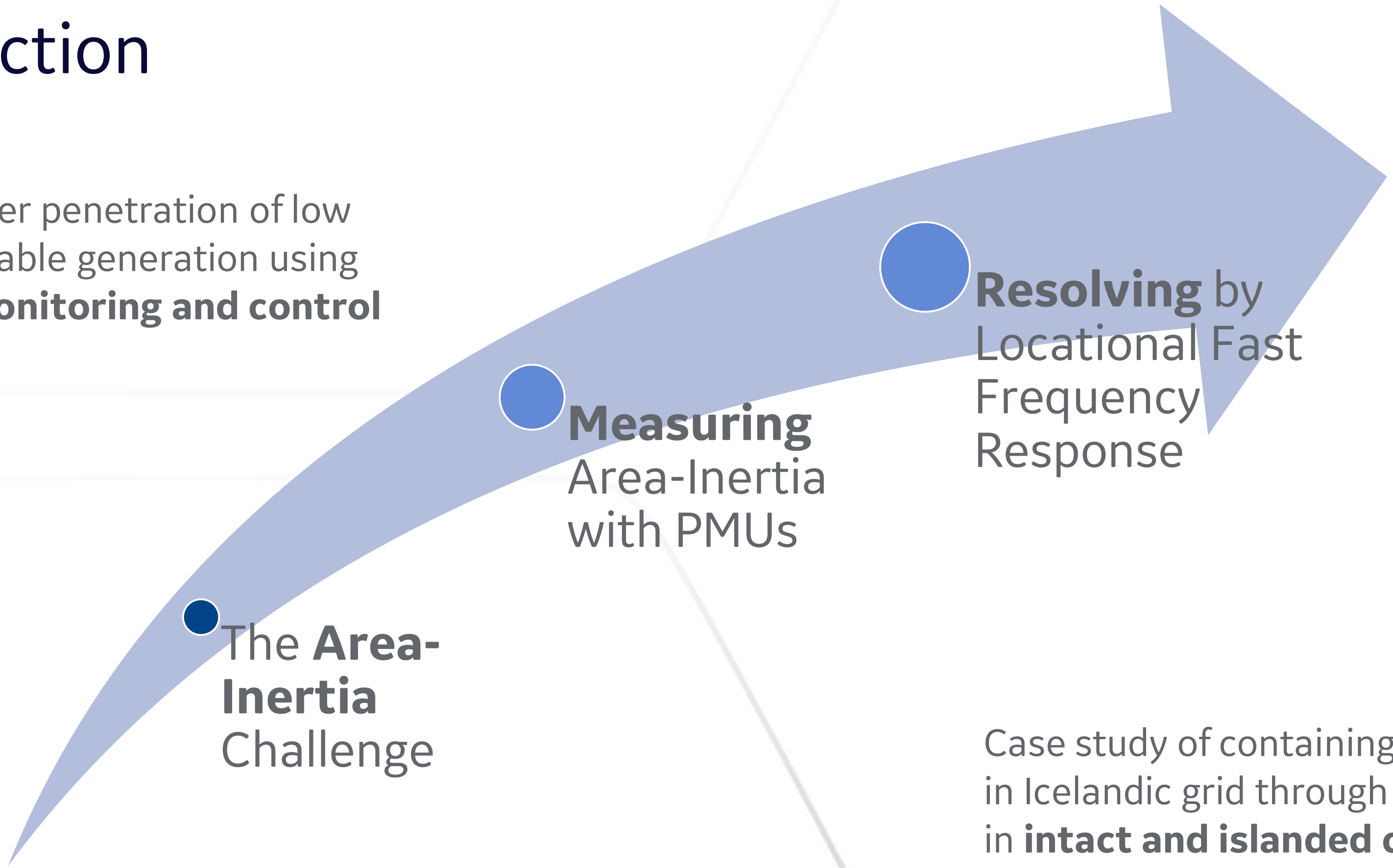
Inertia Measurement & Fast Frequency Control

Vera Silva
CTO GE Renewable Energy

MANAGING LOW INERTIA GRID SCENARIOS

Introduction

Enabling higher penetration of low inertia renewable generation using **wide area monitoring and control**



The **Area-Inertia** Challenge

Measuring Area-Inertia with PMUs

Resolving by Locational Fast Frequency Response

Case study of containing frequency in Icelandic grid through fast control in **intact and islanded conditions**

Low Inertia Grid Solutions

MIGRATE EU Project

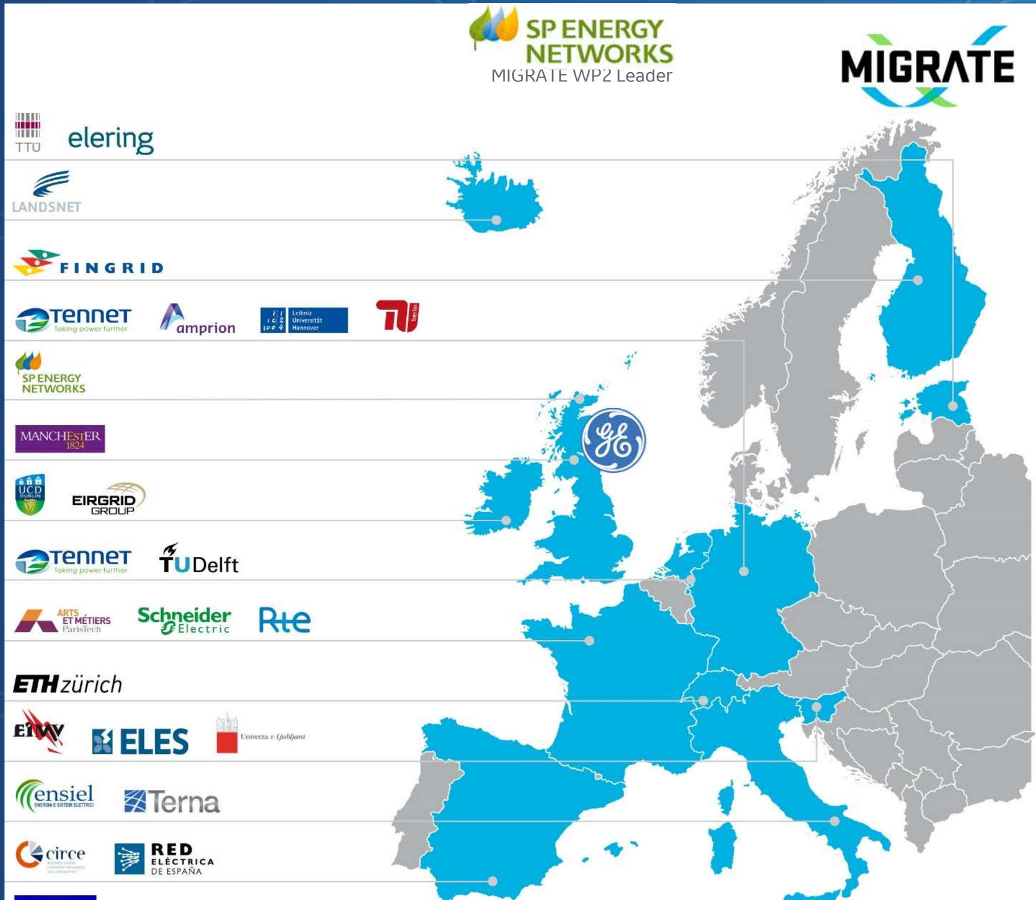
- 13 Countries, 12 TSOs, industry & academia
- SP Energy Networks leading, Landsnet partner in WP2 "Real-time Monitoring & Control"
- Monitored KPIs include ***Effective Area Inertia***

GE Participation in MIGRATE

- Collaboration with SP Energy Networks in defining, developing & trialing KPI protoypes
- Applying generalised low inertia control in live scheme in Iceland
- Inertia investigations in 5 European TSOs

Beyond MIGRATE

- GE R&D using Machine Learning for Inertia Forecasting, Sensitivity & Presentation
- Industrial deployment in UK and Ireland



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691800 (MIGRATE project).

THE INERTIA CHALLENGE

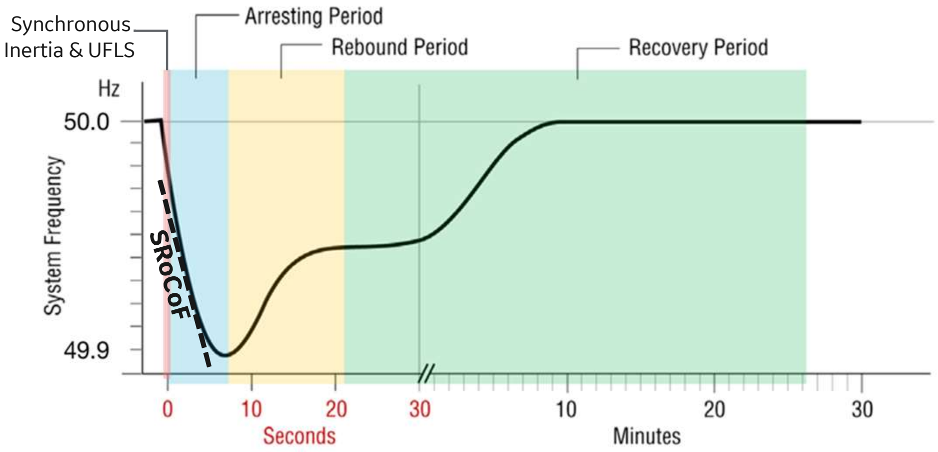
Role of Inertia for Stable Frequency

Conventional generation has large inertia due to rotating mass of generator+turbine.

Single Generator

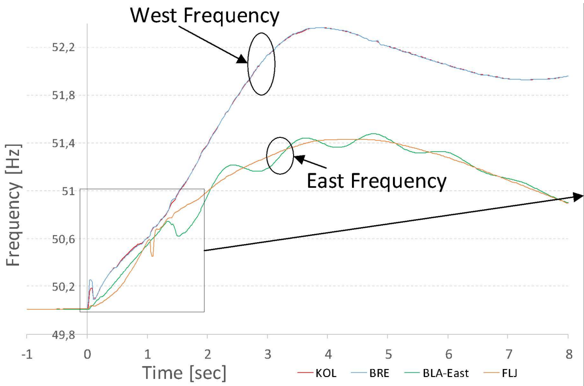
Acceleration = Rate of Change of Frequency (RoCoF)

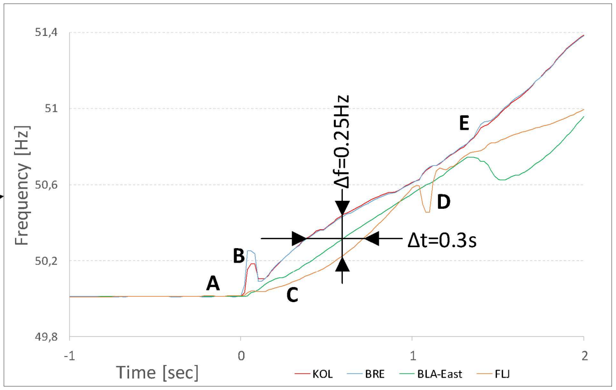
$$\overbrace{\Delta p_e(t) - \Delta p_m(t)}^{\text{Power imbalance}} = -2H\frac{df(t)}{dt}$$



Historical assumptions			Present trends
Frequency changes are slow, so governor controls can arrest the frequency before load shed, typically ~10s	✗	⇨	Inertia reducing so that load shed limits may be reached in <3s, too fast for governors
"System inertia" is sum of all generator H constants which defines RoCoF after a trip	✗	⇨	As share of rotating inertia reduces, other passive devices and active controls influence
Frequency responds as if it was a single mass, ie one frequency and RoCoF applies across the system	✗	⇨	Frequency and RoCoF varies substantially between locations in first seconds

Effect of Sparse Centres of Inertia – Iceland Example

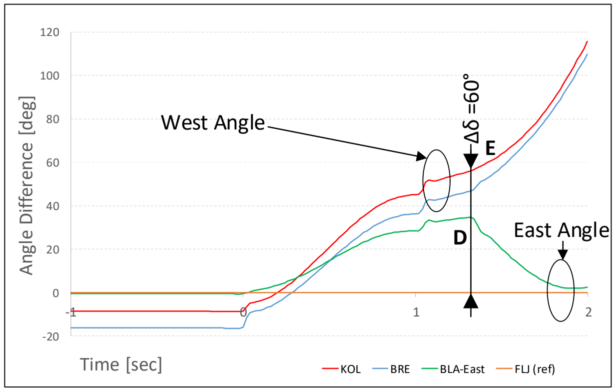


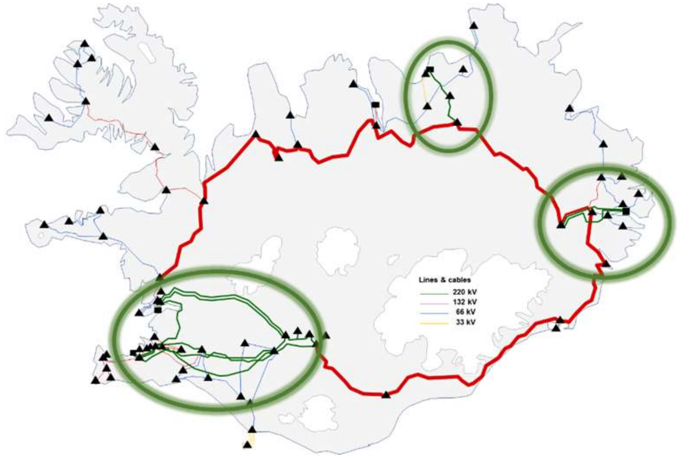


1.2s to Islanding

4s to Frequency Peak

A	T=0s	Industrial load #1 reduction (first stage)
B	T=0.2s	Industrial load #1 reduction (second stage)
C	T=0.36s	Industrial load #1 trip
D	T=1.1s	Area angles separated by 60°, result in high E-W power. One route opens by special protection
E	T=1.2s	Areas accelerate away from each other; synchronism is lost and system islands





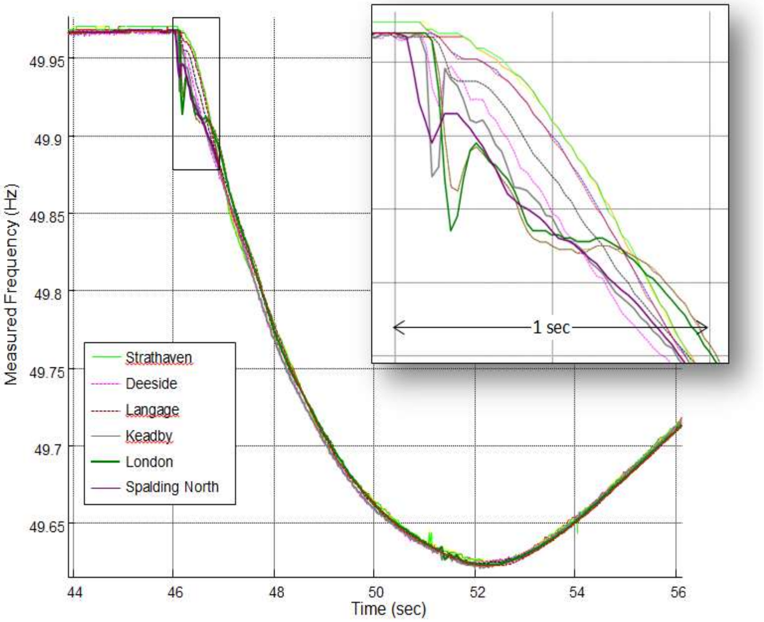
Sparse inertia separated by long transmission distance.

Loss of large load causes rapid, unequal rise in frequency
→ phase angles diverge
➔ **Islanding**

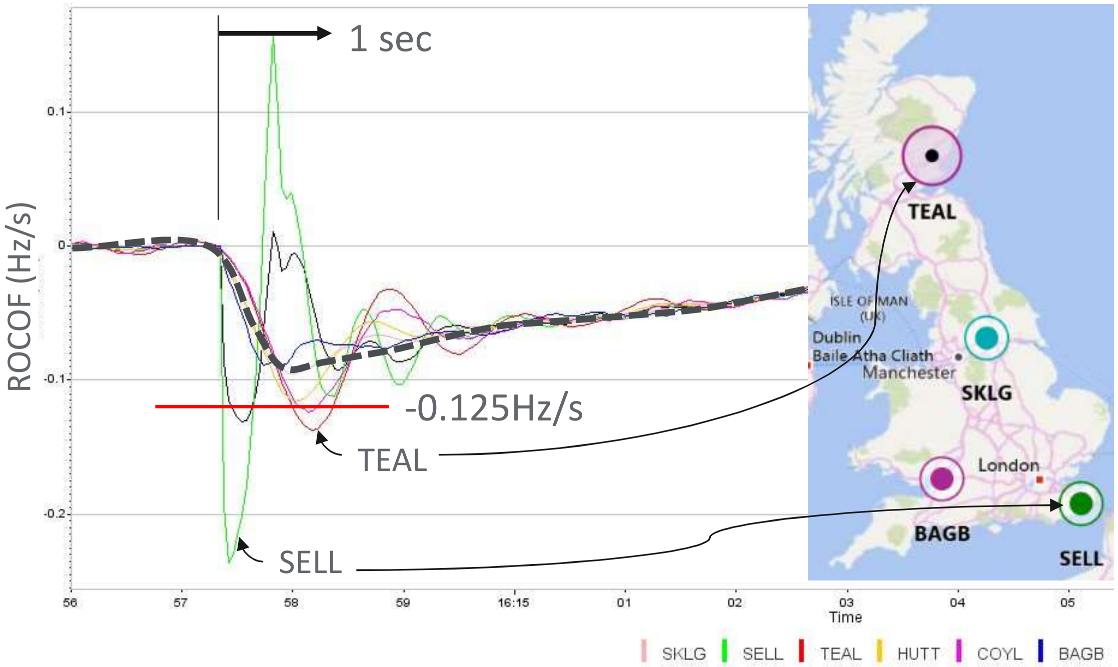
THE INERTIA CHALLENGE

Effect of Sparse Centres of Inertia - GB

Frequency change takes time to propagate
→ Angles diverge → Stability risk



ROCOF hits loss-of-mains limits in north & south



Average system RoCoF within GB 0.125Hz/s limit, but threshold exceeded in both the north & south GB (not Midlands). Risk of regional DER tripping, or in extreme case, loss of angle stability in network.

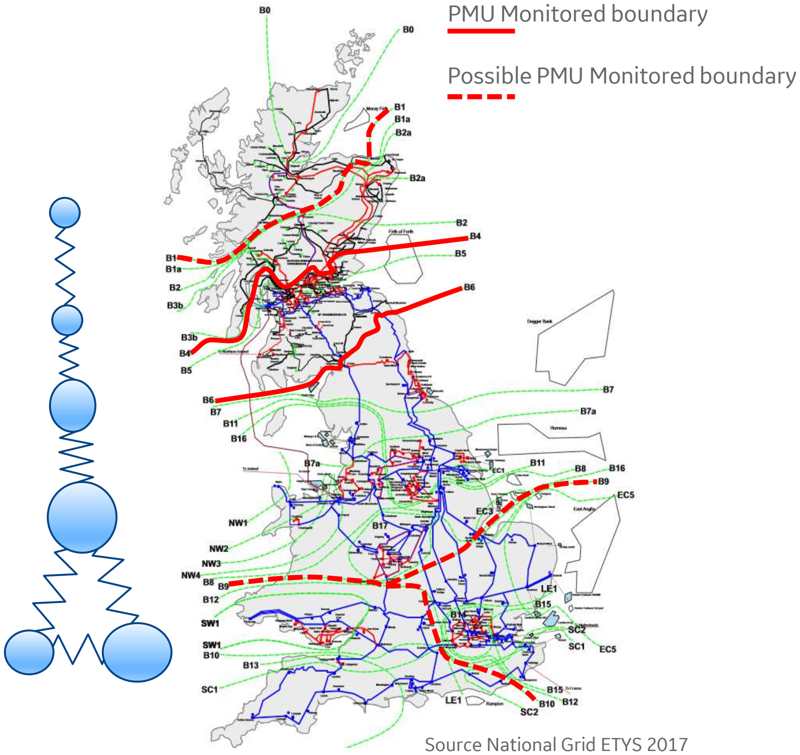
ADDRESSING SPARSE AREA INERTIA

System acts as Multiple Linked Centres of Inertia

Consider system as **dispersed centres of inertia** linked by transmission corridors.

Monitor **effective inertia per area** and address by

1. Constraining infeed loss per area, such that RoCoF limits and grid stability are respected (expensive)
2. Minimising constraint by applying **Locational Fast Frequency Response**:
    - Fast enough to prevent load shed
    - Proportionate to event
    - Reducing the likelihood of split
    - Reducing regional RoCoF



Source National Grid ETYS 2017

GB 2025/26: → **0.6Hz/s** (system)
Min 75GVA.s → **1.33s** contain F<49.2Hz
1800MW max loss **Area RoCoF can be significantly worse!**

PMUs ENABLE INERTIA MANAGEMENT

Measuring Effective Area Inertia

Development and validation of PMU-based methods for continuous measurement of effective area inertia

MEASURING INERTIA EFFECTS WITH PMUS

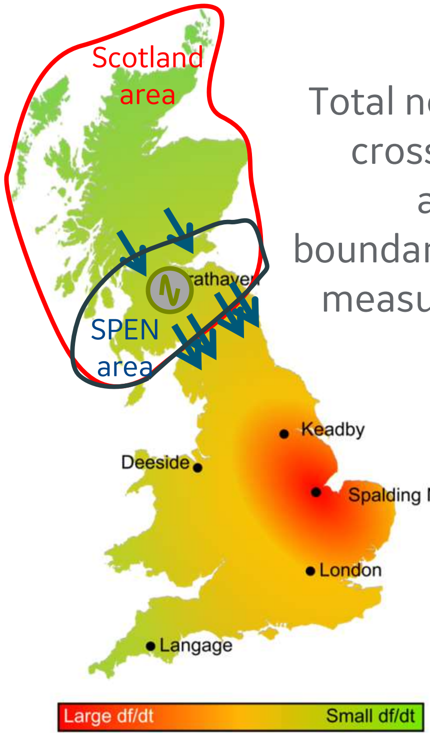
Measuring the **Effective Area Inertia**

Select areas that can act as Centres of Inertia (COI), ie frequency and angle differences are small within the area

Frequency measured at selected points within the area, preferably close to main sources of real inertia
→ area COI frequency → area ROCOF

PMUs are located on all transmission circuits crossing the area boundary → summation of net power exchange

Extract effective area inertia from aggregated signals



Total net P crossing area boundary is measured

MEASURING INERTIA EFFECTS WITH PMUS

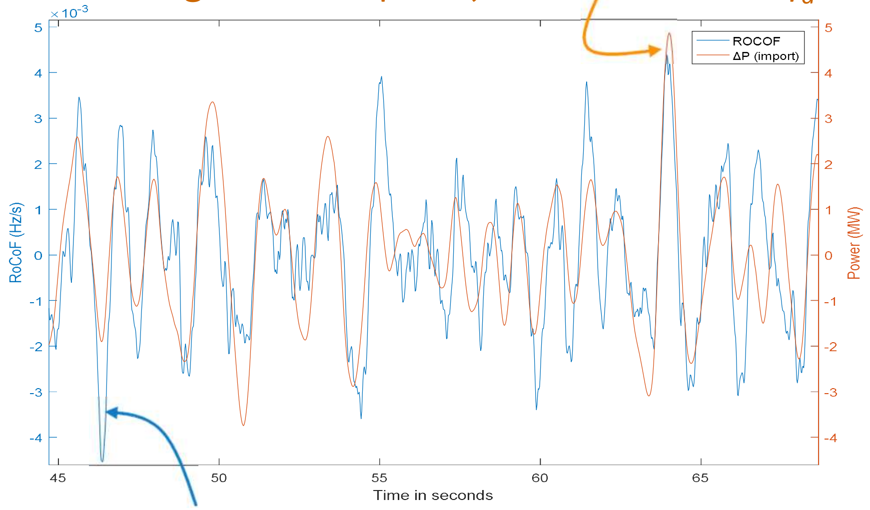
Measuring the **Effective Area Inertia**

Example shows section of Scotland data

- **Area RoCoF** for Scotland COI
- **Net Boundary Power** across the Scotland boundary

These signals are used to compute effective inertia using correlated changes.

Average area frequency → Area RoCoF df_a/dt



Sum of Boundary Power, detrended (Δp_b)

Effective Area Inertia estimation for
(e.g. 30-min windows, steps 1 min)

$$\boxed{H_{EA} = \frac{\Delta p_b(t)}{2\,\frac{df_a(t)}{dt}}}$$

MACHINE LEARNING LAYER

Prediction of Area Inertia

Applying machine learning using predictors relates area inertia to know & predictable values

- Conventional rotating inertia
- Load
- Solar power
- Wind power

24h prediction trialed successfully

Sensitivity of inertia to system state yields insights into contributions of different factors

Inertia Key Values

Area	Current Inertia	Forecast Min Over 24hrs	Current Max Infeed Loss MW	Forecast Min Loss Over 24hrs
1. SHE West	207	138	52	35
2. SHE East	310	208	97	65
3. SPEN	**737.625**	**699.53925**	**92.203125**	**87.43323**
4. NGTO North	310	208	97	65
5. NGTO South	310	208	97	65
Whole System	1874	1461	435	317

PMUs ENABLE INERTIA MANAGEMENT

Mitigation by Wide Area Fast Frequency Response

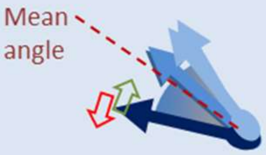
Experience from implementation of locationally sensitive fast acting frequency response services using several diverse technologies in the Icelandic grid.

Wide Area View of Disturbance

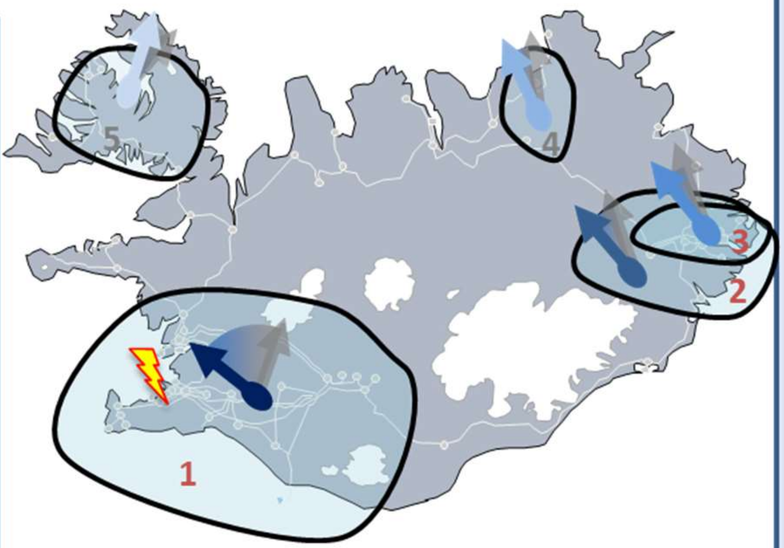
Zones Centres of inertia; islanding may occur between zones, not (successfully) within zones. **Aggregated Angle and Frequency** for each zone shared with all control points.

Angle Difference

Angles swing apart during disturbance → islanding risk

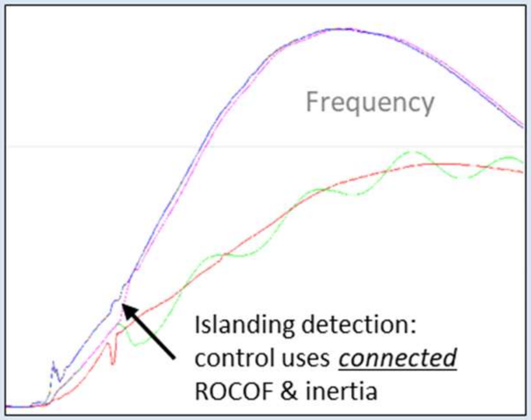


Act in **location** to return angles to system mean angle



Frequency

Disturbance Frequency accelerates in proportion to (MW loss) / (inertia).
BUT not uniform across network

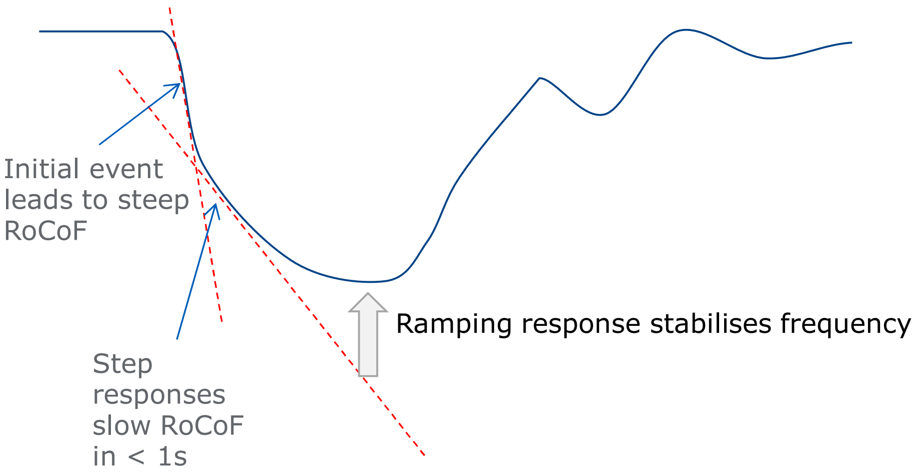


Islanding detection:
control uses *connected*
ROCOF & inertia

System ROCOF Aggregated frequency from all connected zones
→ system ROCOF*inertia → MW loss.

Fast Frequency Response: Proportional to Power Imbalance

Fast initial response, self-correcting



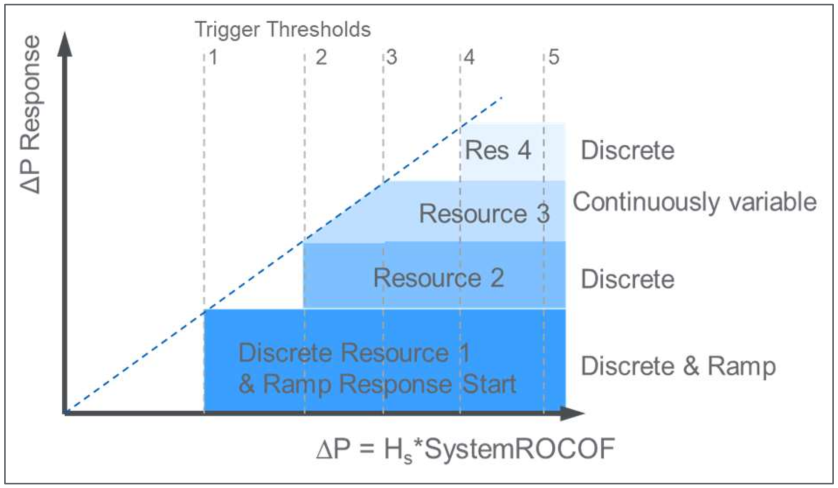
Initial event leads to steep RoCoF

Step responses slow RoCoF in < 1s

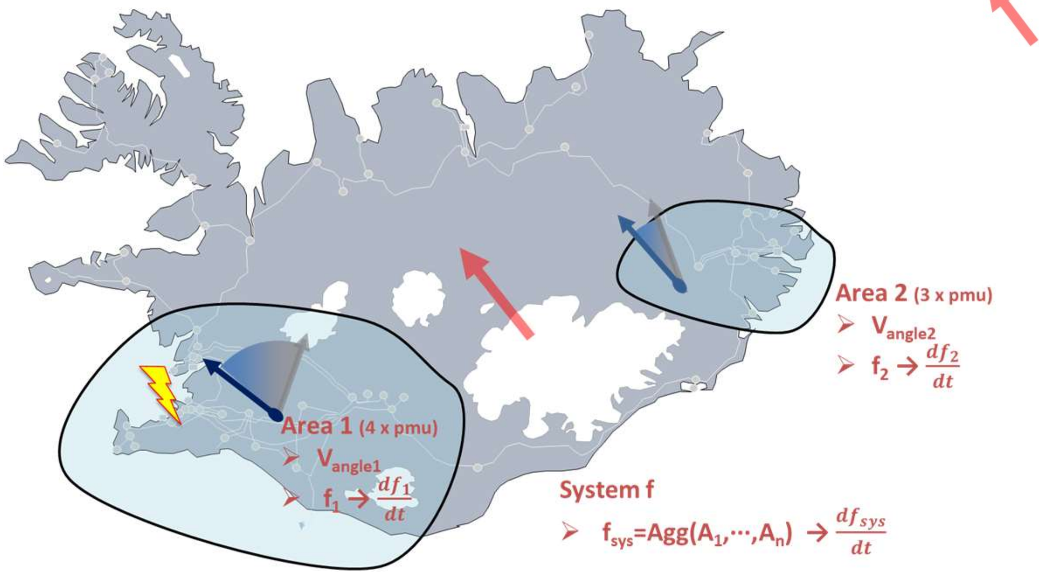
Ramping response stabilises frequency

Responses also subject to **location-enabling**

Resources deployed in proportion to System RoCoF & System Inertia for the currently-connected area(s)



Fast Frequency Response: Locational Enabling



System Average Angle.

Enable High Frequency action in Region if Regional Angle moving ahead.

Enable Low Frequency action in Region if Regional Angle moving back.

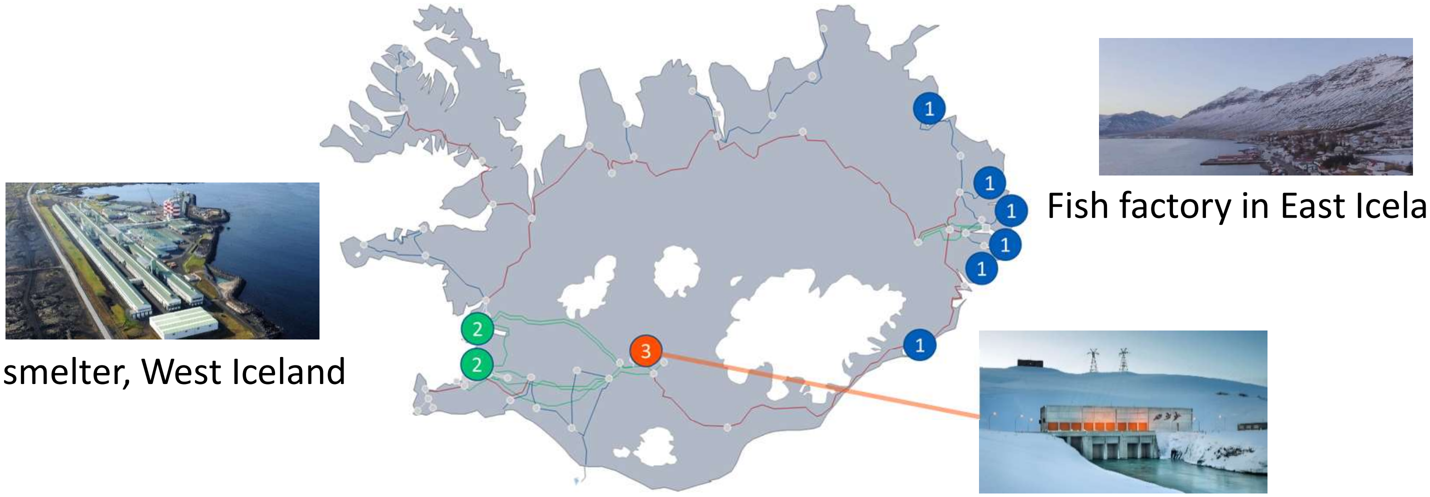
Also compare Region vs System Frequency

	SRoCoF* **Negative** *Net generation loss*	**SRoCoF Positive** *Net load loss*
Zone's Frequency (F) & Angle (δ) **GREATER** than system average	**INHIBIT**; event is far from the zone	**ENABLE**; event is in or near the zone
Zone's Frequency (F) & Angle (δ) **LESS** than system average Zone's	**ENABLE**; event is in or near the zone	**INHIBIT**; event is far from the zone

Distant response may be enabled after 1st swing complete,

Live Pilot WAC in the Icelandic Grid

Category	Location Sensitive Action	Pilot Example
① Discrete Step – trip (HF)	Sheddable load tripping	East Iceland Fish Factory Shedding (6 units @ 15-25MW full load)
② Discrete Step – control (HF&LF)	Fast load step up/down by thyristor controlled load. Short term.	Smelters in West Iceland (ISAL & NAL, target about +20/-50MW control).
③ Ramp Response (HF; future LF)	Ramp ON (up/down), sustained till frequency stabilised. Long term.	Hydro fast ramp (HRA 70MW unit) HF implemented now; LF in future



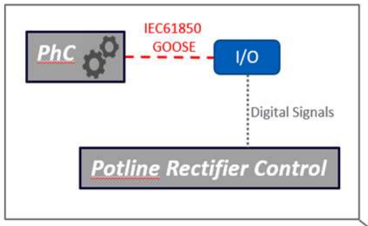
Fish factory in East Iceland

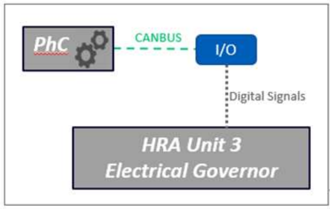
ISAL smelter, West Iceland

Hrauneyjar (HRA) Hydro Plant

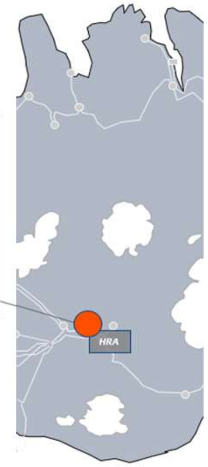
Implementation of Fast Frequency Response Resources

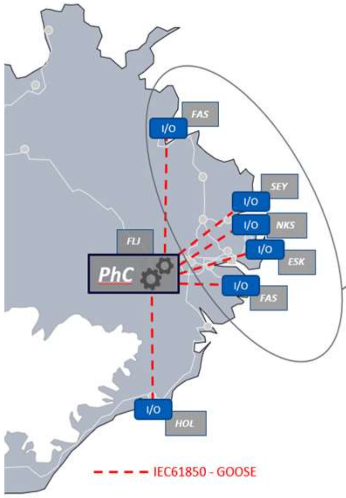
Aluminium Smelter



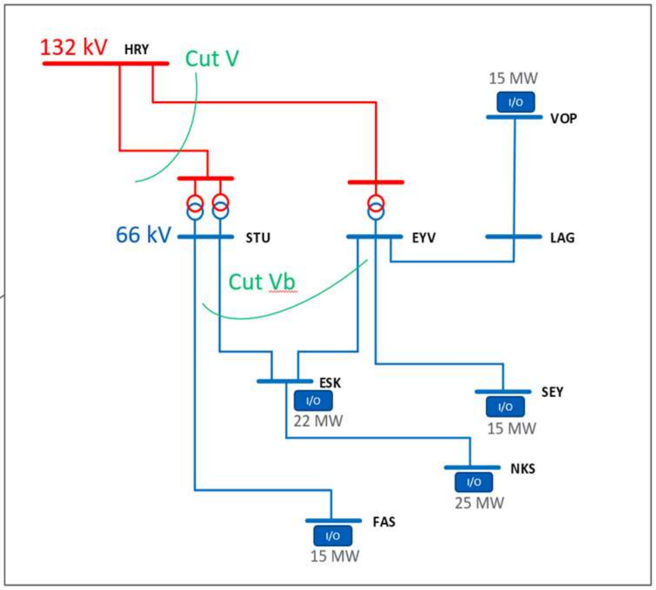


Hydro Fast-Ramp





6x Fish Factories



PhasorController

Lessons from Icelandic Implementation

Wide area control is working well

- Fast acting (<0.5s) & reliable with fault-tolerant distributed control. Handles complex multi-event sequences.
- Frequency containment improved: ~ 0.2-0.4Hz; e.g. trip size previously causing >52Hz contained at 51.8Hz
- Reduced islanding probability & impact with sparse inertia: 4 events expected to cause islanding remained intact
- More connection capacity: 107MW load able to connect with WAC scheme
- Landsnet plans to extend to more sites & new use cases

Enables flexible fast frequency services

- Diverse loads & generators can contribute. New service capability easily added.
- Cost effective – no new capital equipment or dedicated batteries

General applicability

- Could be applied in large interconnection with straightforward revisions

INERTIA MEASUREMENT AND MITIGATION

Conclusion

1. PMU-based **Effective Area Inertia** estimation captures the true nature of distributed inertia
2. Fast frequency response needed, but **local control can destabilise** angle stability and oscillations
3. **Triggered wide area control is fast, stable and predictable**
4. **Live implementation** has shown substantial performance improvement
5. Unlocks **diverse technology** resources to participate in frequency control

Some lessons learned from the Migrate European Project:

How to handle frequency support in systems with high penetration of power electronics converters ?

X. GUILLAUD, Professeur L2EP

L2EP Laboratoire d'électrotechnique et d'électronique de puissance de Lille

Université de Lille

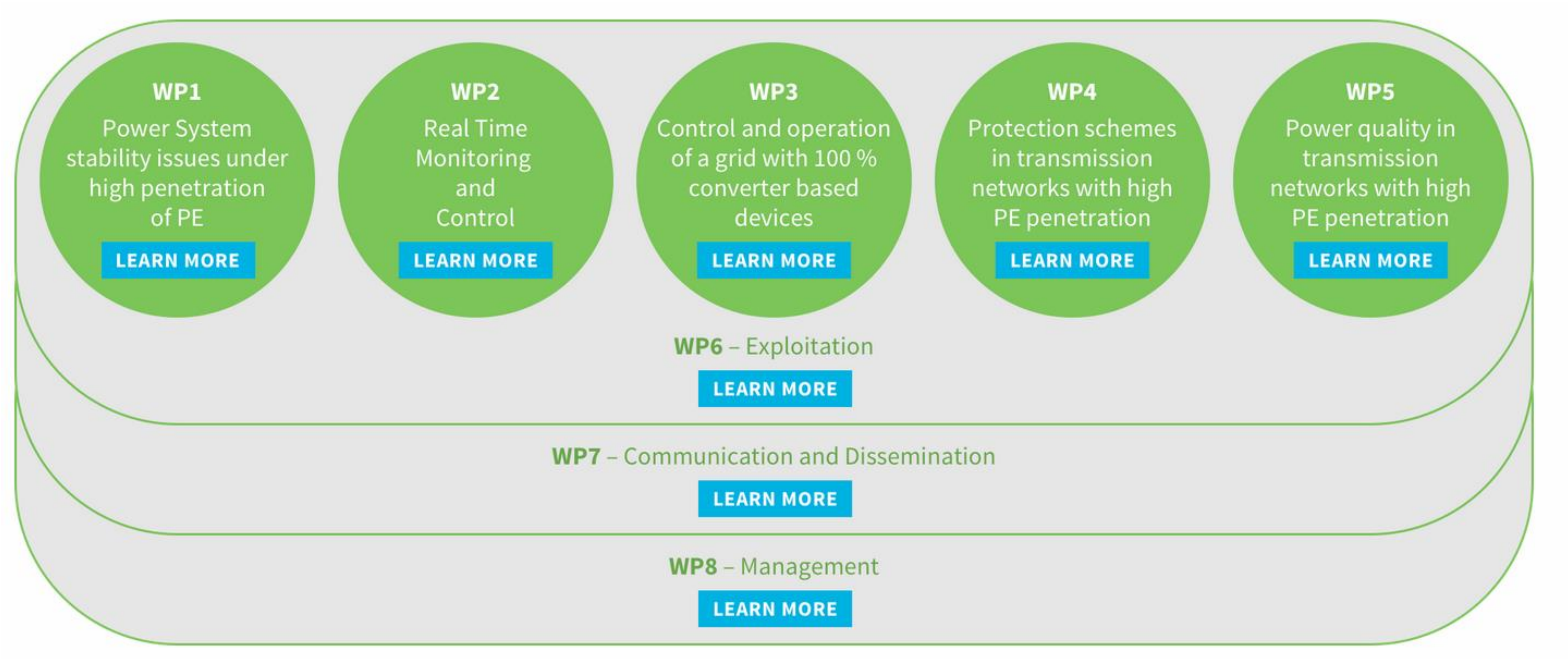
centralelille

Arts et Métiers Institute of Technology

HEI Ingénieurs pour le monde

yncréa

Migrate project - presentation



WP1
Power System stability issues under high penetration of PE
LEARN MORE

WP2
Real Time Monitoring and Control
LEARN MORE

WP3
Control and operation of a grid with 100 % converter based devices
LEARN MORE

WP4
Protection schemes in transmission networks with high PE penetration
LEARN MORE

WP5
Power quality in transmission networks with high PE penetration
LEARN MORE

WP6 – Exploitation
LEARN MORE

WP7 – Communication and Dissemination
LEARN MORE

WP8 – Management
LEARN MORE

https://www.h2020-migrate.eu/about.html

Migrate project - presentation

❑ Summary of the deliverables

- D 3.1 : Definition of the system needs
- D 3.2 : Control and Operation of a Grid with 100% converter-based devices – Model reduction
- D.3.3 : New options for existing system services and needs for new system services
- D 3.4 : New options for system operations
- D 3.5 : Local control for Grid Forming converters
- D 3.6 : Requirement guidelines for operating a grid with 100M power electronic devices

❑

General considerations about grid forming control

Difference between grid forming and following control

What is the role of a power converter ?

#1 Exchanging **active power** with the grid

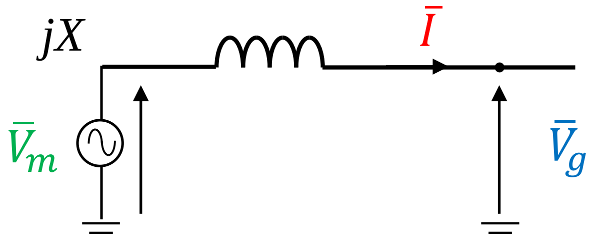
#2 For a number of them : Providing some **ancillary services** (voltage support, frequency support …)

The control of the **active power** is a key point in the control of a VSC.

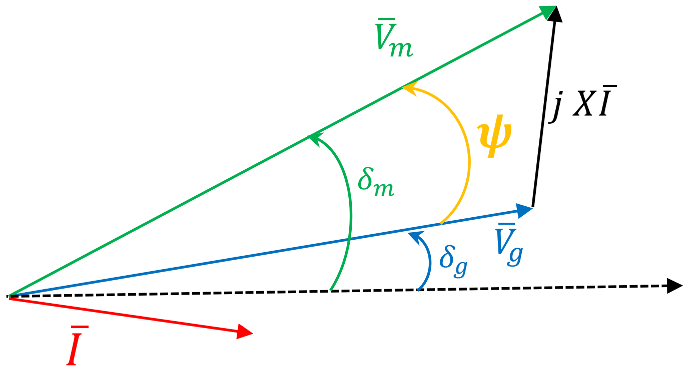
Let’s see the 2 different ways to control the active power and the fundamental consequence in term of control

Origin of the grid-forming control

Let’s recall the well-known **voltage** formulation $P = \frac{V_g V_m}{X} sin(\psi)$



$\bar{V}_m = V_m\, e^{j\delta_m}$ $\bar{V}_g = V_g\, e^{j\delta_g}$



V_g cannot be modified directly by the control.

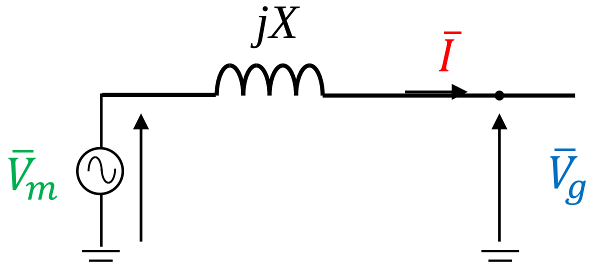
A modification on V_m has a strong influence on the reactive power

ψ is the only way to control the active power

This is the origin of the grid-forming control

Principle of the grid-forming control

The output of the power controller is defining the angle ψ

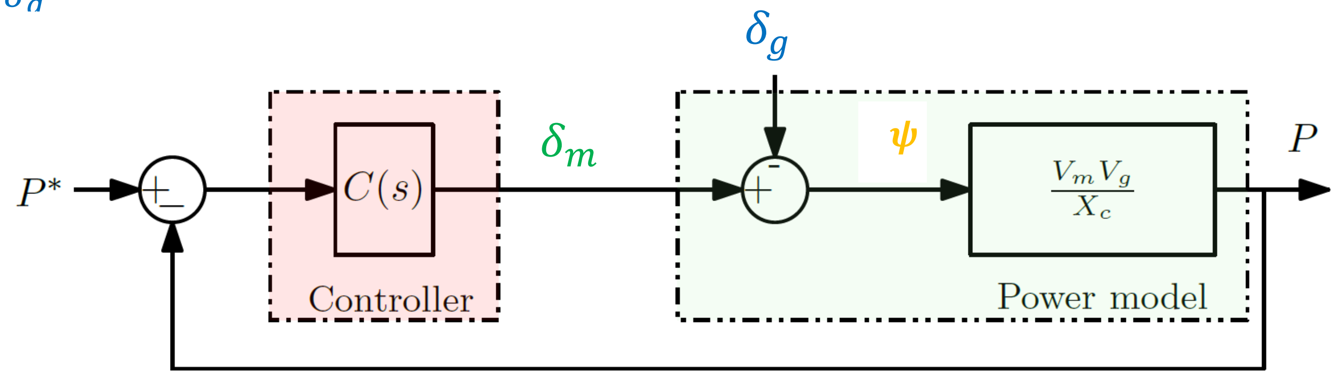


$\bar{V}_m = V_m\, e^{j\delta_m}$

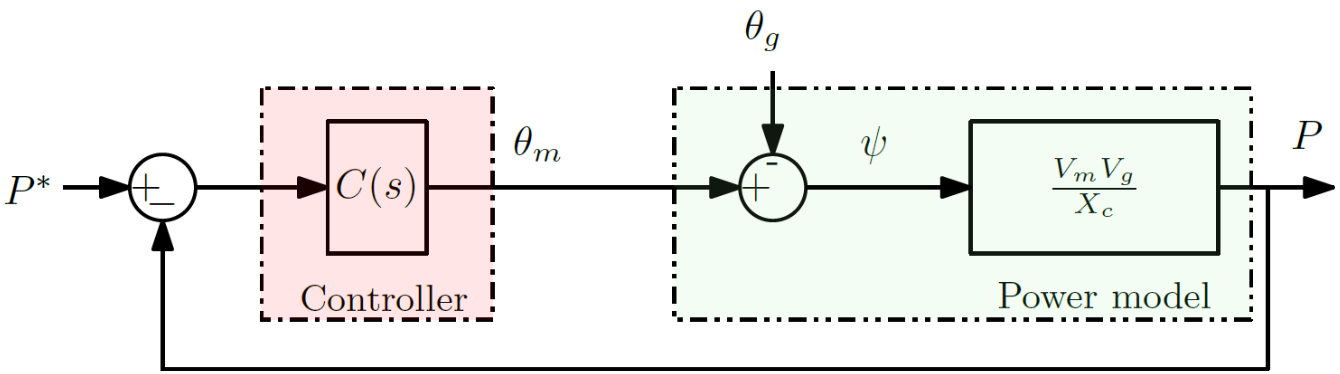
$\bar{V}_g = V_g\, e^{j\delta_g}$

$\psi = \delta_m - \delta_g$

Since, only the modulated voltage angle (δ_m) can be driven by the converter. The control is slightly modified



Different variants on the grid-forming control



First requirement : Active power control and $\boldsymbol{P = P^*}$ in steady state

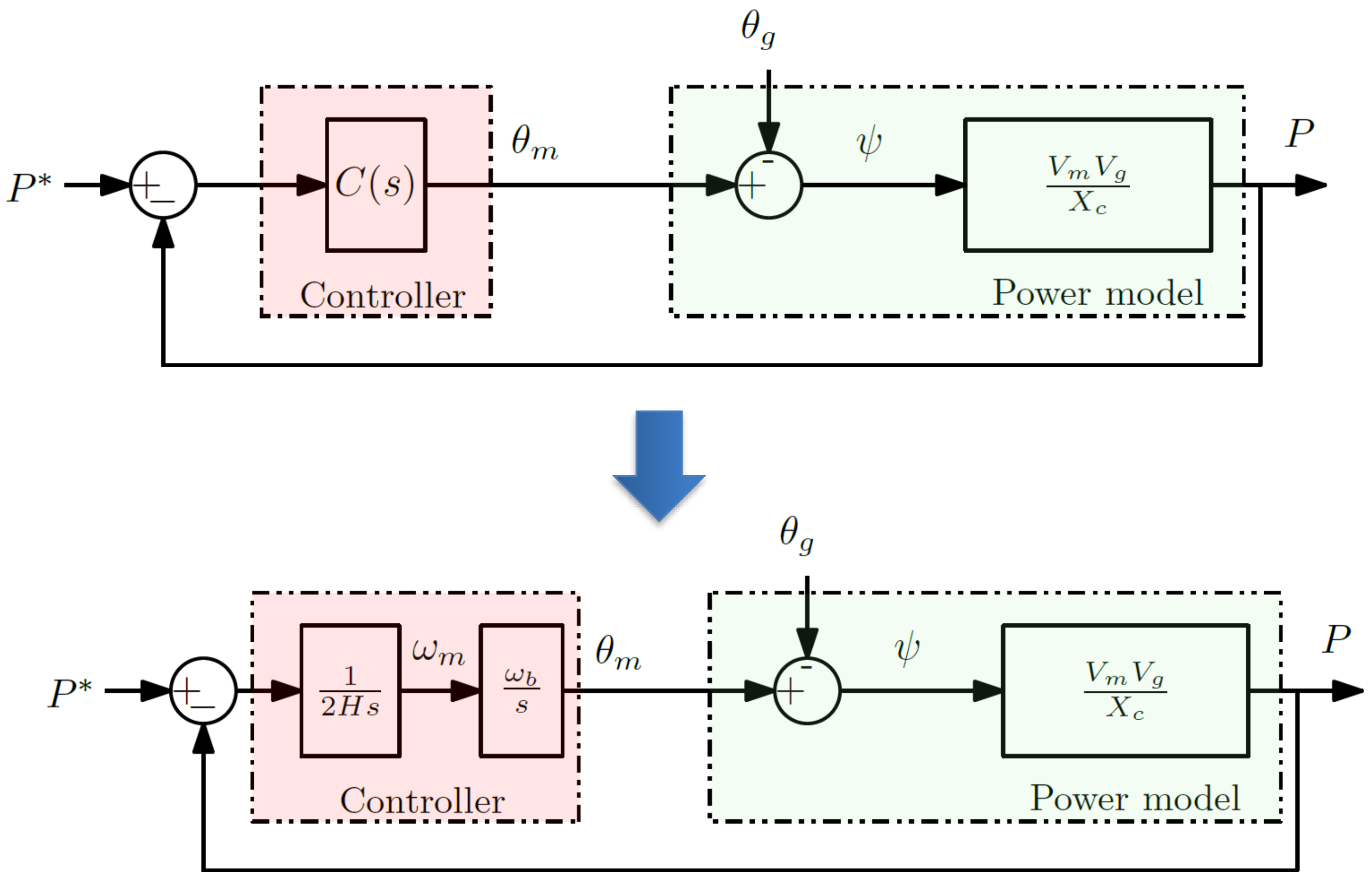
Second requirement : inertial effect

In mechanical systems, the inertial effect, is linked with the storage of kinetic energy

$$\Delta P_{meca} = 2\ H\ \frac{d\omega}{dt} = \frac{2\ H}{\omega_b}\ \frac{d^2\theta}{dt^2}$$

In the power converters, it is ***possible to mimic this inertial effect*** by creating a link between the active power and the second derivative of an angle thanks to the control

Different variants on the grid-forming control

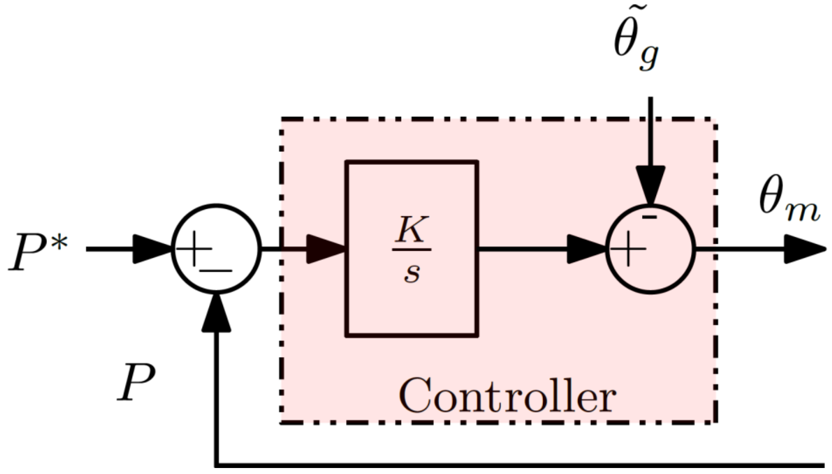


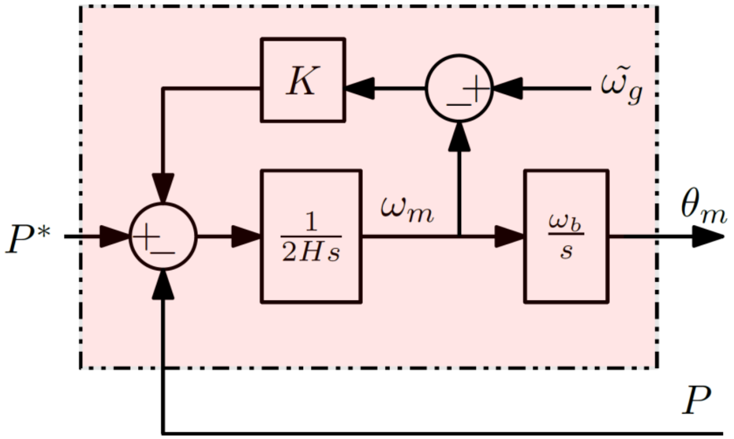
This is a perfect oscillator.

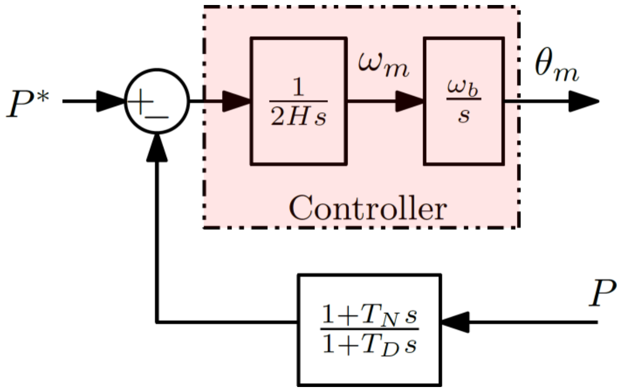
This system has to be damped

$$\Delta P = 2\,H\,\frac{d\omega_{\,m}}{dt} = \frac{2\,H}{\omega_b}\,\frac{d^2\theta_m}{dt^2}$$

Different variants on the grid forming control







Many variants can be deduced from these 3 types of control but, **in case of high voltage applications**, the fundamental properties are not really very different.

The aim of the controller is to generate a voltage reference in phase and magnitude.

The magnitude voltage computation has to be analyzed.

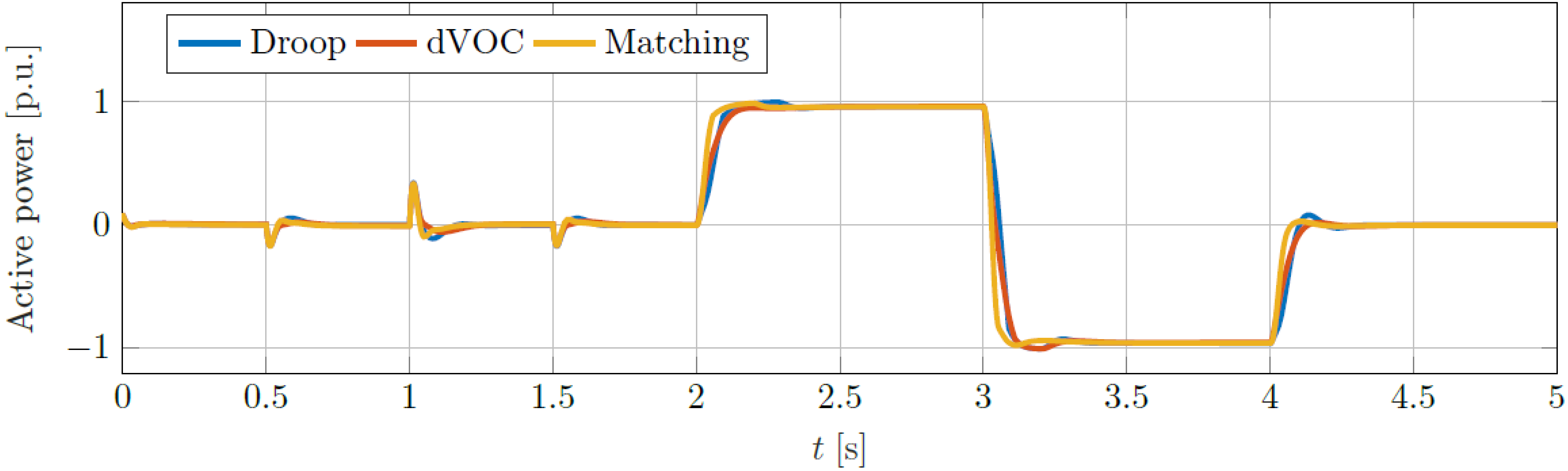
[6] "*A PLL-free grid-forming control with decoupled functionalities for high-power applications"* IEEE Access, (**under review**), **QORIA Taoufik**, ROKROK Ebrahim, BRUYERE Antoine, FRANCOIS Bruno, GUILLAUD Xavier

Different variants on the grid forming control

Two other very different types of control has been introduced by ETH Zurich :

Matching control

Dispatchable virtual Oscillator



No fundamental differences has been found between the various types of control in term of performance

Experimental test bench

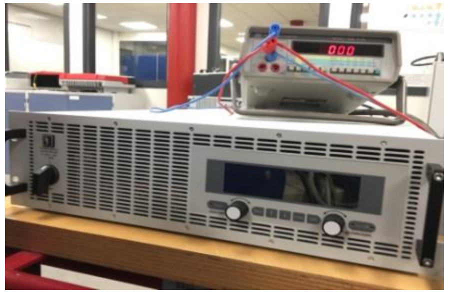
Introduction

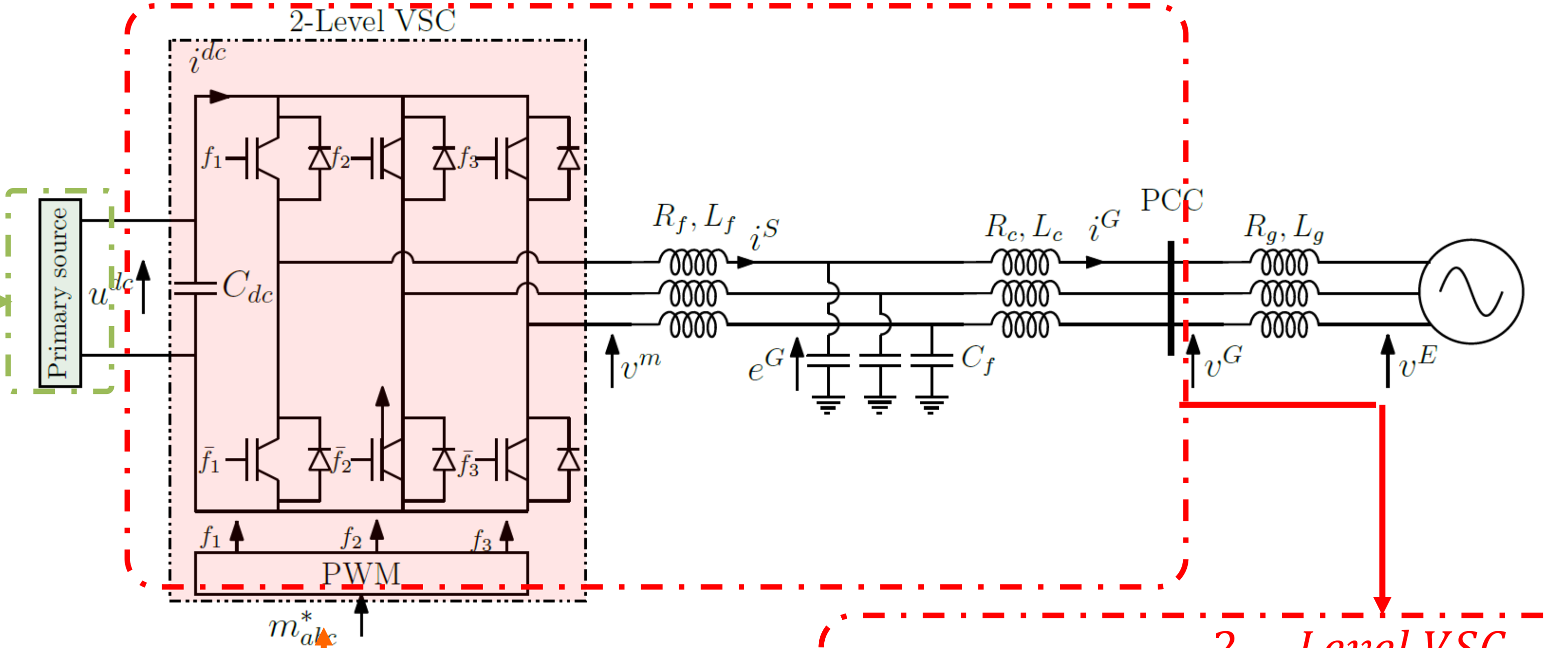
1. The aim of the test bench is to validate the approaches proposed in the theoretical part for the grid forming converter in term of :
    1. Active power control
    2. Behaviour in case of current limitation
    3. Interoperability between several control algorithms
    4. Islanding operation
2. Three solutions of connexion for the grid forming converter
    1. Connection on a ideal voltage source
    2. Connection on a three nodes power system
    3. Connection on the Irish grid

Need of real-time simulation

Test bench description – grid-forming inverter

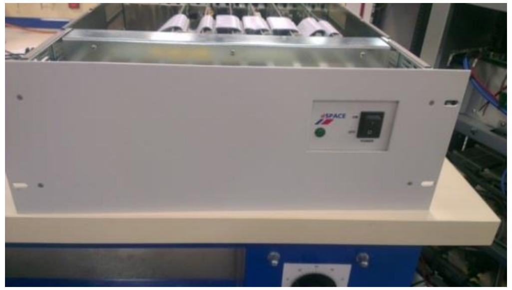
Up to 750V DC BUS





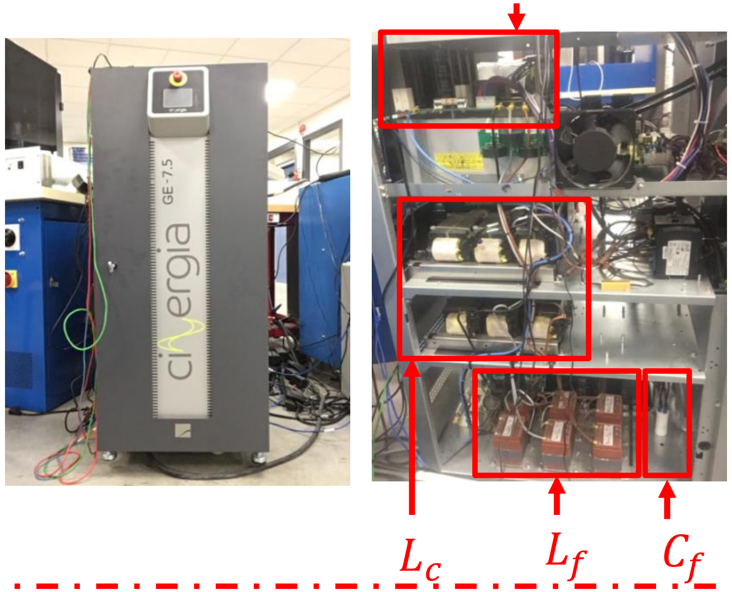
VSC designed with ciNergia
Totally open:

- Nominal Power : 7kVA
- Local hardware protection
- Use of local measurements
- Nominal DC Voltage up to 700V

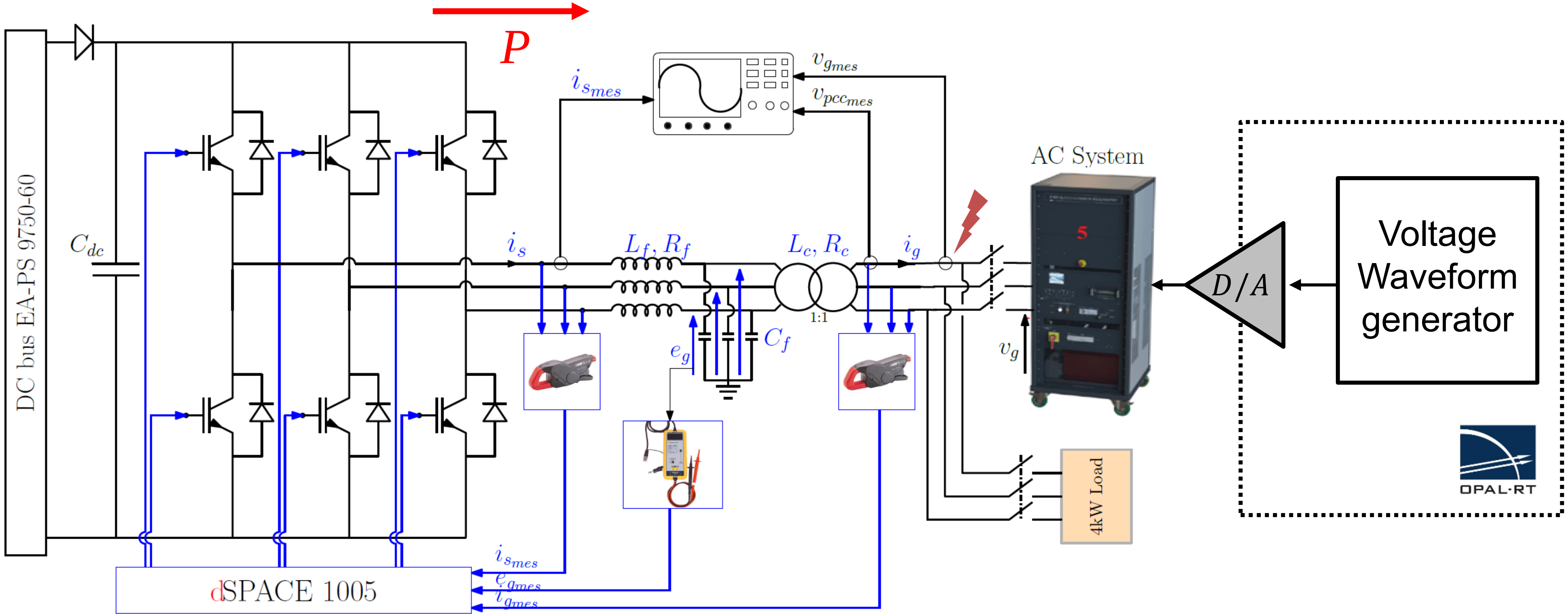


dSPACE 1005

2 – Level VSC



Description of the test bench



1- Power exchange

2- Event: 100% AC voltage sag

3- and many other events Islanding, phase shift …

Experimental Results

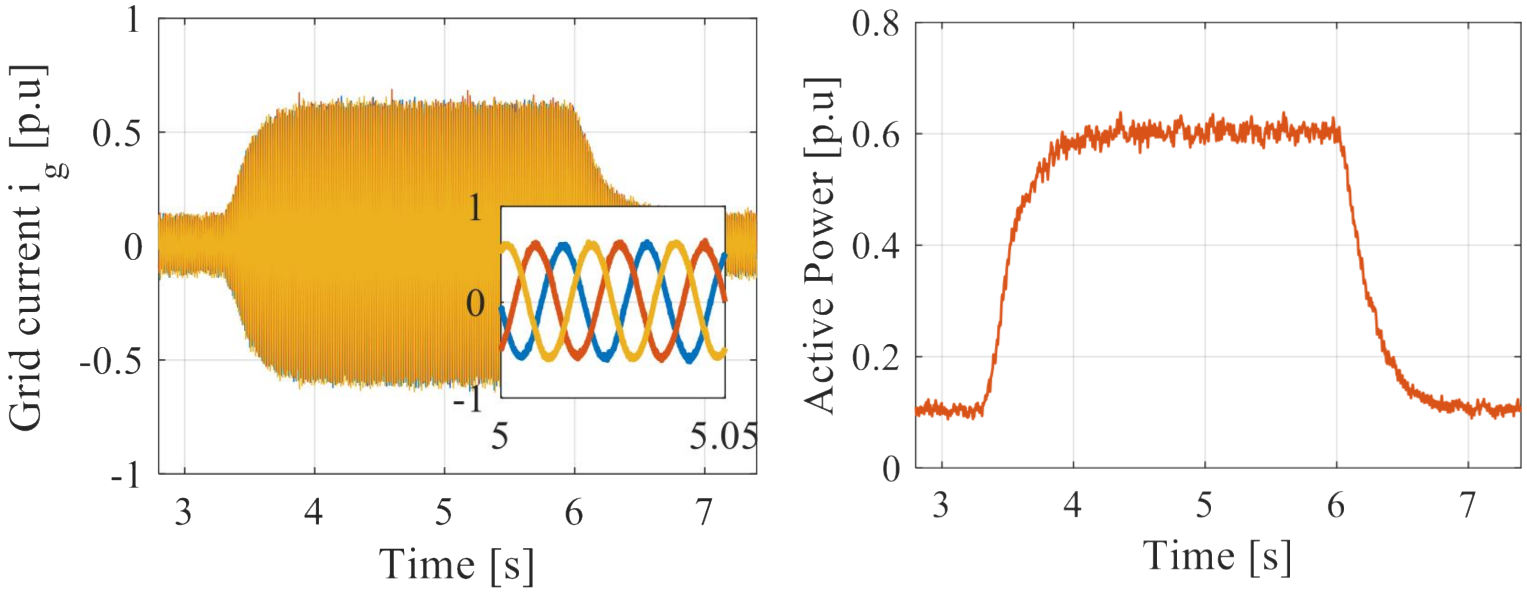
1. Grid forming inverter
    - power control
    - fault behaviour
    - islanding situation

2. 3-nodes tests case
    - Classical behaviour (connection and power control)
    - Line tripping

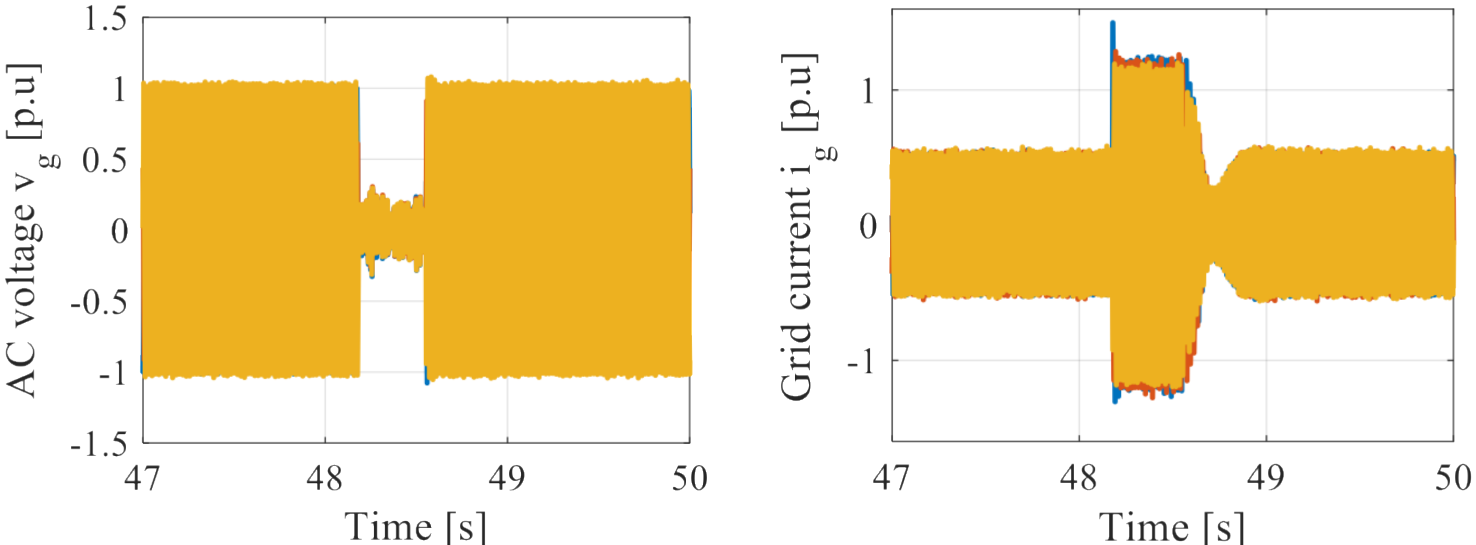
3. Irish power system
    - Classical behaviour (connection and power control)
    - Generator tripping

Experimental Results

- Power exchange



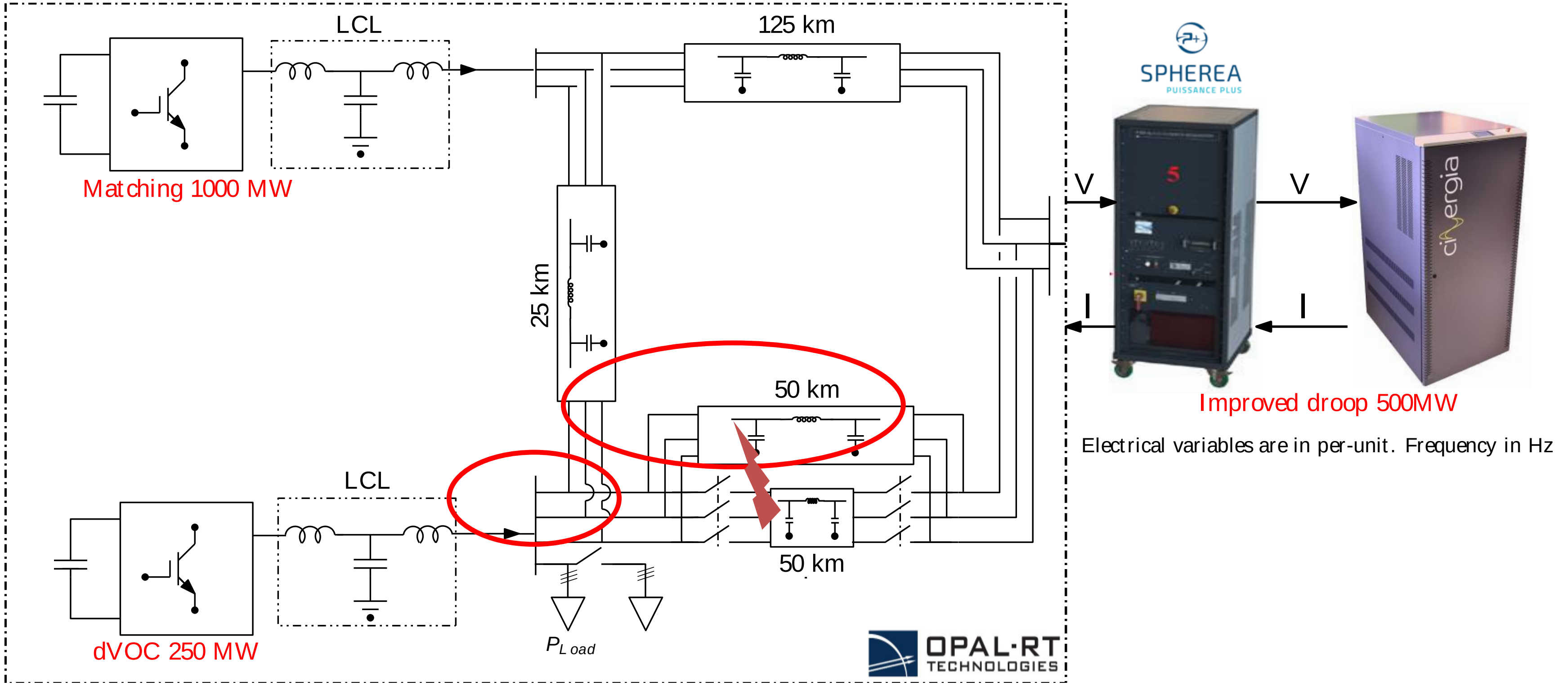
- 100% Voltage sag



3 nodes test case

500MW
U=320kV

5kW
U=300V

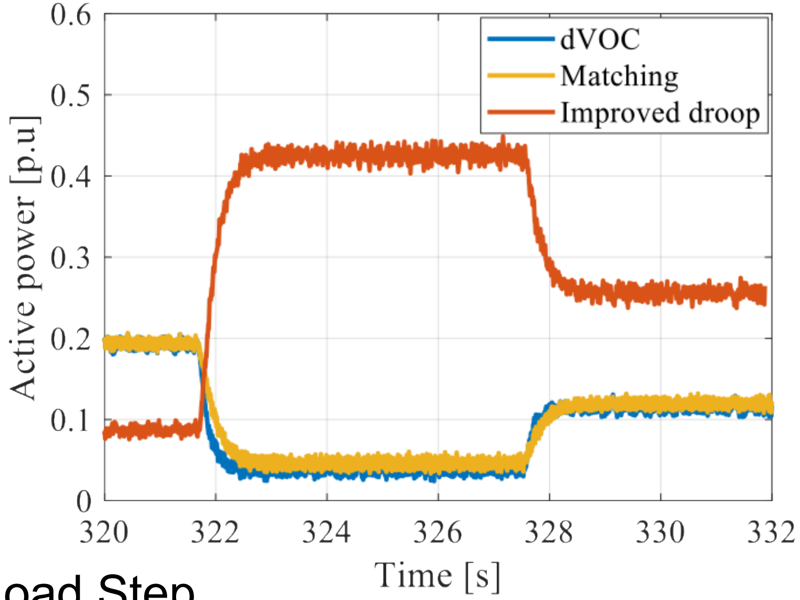


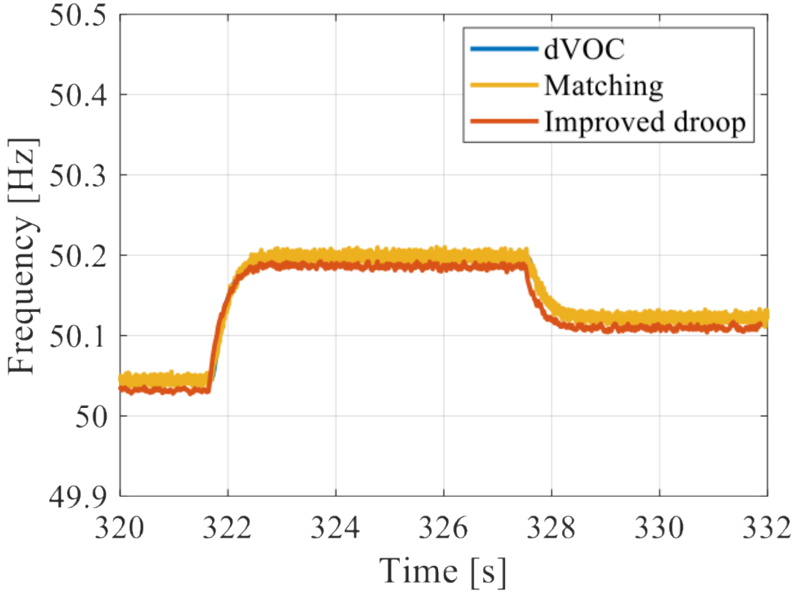
Electrical variables are in per-unit. Frequency in Hz

Events
1- Power Step
2- Load step (step of 840MW)
3- Fault then Line tripping

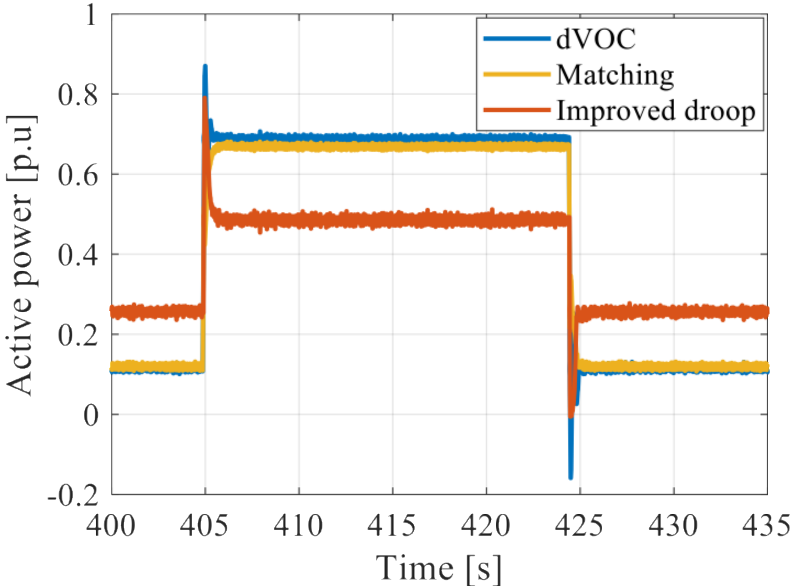
Results

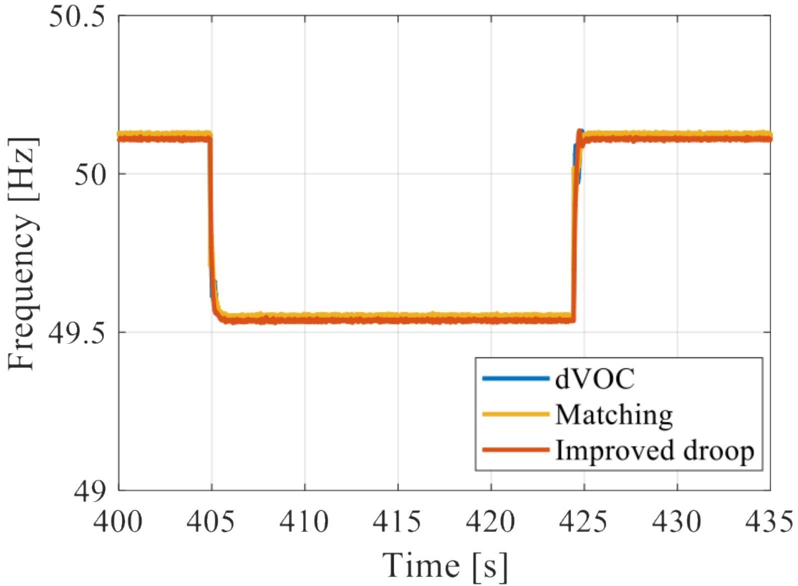
- Power exchange





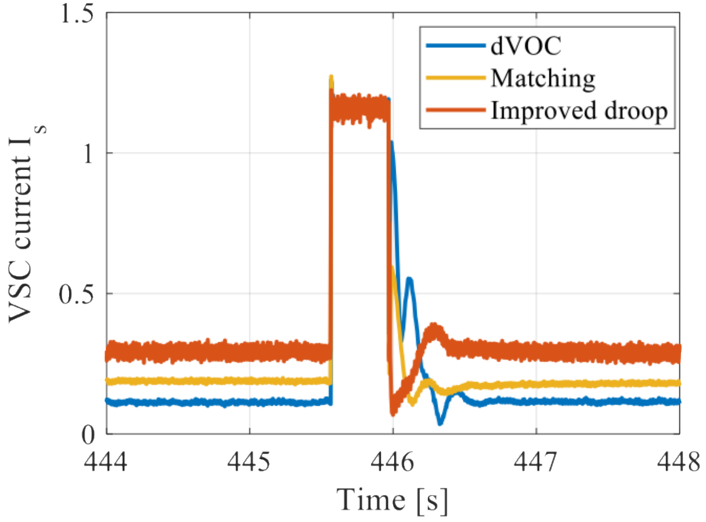
- Load Step

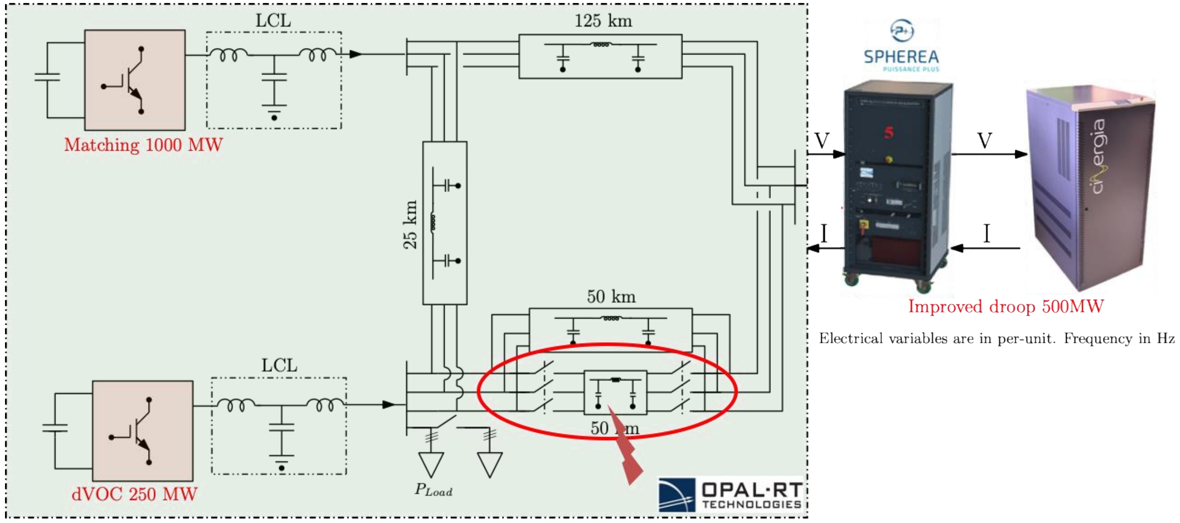




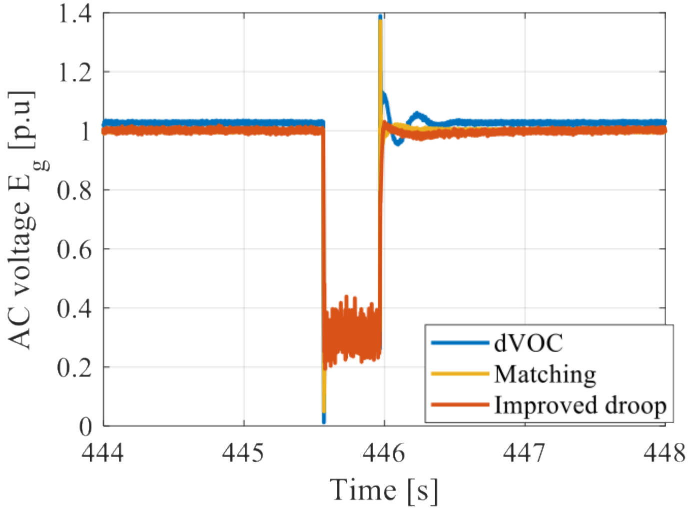
Results

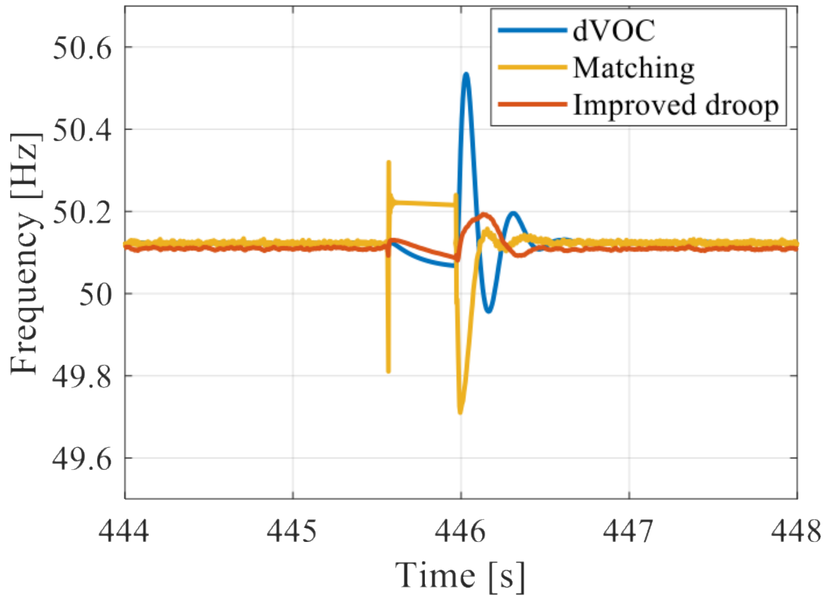
- Fault then line tripping





Electrical variables are in per-unit. Frequency in Hz





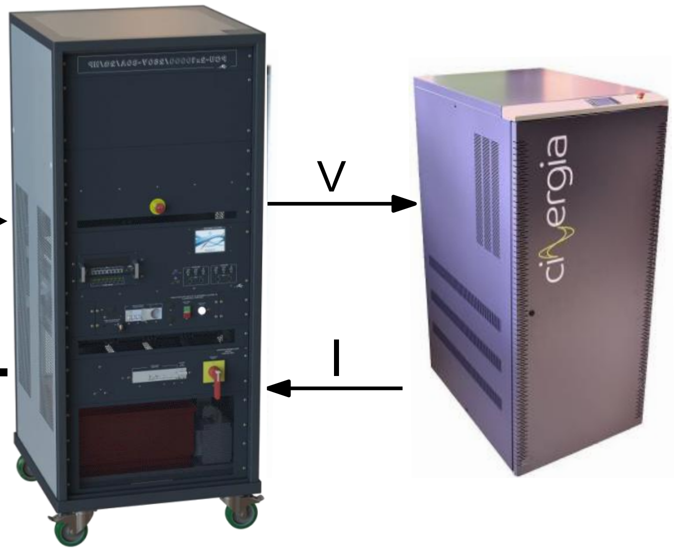
Demonstrations

1. Grid forming inverter
    - power control
    - fault behaviour
    - islanding situation

2. 3-nodes tests case
    - Classical behaviour (connection and power control)
    - Line tripping

3. Irish power system
    - Classical behaviour (connection and power control)
    - Generator tripping

Simplified Irish power system simulation



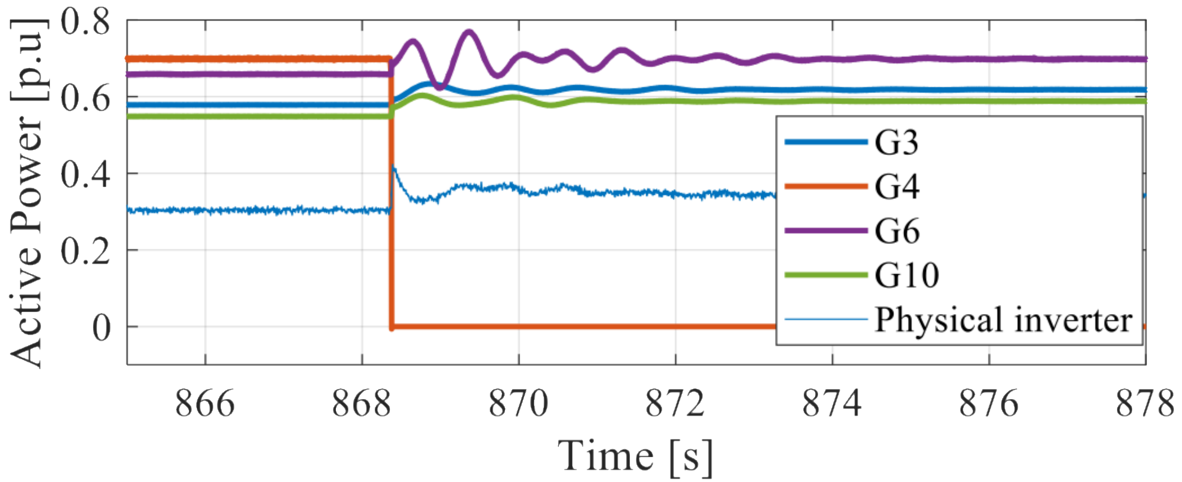
Characteristics:

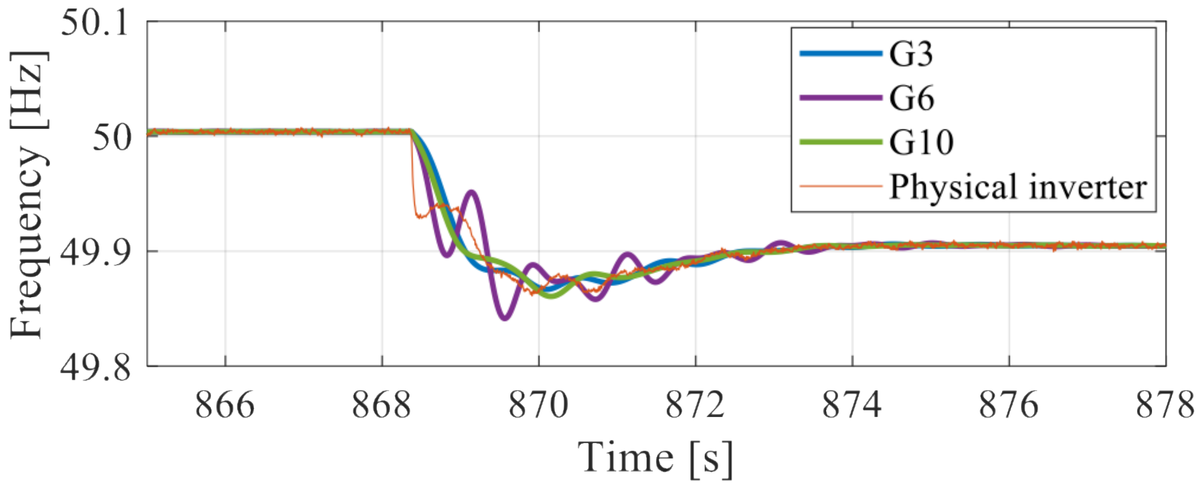
- Total Load 3.5GW
- 14 generators (simplified representation)
- 100 buses
- Line are modeled with PI section or distributed parameters line for parallel computation

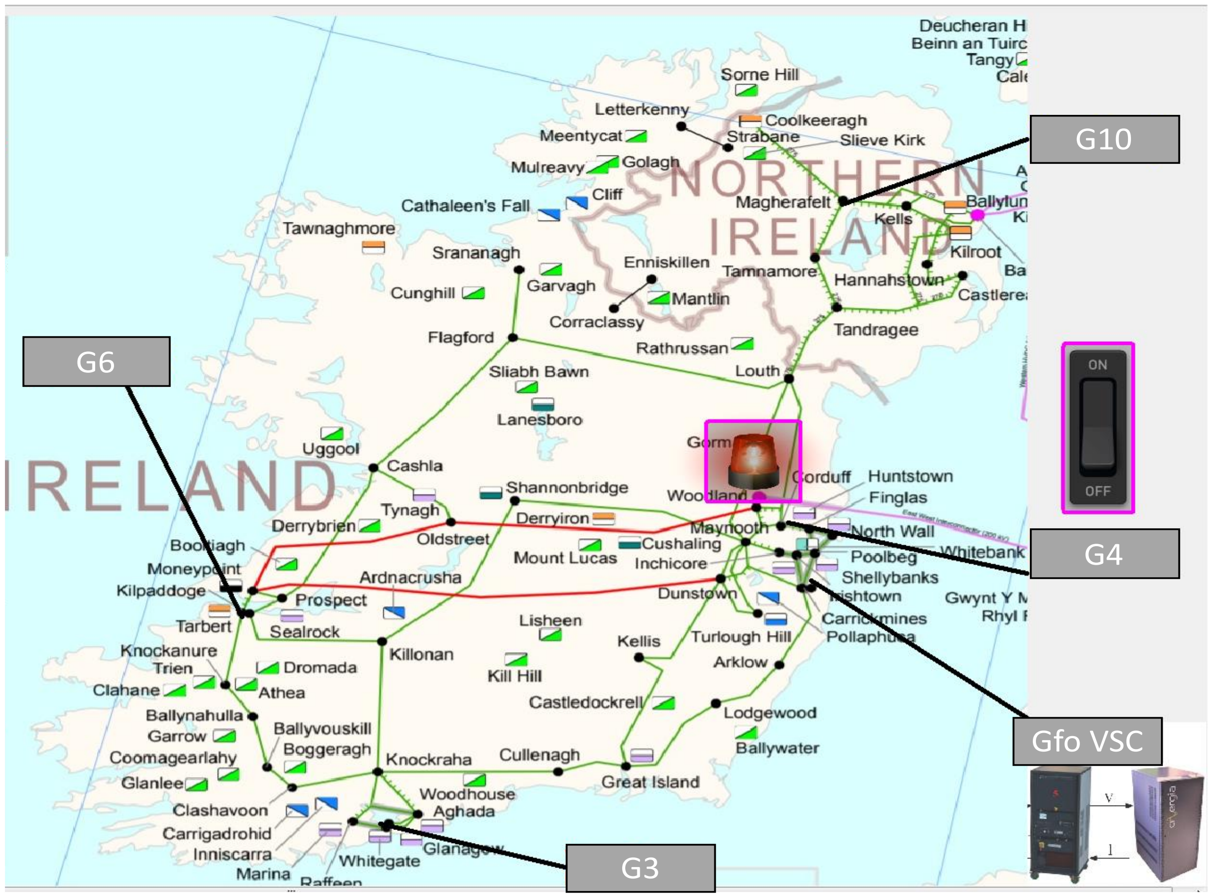
Event:

- Loss of 1 generator located in Huntsown

Results


Active Power [p.u]
0.8
0.6
0.4
0.2
0
866
868
870
872
874
876
878
Time [s]
G3
G4
G6
G10
Physical inverter


Frequency [Hz]
50.1
50
49.9
49.8
866
868
870
872
874
876
878
Time [s]
G3
G6
G10
Physical inverter


G10
G6
G4
Gfo VSC
G3
ON
OFF
NORTHERN IRELAND
IRELAND
Deucheran H
Beinn an Tuirc
Tangy
Sorne Hill
Letterkenny
Coolkeeragh
Strabane
Slieve Kirk
Meentycat
Mulreavy
Golagh
Cliff
Cathaleen's Fall
Magherafelt
Ballylun
Kells
Kilroot
Tawnaghmore
Sranangh
Enniskillen
Tamnamore
Hannahstown
Castlerea
Cunghill
Garvagh
Mantlin
Corraclassy
Tandragee
Flagford
Rathrussan
Louth
Sliabh Bawn
Lanesboro
Uggool
Cashla
Gorm
Corduff
Huntstown
Finglas
Shannonbridge
Woodland
Tynagh
Derryiron
Maynooth
North Wall
Derrybrien
Oldstreet
Cushaling
Poolbeg
Whitebank
Booltiagh
Mount Lucas
Inchicore
Shellybanks
Moneypoint
Ardnacrusha
Kilpaddoge
Prospect
Dunstown
Tarbert
Sealrock
Lisheen
Carrickmines
Pollaphuca
Knockanure
Trien
Killonan
Kellis
Turlough Hill
Arklow
Dromada
Kill Hill
Clahane
Athea
Castledockrell
Ballynahulla
Lodgewood
Garrow
Ballyvouskill
Ballywater
Coomagearlahy
Boggeragh
Knockraha
Cullenagh
Great Island
Glanlee
Woodhouse
Clashavoon
Aghada
Carrigadrohid
Inniscarra
Whitegate
Glanagow
Marina
Raffeen
Gwynt Y M
Rhyl F

Conclusion

1. Grid forming control is working properly to control the active power in a converter.

2. It is possible to limit the current in the converter for various types of events which may induce some overcurrent.

3. Test on a three nodes grid : Interoperability of various control algorithms

4. Test on the Irish grid : the grid forming converter is stable for various events.
   - Step on power control
   - fault behaviour
   - Line tripping

On going work and future projects

1. Critical clearing time with grid forming converter : it is possible to modify the control during the transient to improve the critical clearing time

2. Current work : Importance to take into account the DC bus voltage management in the grid forming converter stability analysis.

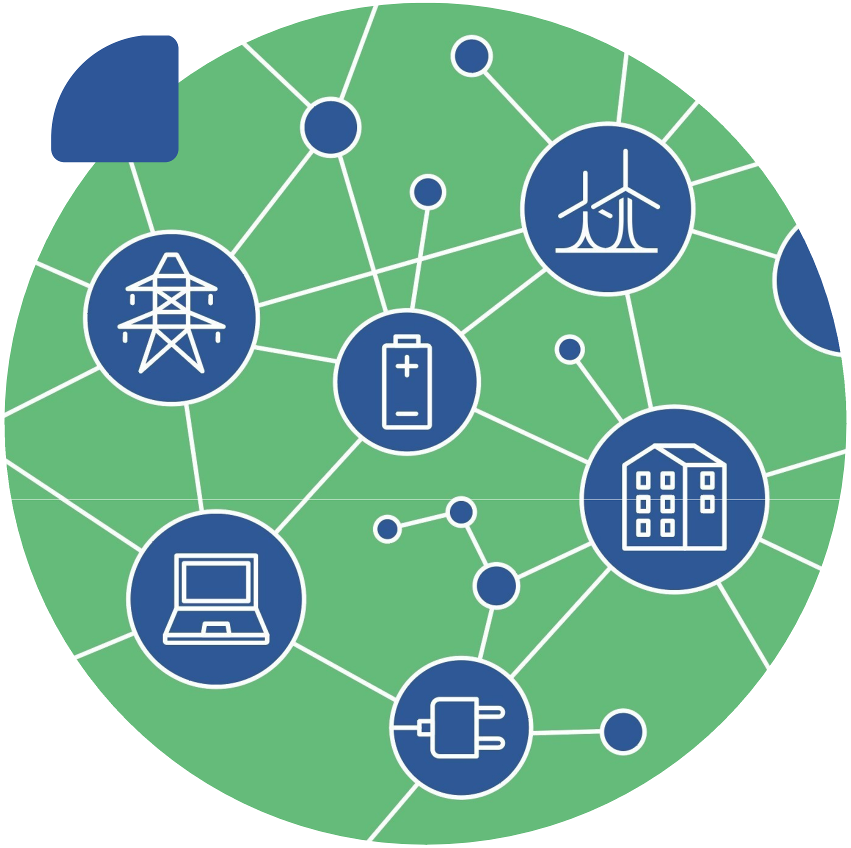
3. Work on unbalanced faults

L2EP
Laboratoire d'électrotechnique et
d'électronique de puissance de Lille

UCD
DUBLIN

Thank you for your attention

MIGRATE



OSMOSE

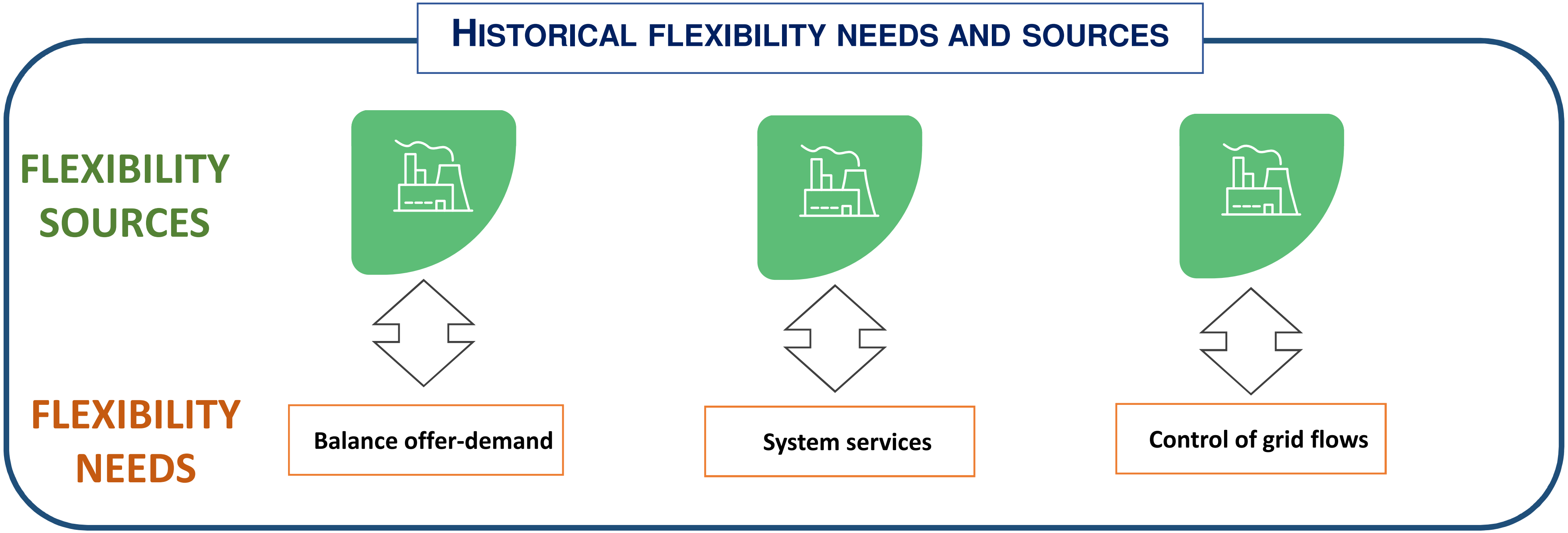
OPTIMAL SYSTEM-MIX OF FLEXIBILITY
SOLUTIONS FOR EUROPEAN ELECTRICITY

Project Summary

The project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 773406

What is flexibility?

Flexibility is understood as a power system's ability to cope with variability and uncertainty in demand, generation and grid, over different timescales.



HISTORICAL FLEXIBILITY NEEDS AND SOURCES

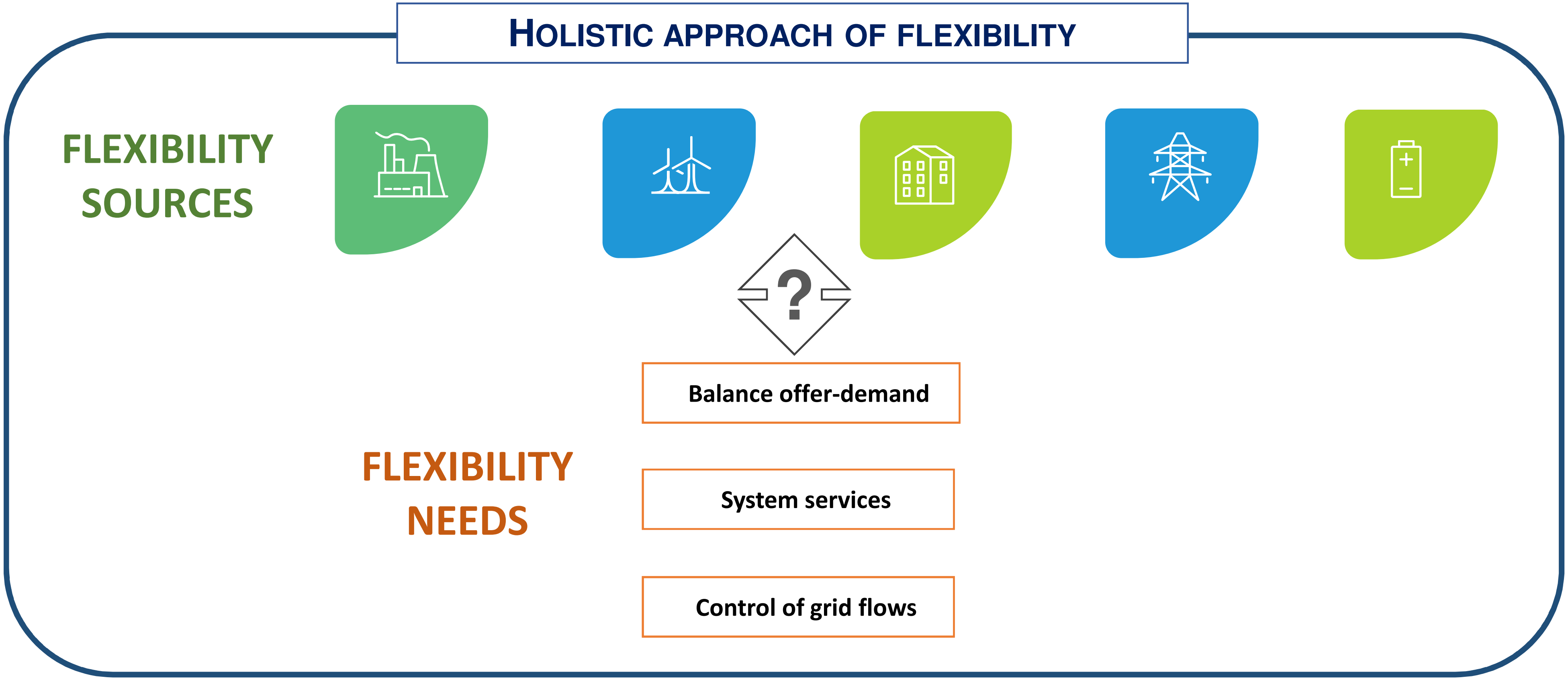
FLEXIBILITY SOURCES

FLEXIBILITY NEEDS

- Balance offer-demand
- System services
- Control of grid flows

OSMOSE PROJECT

Combining new needs and solutions



HOLISTIC APPROACH OF FLEXIBILITY

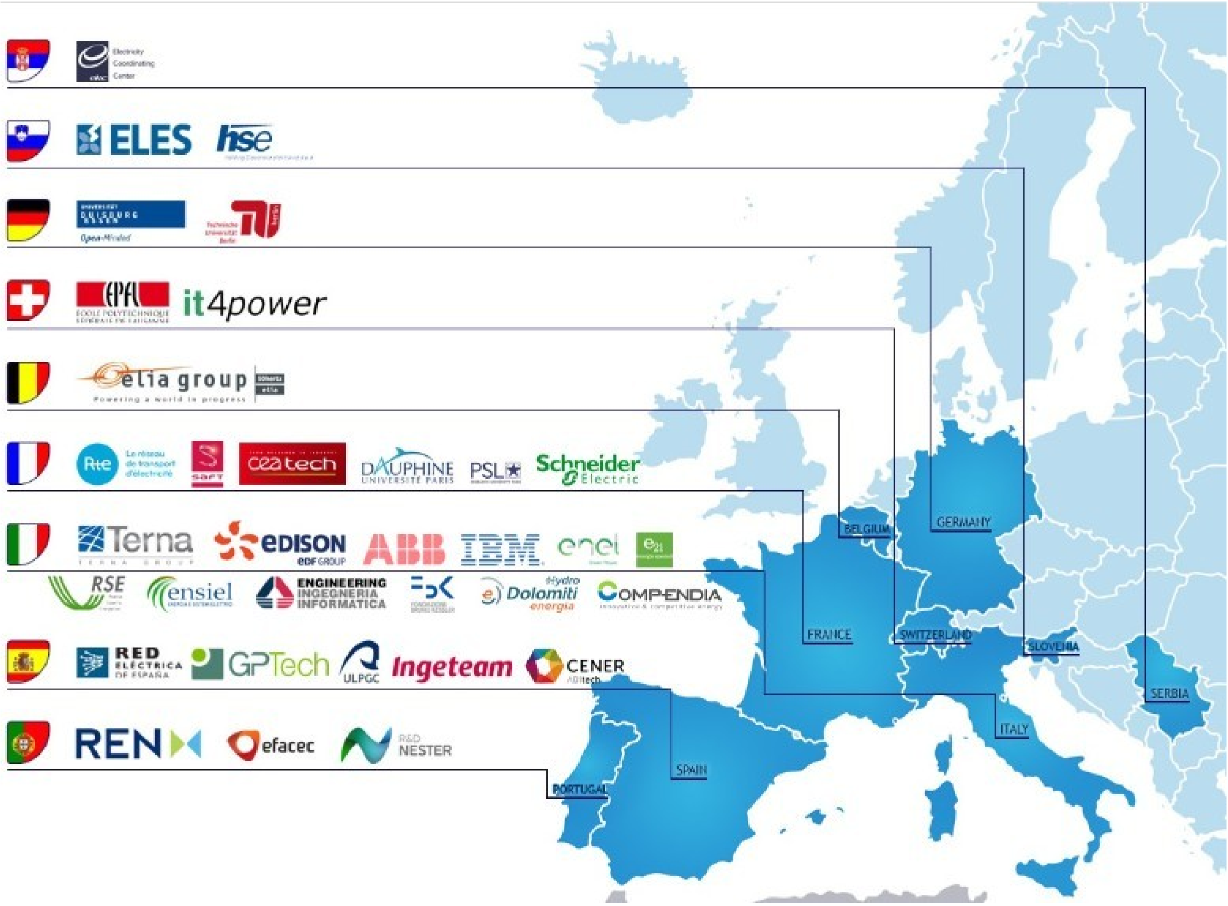
FLEXIBILITY SOURCES

FLEXIBILITY NEEDS

- Balance offer-demand
- System services
- Control of grid flows

The consortium

- ✓ H2020 EU funded
- ✓ 28M€ budget
- ✓ 33 partners
- ✓ Leaders: **RTE**, REE, TERNA, ELES, CEA, TUB
- ✓ 2018 – 2021



OSMOSE PROJECT

Project structure

Methods and simulations

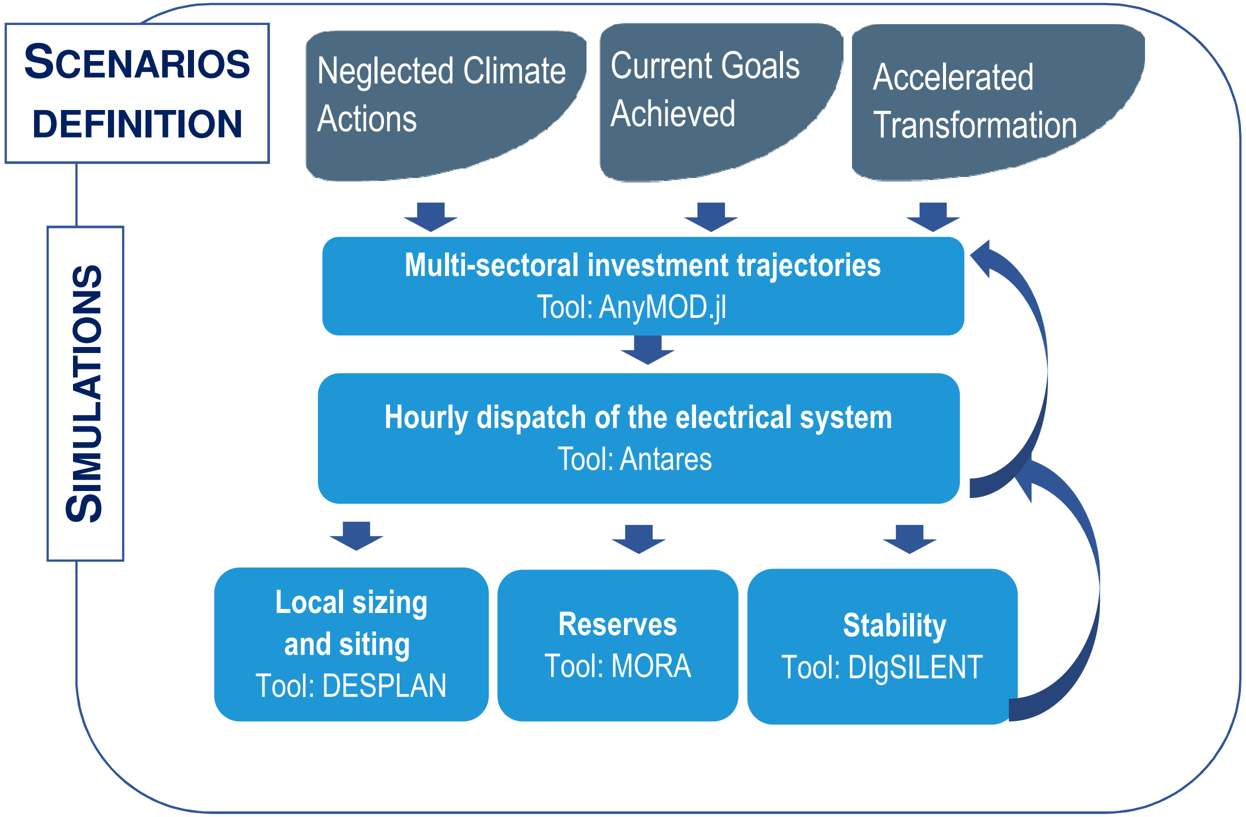
- Optimal mix of flexibilities (WP1)
- Market designs and regulations (WP2)

Demonstrators

- Grid forming by multi-services hybrid storage (WP3)
- Multi-services by different storage and FACTS devices (WP4)
- Multi-services by coordinated grid devices, large demand-response and RES (WP5)
- Near real-time cross-border energy market (WP6)

Scaling-up & replication (WP7)

WP1: Optimal Mix of Flexibilities



SCENARIOS DEFINITION

Neglected Climate Actions

Current Goals Achieved

Accelerated Transformation

SIMULATIONS

Multi-sectoral investment trajectories
Tool: AnyMOD.jl

Hourly dispatch of the electrical system
Tool: Antares

Local sizing and siting
Tool: DESPLAN

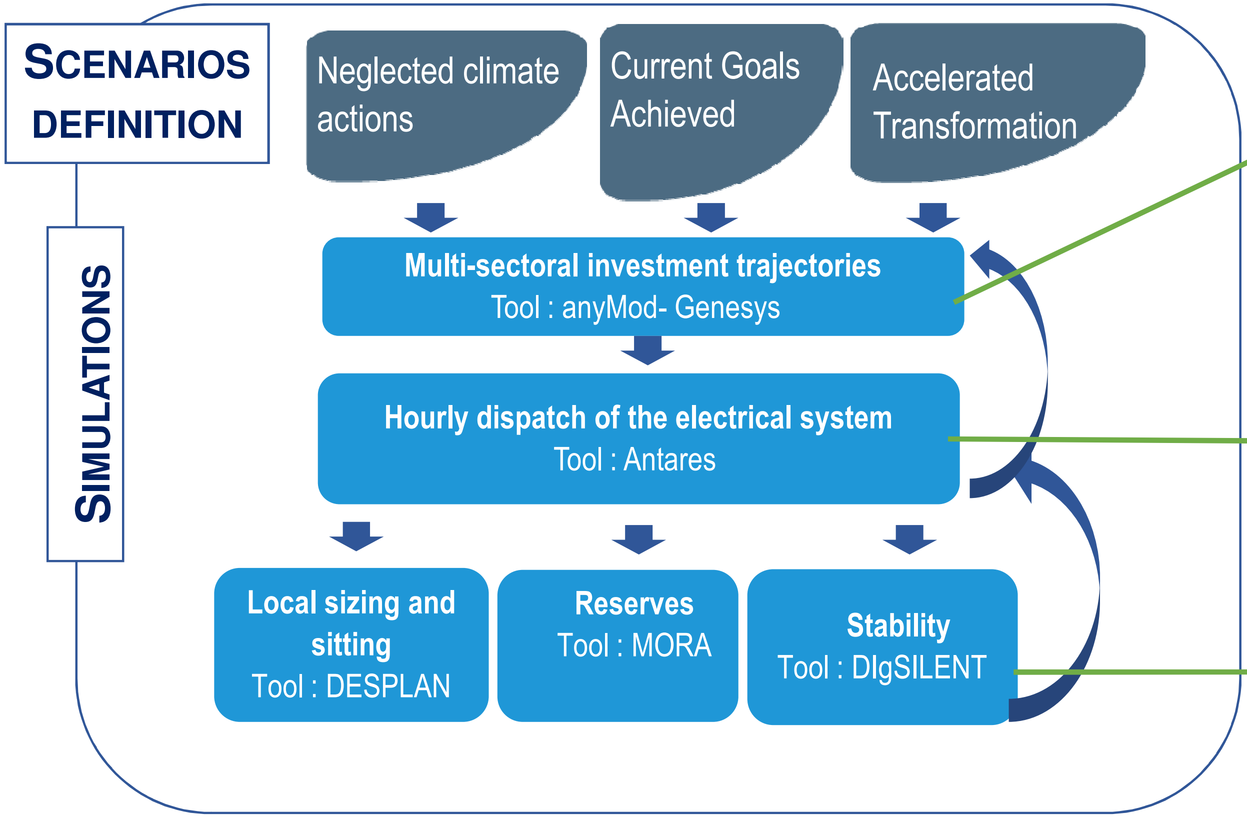
Reserves
Tool: MORA

Stability
Tool: DIgSILENT

OBJECTIVES

- ✓ Quantify the needs of flexibility in different long-term scenarios
- ✓ Define the best sources of flexibility in the scenarios
- ✓ Create advanced tools and methodologies to analyze flexibility

WP1: Status


SCENARIOS DEFINITION

SIMULATIONS

Neglected climate actions

Current Goals Achieved

Accelerated Transformation

Multi-sectoral investment trajectories
Tool : anyMod- Genesys

Hourly dispatch of the electrical system
Tool : Antares

Local sizing and sitting
Tool : DESPLAN

Reserves
Tool : MORA

Stability
Tool : DIgSILENT

✓Scenarios developed (see Deliverable 1.1) + TSOs feedback
✓AnyMOD.jl tool available open-source to better take into account sector coupling

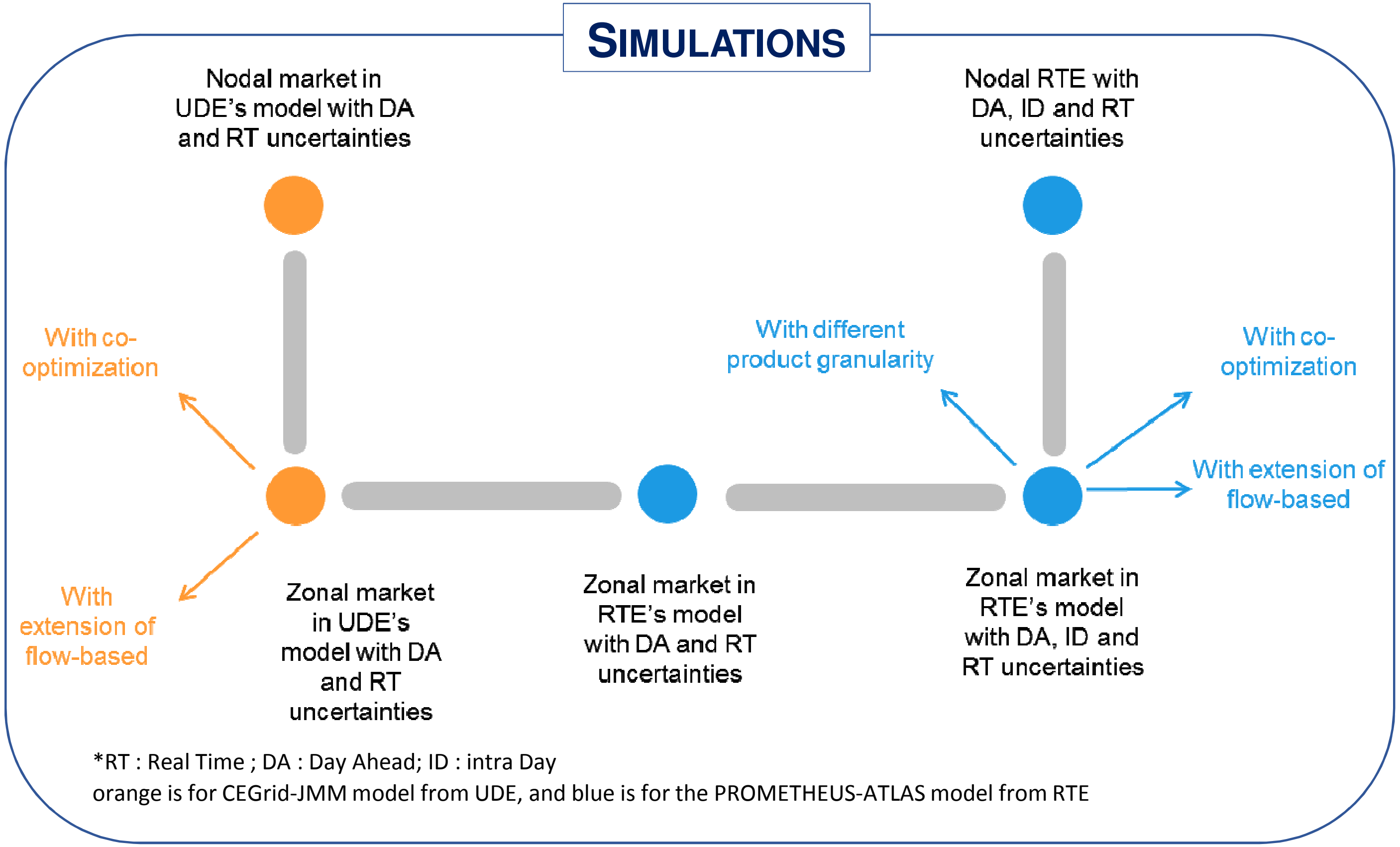
✓Methodology for flexibility assessment
✓All scenarios simulated with Antares

✓Routines and models ready

OSMOSE PROJECT

WP2: market designs & regulations

SIMULATIONS



Nodal market in UDE's model with DA and RT uncertainties

Nodal RTE with DA, ID and RT uncertainties

With co-optimization

With extension of flow-based

Zonal market in UDE's model with DA and RT uncertainties

Zonal market in RTE's model with DA and RT uncertainties

Zonal market in RTE's model with DA, ID and RT uncertainties

With different product granularity

With co-optimization

With extension of flow-based

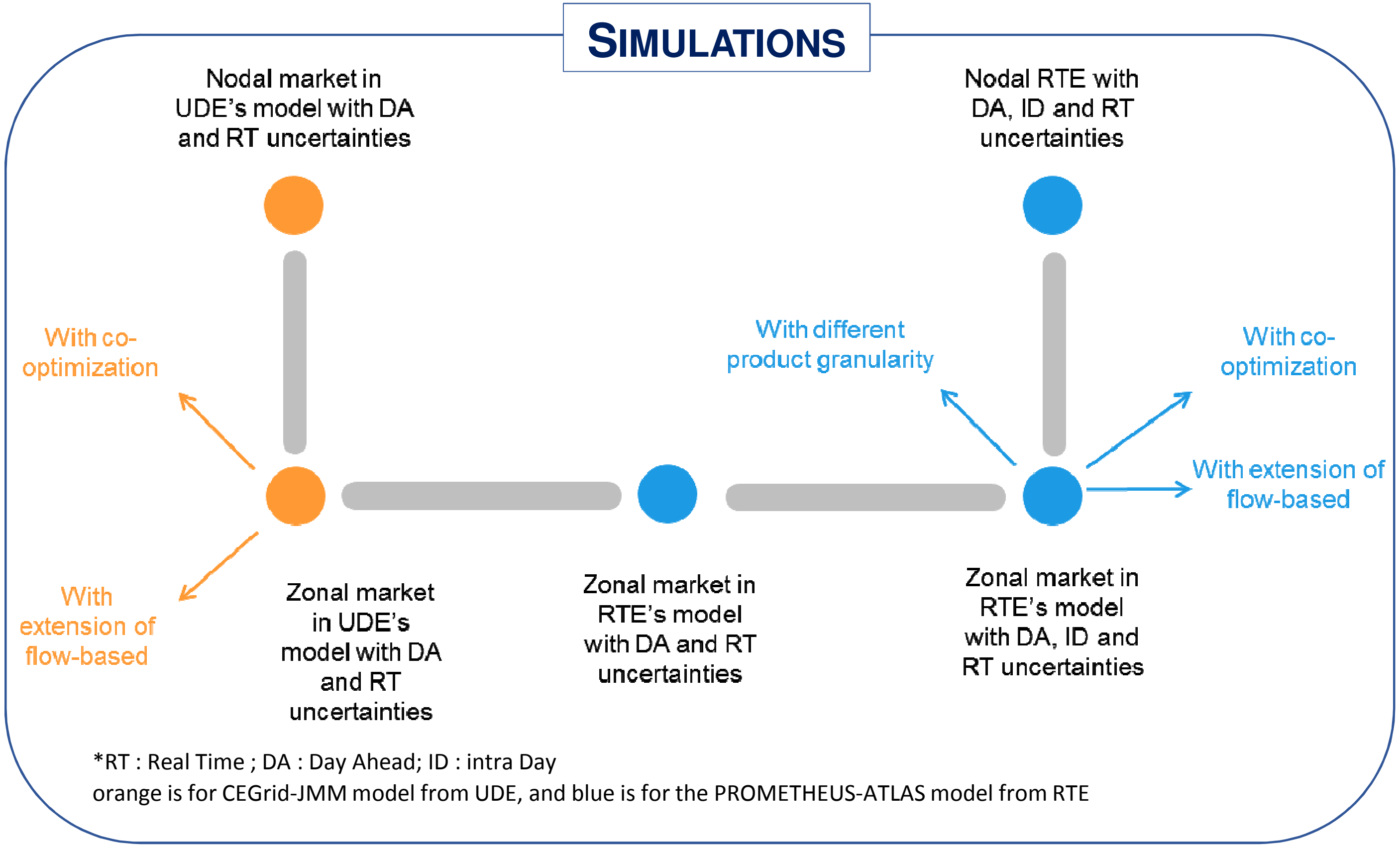
*RT : Real Time ; DA : Day Ahead; ID : intra Day
orange is for CEGrid-JMM model from UDE, and blue is for the PROMETHEUS-ATLAS model from RTE

OBJECTIVES

- ✓ Explore and propose some market-based solutions for the development of an optimal mix of flexibility sources in Europe
- ✓ Create advanced tools and methodologies for market design analysis

OSMOSE PROJECT

WP2: status



SIMULATIONS

Nodal market in UDE's model with DA and RT uncertainties

Nodal RTE with DA, ID and RT uncertainties

With co-optimization

With different product granularity

With co-optimization

With extension of flow-based

With extension of flow-based

Zonal market in UDE's model with DA and RT uncertainties

Zonal market in RTE's model with DA and RT uncertainties

Zonal market in RTE's model with DA, ID and RT uncertainties

*RT : Real Time ; DA : Day Ahead; ID : intra Day
orange is for CEGrid-JMM model from UDE, and blue is for the PROMETHEUS-ATLAS model from RTE

- ✓Market designs selected for study (see D2.2)
- ✓First simulations on Zonal and Nodal markets ongoing – see Milestone M2.2
- ✓Interpolation module ready, for 15-mn time steps studies in zonal market designs

- ✓77 KPIs referenced to analyze the simulations and assess the performance of each candidate market design
- ✓Comprehensive overview of existing and potential sources of revenues for flexibility providers

OSMOSE PROJECT

Overview of demonstrations

WP3 DEMO: Grid forming for the synchronisation of large power systems by multi-service hybrid storage

Supercapacitors 1MW-10s
0.5MVA-60min Li-ion battery
RTE substation

720 kVA/560 kWh LTO battery
25 kWh LOT battery
EPFL campus

WP6 DEMO: Near real-time cross-border energy market

Soverzene plant
20MW
ENEL

Santa Massenza plant
70MW
HDE

DEM, TES and SENG plants
135MW
HSE

High voltage grid
TERNA &
ELES

WP4 DEMO: Multiple services provided by the coordinated control of different storage and FACTS devices

STATCOM 4 Mvar
Supercapacitors 0.8MW
1500 V Li-Ion batteries (2MW/0.5MWh)

CENER 20 kV grid-connected facilities
Microgrid in CENER
Different batteries

WP5 DEMO: Multiple services provided by grid devices, large demand-response and RES generation coordinated in a smart management system

7 industrial consumers
~120 MW of flexibility

2 wind farms - 53 MW
+1 battery (2 MW - 2 MWh)
ENEL, E2i

7x150kV lines
Dynamic Thermal Ratings
TERNA

WP3 Demo:
Grid forming by multi-service hybrid storage

DEVICES

720 kVA/560 kWh LOT battery
25 kWh LTO battery
EPFL campus

Supercapacitors 1MW-10s
0.5MVA-60min Li-ion battery
RTE substation

TARGET SERVICES

- Grid Forming
- Fast frequency control, FCR, aFRR, Congestion management

WP3 Demo: Status

DEVICES

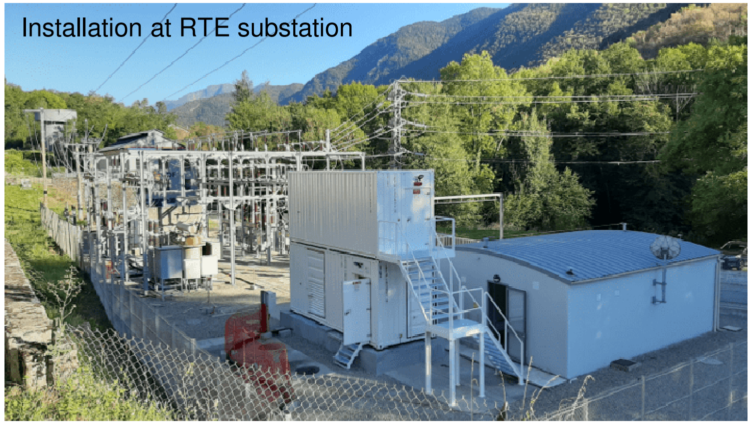
720 kVA/560 kWh LOT battery
25 kWh LTO battery
EPFL campus

Supercapacitors 1MW-10s
0.5MVA-60min Li-ion battery
RTE substation

- ✓ Demo running since May 2020
- ✓ PMU at BESS successfuly measures impacts of VSC mode on local frequency
- ✓ Exprimental tests to study KPIs evolution
- ✓ Simulation tests to assess BESS response in different grid cases


Installation on EPFL campus

- ✓ FAT completed in July 2020
- ✓ SAT close to completion


Installation at RTE substation

WP4 Demo: Multiple services provided by coordinated control of storage and FACTS

DEVICES

STATCOM 4 Mvar
Supercapacitors 0.8MW
1500 V Li-Ion batteries (2MW/0.5MWh)

CENER 20 kV grid-connected facilities
Microgrid in CENER
Different batteries

TARGET SERVICES

- Emulation of inertia, Fast Fault Current Injection, Power oscillation Damping
- Frequency regulation
- Setpoint tracking, Management of renewable energy variability, program management
- Congestion Management, Voltage Control

WP4 Demo: Status

DEVICES

STATCOM 4 Mvar
Supercapacitors 0.8MW
1500 V Li-Ion batteries
(2MW/0.5MWh)

CENER 20 kV grid-connected facilities
Microgrid in CENER
Different batteries

SAFT Battery

CENER facilities (Sangüesa - Navarra)

- ✓ FAT of the 0.5MWh/2MW Lithium-ion battery system completed
- ✓ Containerization and wiring of all power module components in the container close to completion
- ✓ Ongoing modelling of the Hybrid Flexible Device and microgrid for the development of the master control and its SCADA
- ✓ Simulations conducted on the Lanzarote-Fuerteventura system to select optimal parameters for the HFD Device control system

WP5 Demo: Multiple services provided by grid devices, large DR and RES coordinated in a smart management system

DEVICES

7 industrial consumers ~120 MW of flexibility

2 wind farms - 53 MW +1 battery (2 MW - 2 MWh)
ENEL, E2i

7x150kV lines Dynamic Thermal Ratings
TERNA

TARGET SERVICES

- Frequency Restoration Reserve and Automatic Voltage Control
- Automatic Voltage Control and Synthetic Inertia
- Congestion management with an EMS

WP5 Demo: Multiple services provided by grid devices, large DR and RES coordinated in a smart management system

DEVICES

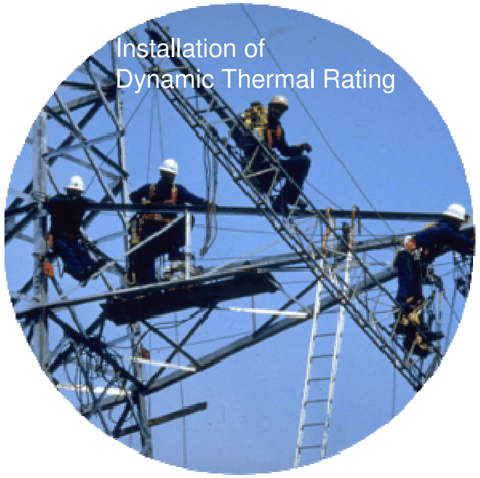
7 industrial consumers ~120 MW of flexibility

2 wind farms - 53 MW +1 battery (2 MW - 2 MWh) ENEL, E2i

7x150kV lines Dynamic Thermal Ratings TERNA

- ✓ Dynamic Thermal Rating sensors installed on seven 150kV lines and Master node installed at Terna substation
- ✓ Upgrade of 7 industrial sites ongoing for Demand Response
- ✓ Ongoing Thermostatic Load Control tests & Synthetic Inertia tests in the 2 windparks
- ✓ Zonal Energy Management software developed and under testing


Pietragalla site with BESS & wind turbines


Installation of Dynamic Thermal Rating

WP6 Demo:
Near real-time cross-border energy market

DEVICES

- Soverzene plant 20MW, ENEL
- Santa Massenza plant 70MW HDE
- DEM, TES and SENG plants 135MW, HSE
- High voltage grid, TERNA & ELES

TARGET SERVICES

- Near real-time energy cross border market taking into account grid constraints

WP6 Demo: Status

DEVICES

Soverzene plant 20MW,
ENEL

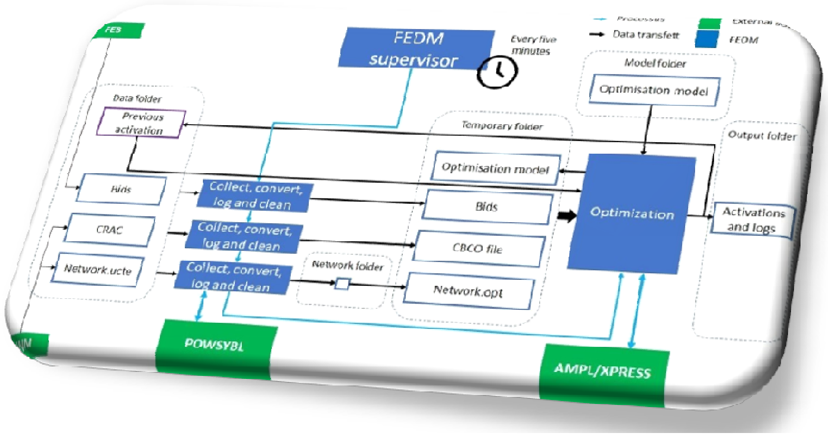
Santa Massenza plant 70MW
HDE

DEM, TES and SENG plants
135MW, HSE

High voltage grid,
TERNA & ELES

- ✓ Software demo platform specs; KPIs and use cases available (D6.2 to D6.4)
- ✓ Software package “*Electricity Network For Market”* successfully installed into ELES IT business environment
- ✓ Open loop tests ongoing
- ✓ Installation and testing of the bidding tool underway at generators’ premises

Lake Santa Massenza (Santa Massenza plant)



FlexEnergy Market Optimisation Platform

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WP7: Scaling up and replication

INTEROPERABILITY

Objectives:

- ✓ Refine IEC61850 interoperability framework
- ✓ Demonstrate the engineering process of IEC61850 ENTSOE profile with different specifications tools
- ✓ Demonstrate IEC61850 interoperability framework with products from different manufacturers

TSO-DSO FLEXIBILITIES COORDINATION

Objectives:

- ✓ Provide an optimization framework taking into account different time scales for voltage control on the DSO grid in coordination with the TSO
- ✓ Demonstrate the tool and its benefits in a demo in real-time simulation

BATTERY ENERGY STORAGE SYSTEM: DESIGN & CONTROL AND SHARED DATABASE

Objectives:

- ✓ Develop methods and tools for BESS design & control for a decrease of Levelised Cost
- ✓ Creation of a shared database with advanced data analytics for Energy Storage Systems in operation

WP7: Scaling up and replication

INTEROPERABILITY

Objectives:

- ✓ Refine IEC61850 interoperabi framework
- ✓ Demonstrate the engineering process of IEC61850 ENTSOE profile with different specifications tools
- ✓ Demonstrate IEC61850 interoperability framework with products from different manufacturers

Deliverable D7.1

First tests done

TSO-DSO FLEXIBILITIES COORDINATION

Objectives:

- ✓ Provide an optimization framework taking into account different time scales for voltage control on the DSO grid in coordination with the TSO
- ✓ Demonstrate the tool and its benefits in a demo in real-time simulation

First tests of Flexibility Scheduler software ongoing

BATTERY ENERGY STORAGE SYSTEM: DESIGN & CONTROL AND SHARED DATABASE

Objectives:

Optimal sizing method: D7.5

- ✓ Develop methods and tools for BESS design & control for a decrease of Levelised Cost
- ✓ Creation of a shared database with advanced data analytics for Energy Storage Systems in operation

- ✓ **Database developed & tested**
- ✓ **Integration of on-fields BESS data from WP3-WP4 demo in preparation**

Thank you!

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