ENTSO-E Grid Stability Initiatives – How is grid stability ensured in a changing power system?

ESIG-Webinar 28.10.24

15 YEARS OF entsoe
ELECTRIFYING EUROPE

Introduction

Presentation on behalf of ENTSO-E

- Research Development and Innovation Committee, RDIC, WG2 – Security and Operations of Tomorrow
- System Protection and Dynamics, SPD

Contributors

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AGENDA

Part I: Introduction and Context

- ENTSO-E Vision 2050 and RDI roadmap
- Key stability phenomena
- Grid stability challenges with increasing renewable energy penetration, examples

Part II: ENTSO-E RDI actions

- Modelling and simulation techniques
- Grid forming converters and their role in enhancing stability
- Instability analysis
- Future directions and research needs

ENTSO-E: 40 TSOs operating one of the world's largest interconnected grids

*Figure from https://www.entsoe.eu/data/map/downloads/

- ✓ ENTSO-E is the association for the **cooperation** of the European transmission system operators (TSOs).

- ✓ 40 member TSOs, representing 36 countries and serving about 500 million citizens, responsible for the **secure and coordinated operation** of Europe's electricity system.

- ✓ ENTSO-E is also the **common voice of TSOs in Europe**.

- ✓ ENTSO-E **serves the interests of society by optimising social welfare** in its dimensions of safety, economy, environment, and performance.

Part I: Introduction and Context

Stability issues and challenges in the European context

ENTSO-E Vision 2050 and RDI Roadmap

A Power System for a Carbon Neutral Europe (entsoe.eu)

Infrastructure & Investments

Operating future grids

Market Design

Energy System Flexibility

Innovation

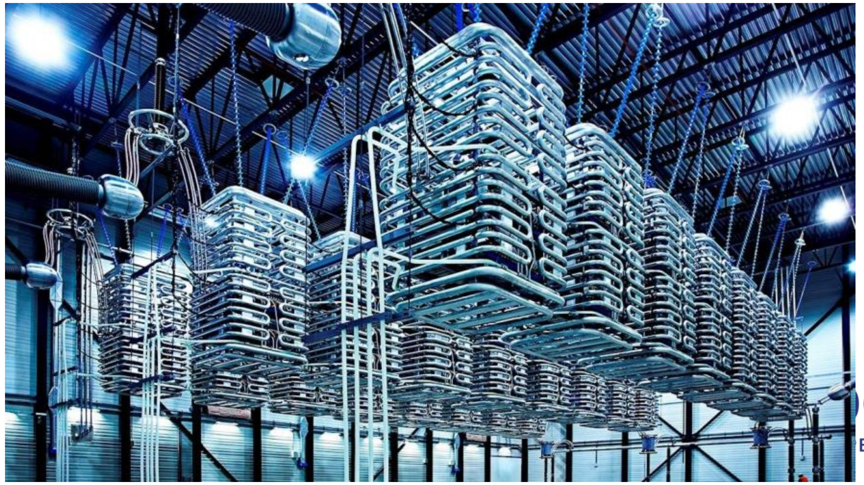
entsoe VISION

A POWER SYSTEM FOR A CARBON NEUTRAL EUROPE

ENTSO-E RDI Roadmap 2024-2034 (eepublicdownloads.blob.core.windows.net)

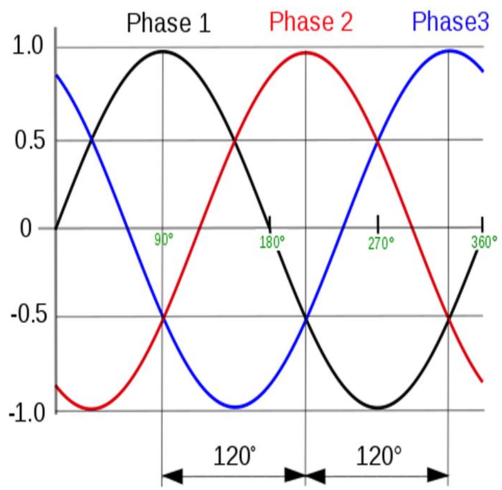
Key Stability Phenomena

Generation unit's inherent properties are different: from heavy fast generator rotors to power electronics connected infeed



Key Stability Phenomena

Old and new phenomena pose challenges to system stability



Power System Stability Phenomena

- **Resonance stability**
  - Electrical
  - Torsional
- **Converter driven stability**
  - Fast interaction
  - Slow interaction
- **Rotor angle stability**
  - Transient
  - Small-disturbance
- **Voltage stability**
  - Large-disturbance
  - Small-disturbance
- **Frequency stability**
  - Short-term
  - Long-term

New phenomena
Timeframe of milliseconds

Growing and changing phenomena
Timeframe of seconds

8

Key Stability Phenomena

Stabilising technologies must be deployed

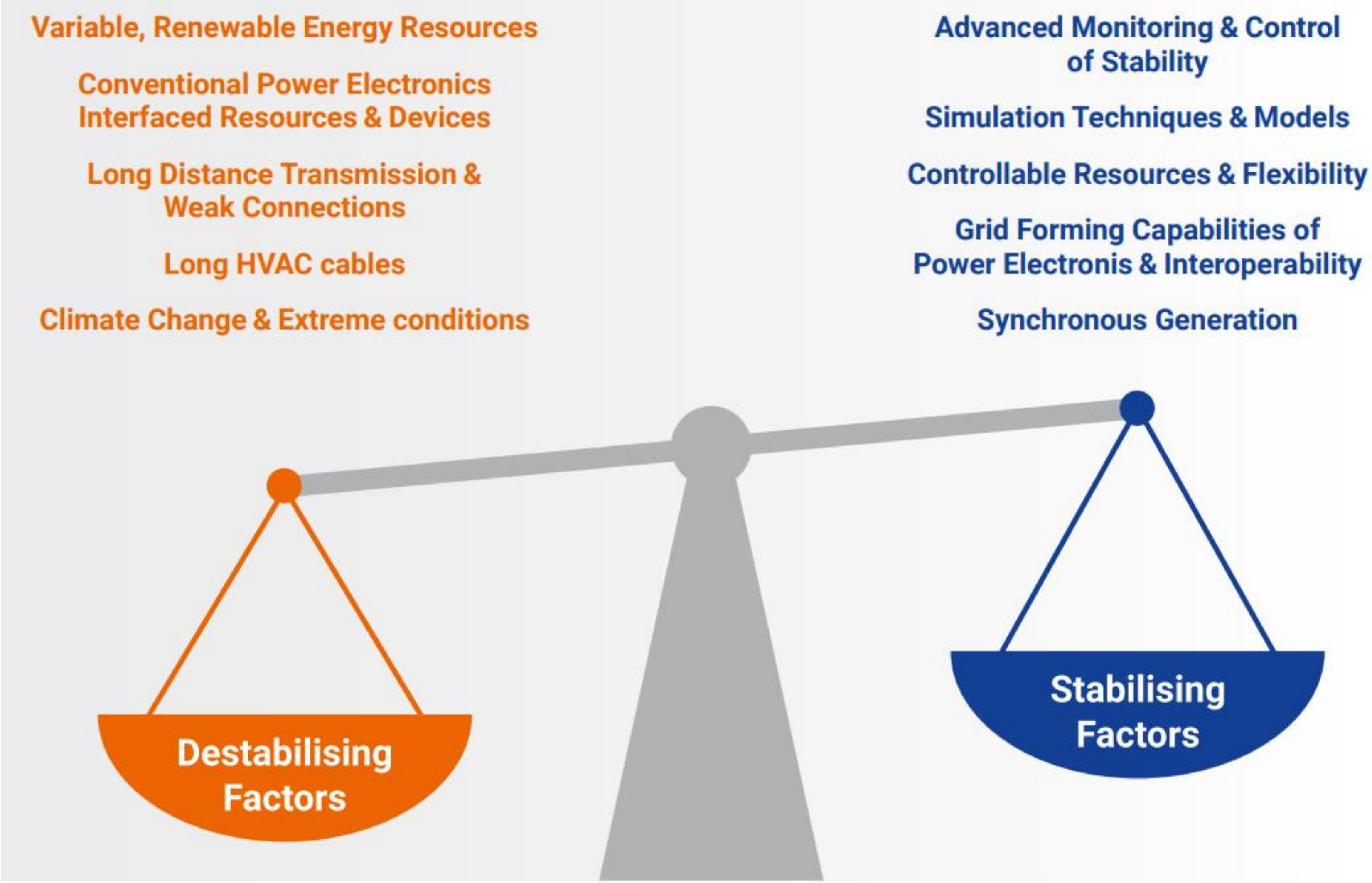


Figure from ENTSO-E position paper: Stability Management in Power Electronics Dominated Systems: A Prerequisite to the Success of the Energy Transition June 2022

Key Stability Phenomena

Possible approaches to system services for stability management

Services Timeframe		System Services for Stability Management	
		Active Power/ Frequency Control	Reactive Power/ Voltage Control
	Activation **up to 1 second** Response for fast transient state	Inertia	Dynamic voltage control
		Fast Frequency Reserves (FFR)	Fault right through (ower ride through, lower ride through)
		Damping of Power System Oscillation	Provision of short circuit power
	Activation > **1s** Response for slow transient state	Automatic Frequency Restoration Reserve (aFRR)	Voltage and reactive power control
		Frequency Containment Reserves (FCR)	
		Load reduction / Demand response	

Key Stability Phenomena

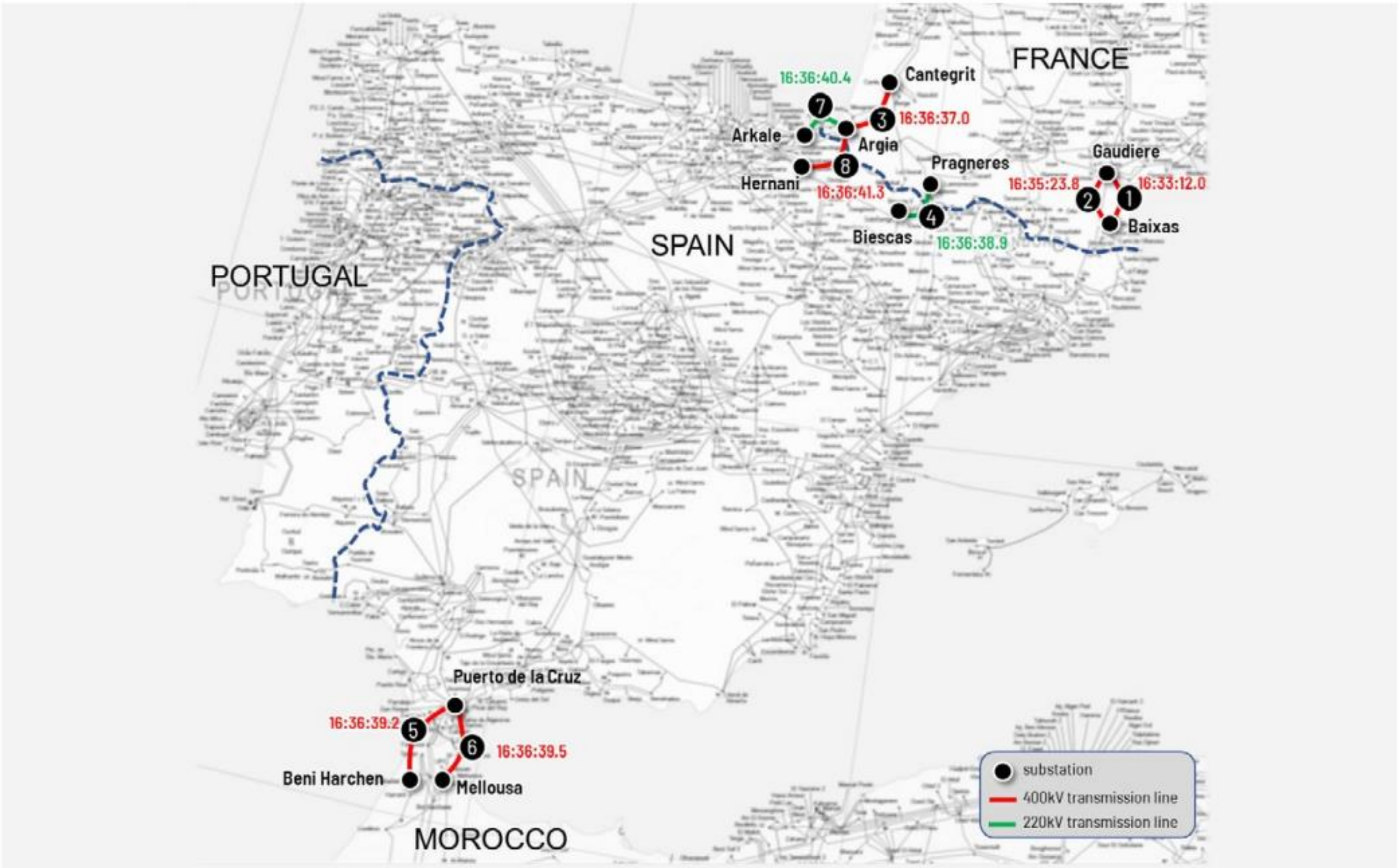
A need for Wide Area Monitoring Systems arises – PMUs play a significant role

WIDE AREA 	REAL TIME 
FINER TIMRESOLUTION **1 vs. 500** *(observations per 10 sec)*	SYNCRONIZED 

Grid stability challenges with increasing renewable energy penetration, examples

System Split on 24th of July 2021 - Iberian peninsula

- Power transport of approx. 2400 MW from France towards Spain
- A fire in the Gaudiere, Baixas region led to a failure of the "Baixas-Gaudiere" double circuit
- Load flow shift to the west led to an overloading of the "Argia-Cantegrit" circuit
- After disconnection of "Argia-Cantegrit" point of no return was reached and both parts of the system became asynchronous
- Voltage fluctuations in Spain/Portugal as a result of the system split led to the disconnection of generation units (approx. 2700 MW)



More Information can be found here:
[Final report on the power system separation of Iberia from Continental Europe on 24 July 2021]

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Grid stability challenges with increasing renewable energy penetration, examples

System Split on 24th of July 2021 - Iberian peninsula

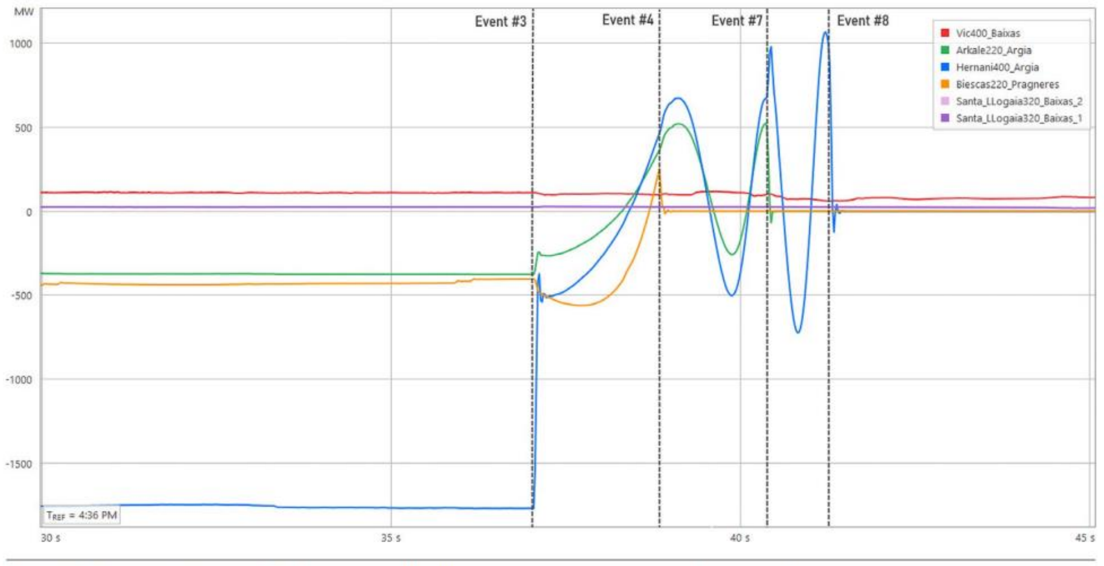
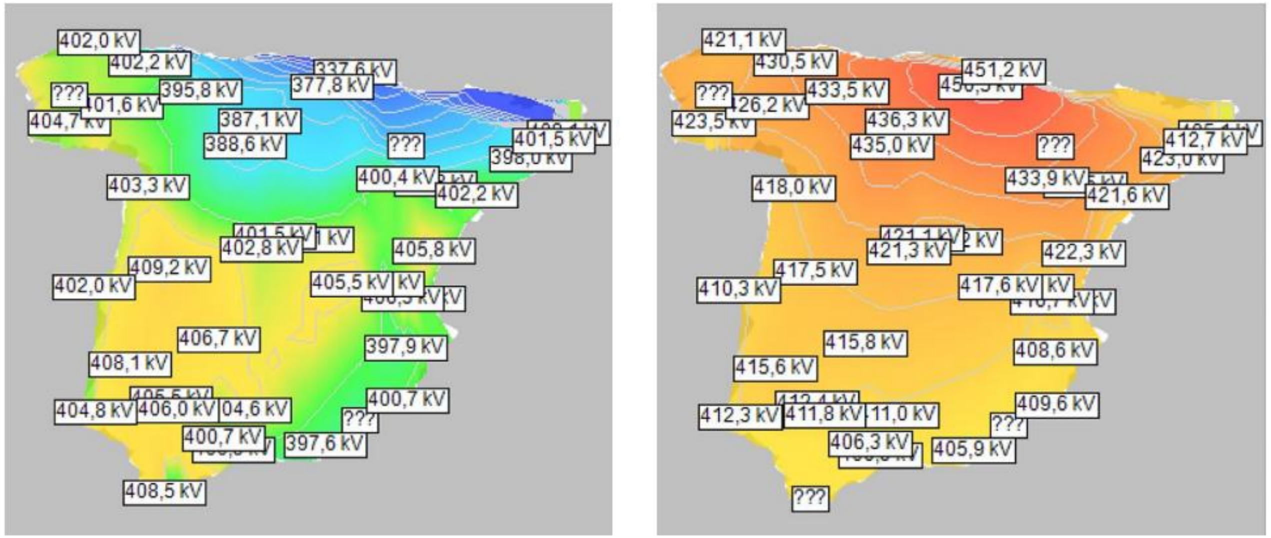


Figure 24: Active power of France–Spain tie lines as measured by PMUs (positive indicates power transfer from Spain to France).



(a) 16:36:32 between Event #2 and #3

(b) 16:37:40 after Event #3

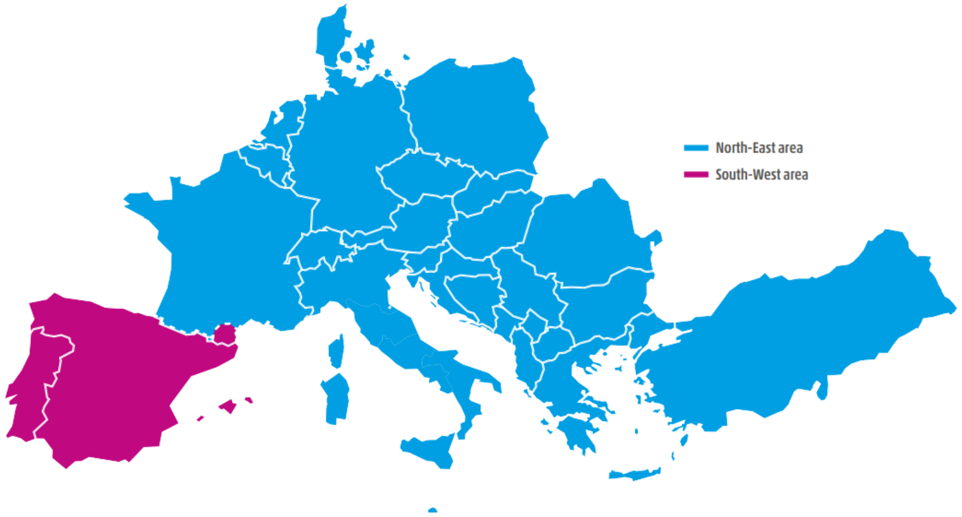
Figure 27: Voltages in Spanish 400 kV network.

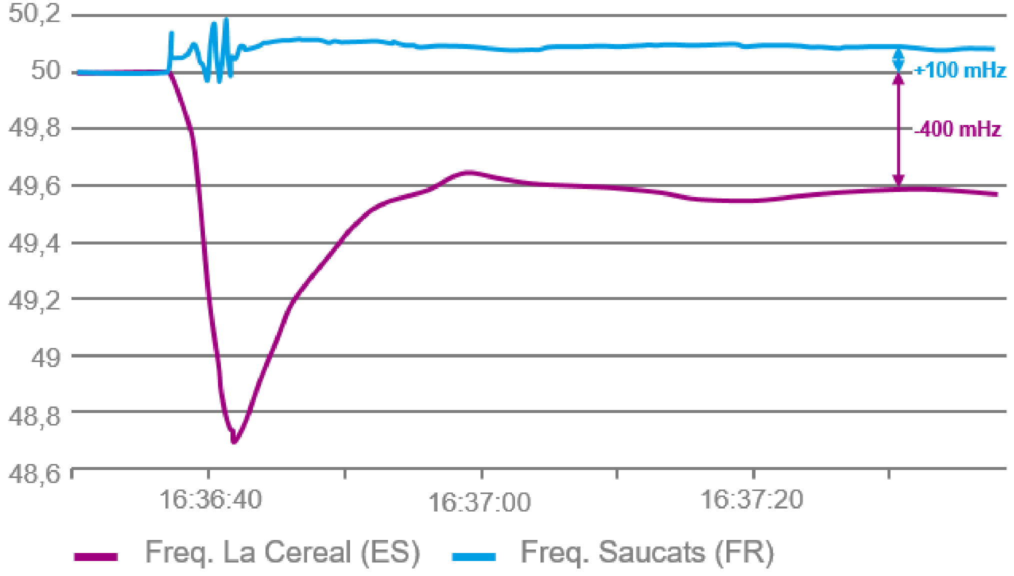
More Information can be found here:
[Final report on the power system separation of Iberia from Continental Europe on 24 July 2021]

Grid stability challenges with increasing renewable energy penetration, examples

System Split on 24th of July 2021 - Iberian peninsula

- Frequency in Spain/Portugal fell with a maximum gradient of approx. -1 Hz/s to 48.7 Hz
- Frequency in the ENTSO-E grid increased to 50.1 Hz
- Frequency was stabilized by system defense plan
  - Disconnection of pumped storage in pumped operation (approx. 2300 MW in Spain/Portugal)
  - Underfrequency load shedding (approx. 4800 MW in Spain/Portugal)
  - Activation of primary control (approx. 370 MW in Spain/Portugal)





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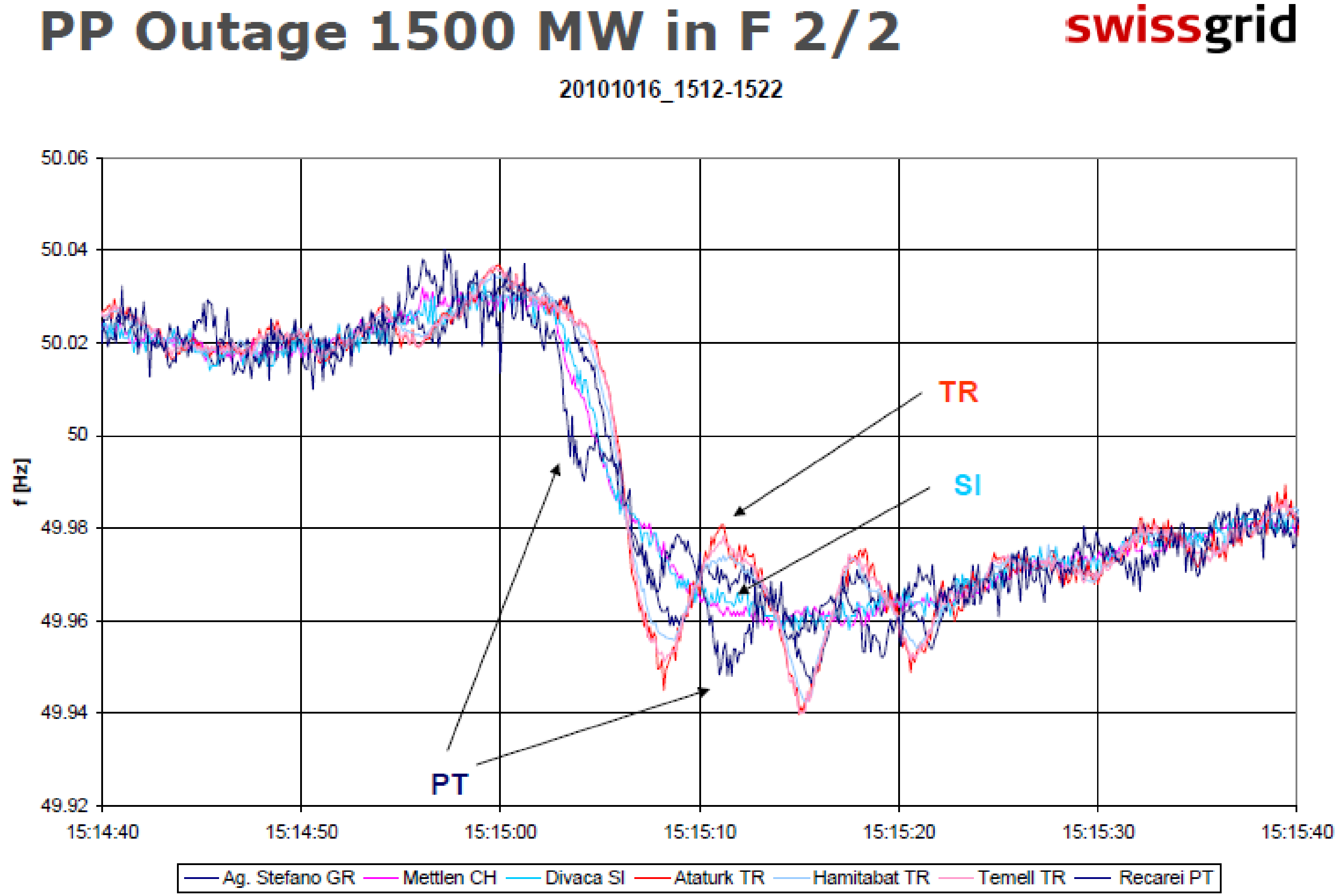
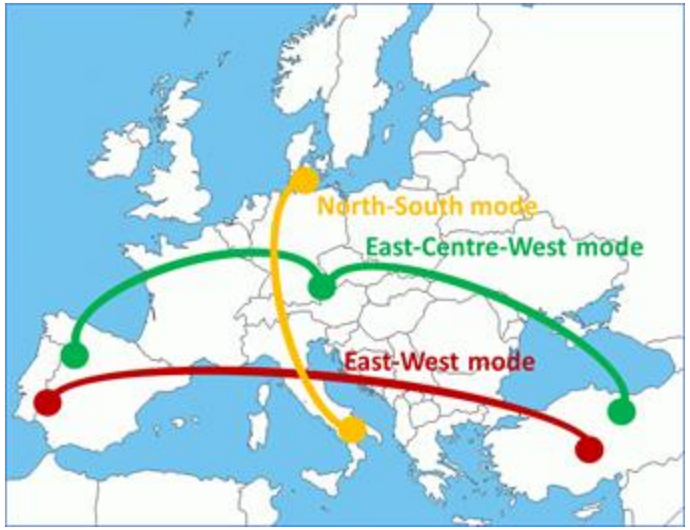
Grid stability challenges with increasing renewable energy penetration, examples

East & West Oscillation in Continental Europe: Trip of generation may cause oscillation



Portugal and Turkey are in oppositive mode



For more information: Microsoft Word - CE_inter-area_oscillations_Dec_1st_2016_PUBLIC_V7.docx (entsoe.eu)

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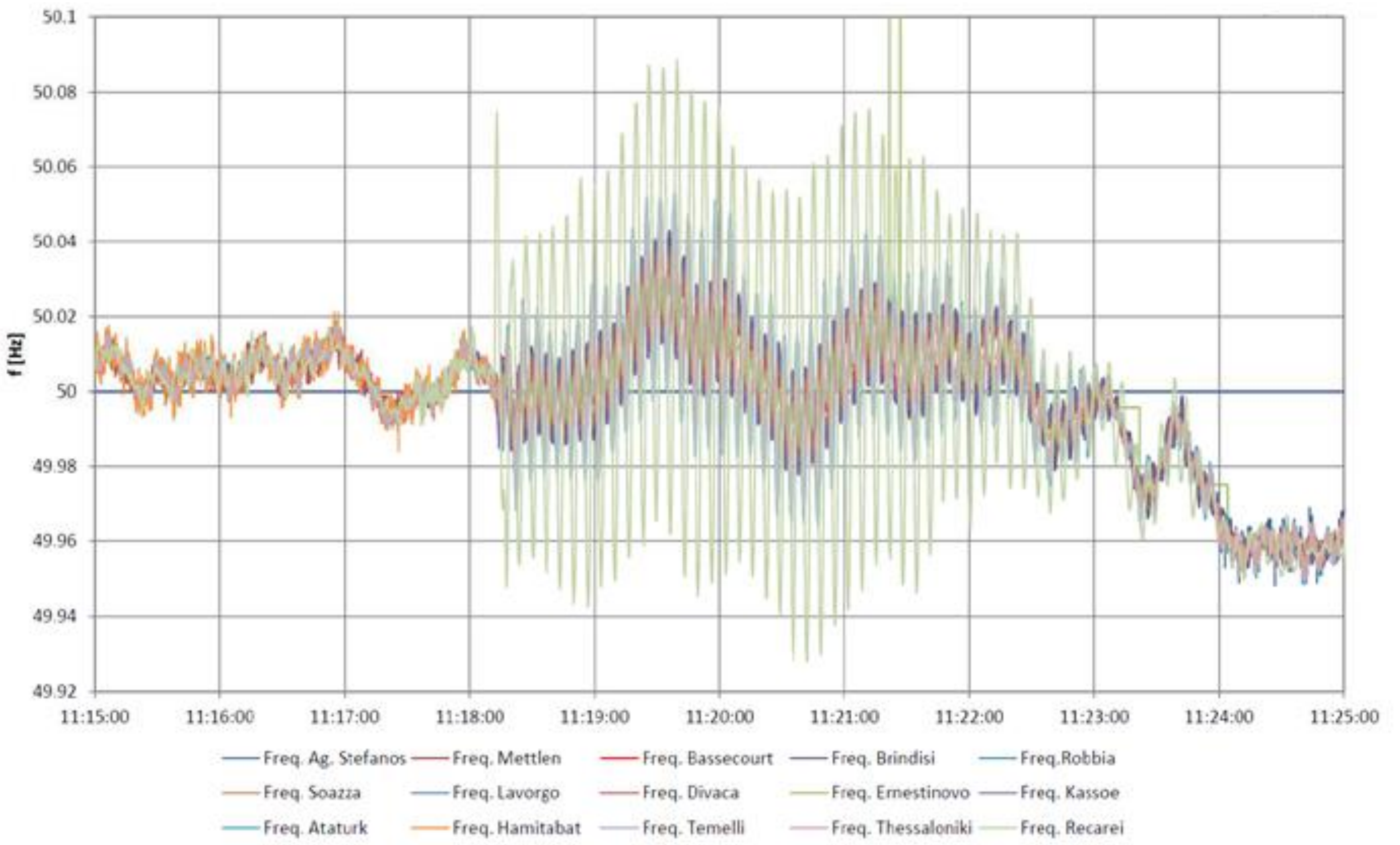
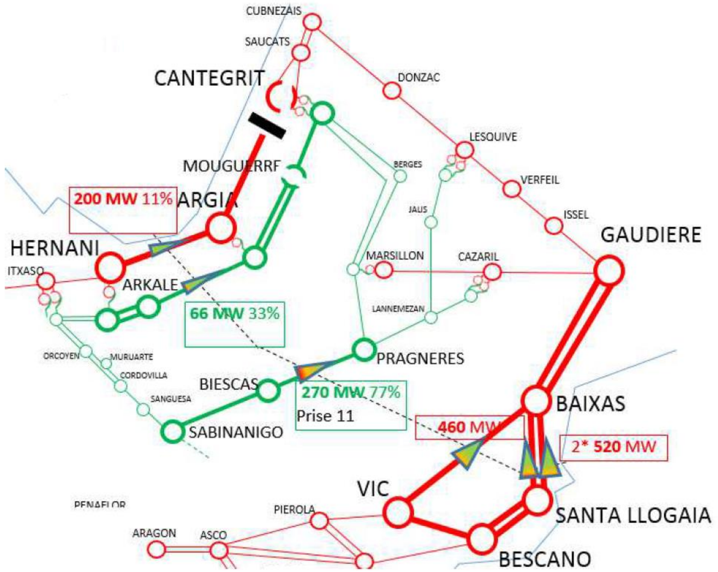
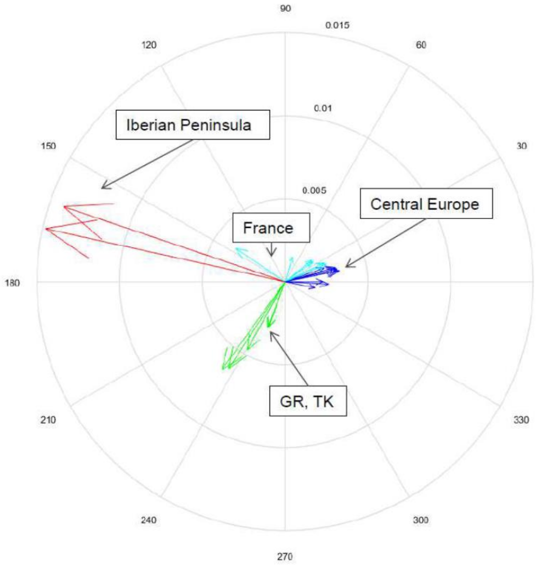
Grid stability challenges with increasing renewable energy penetration, examples

East & West Oscillation in Continental Europe: Opening a circuit-breaker near the tie-lines may cause oscillation

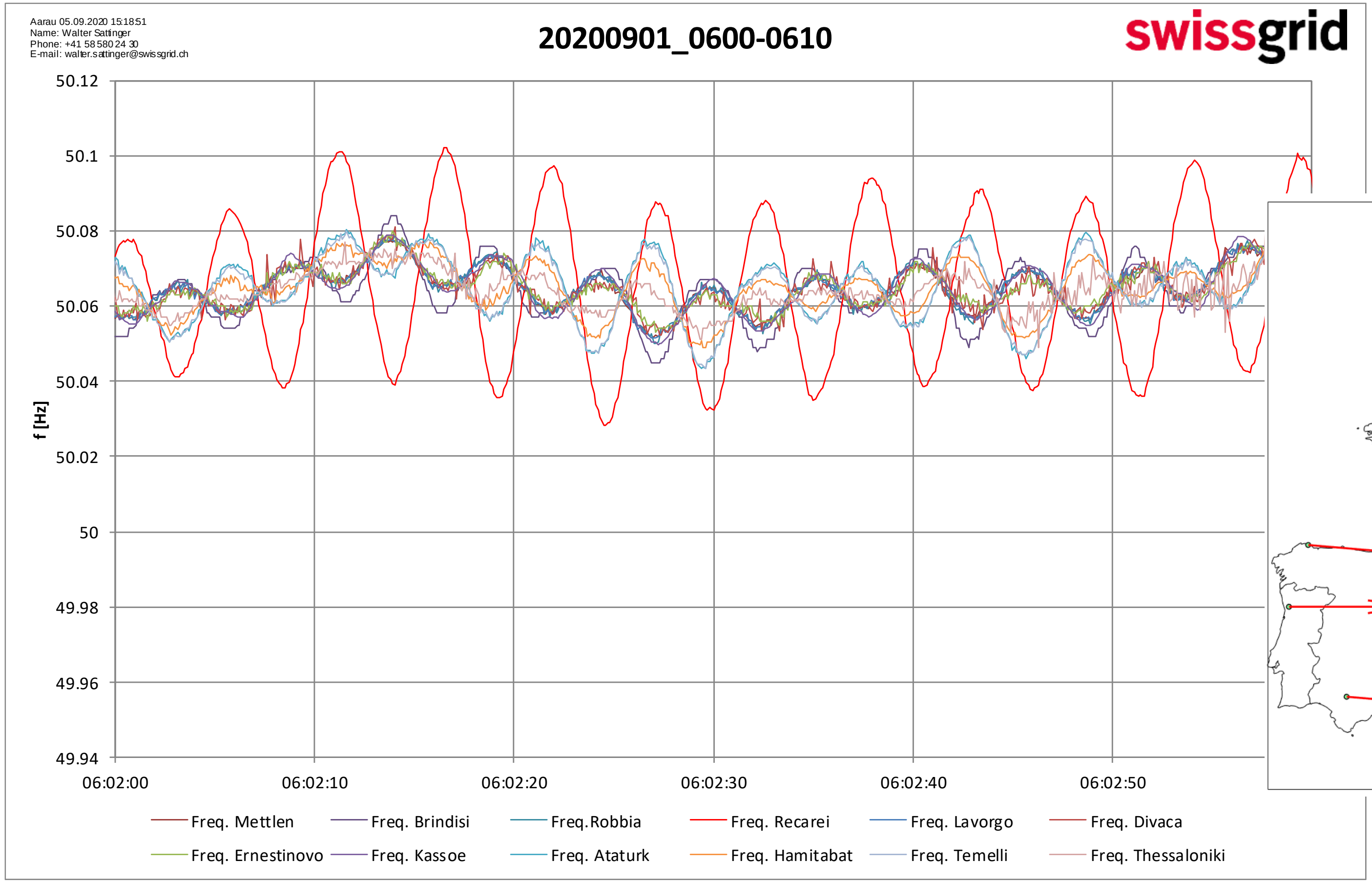




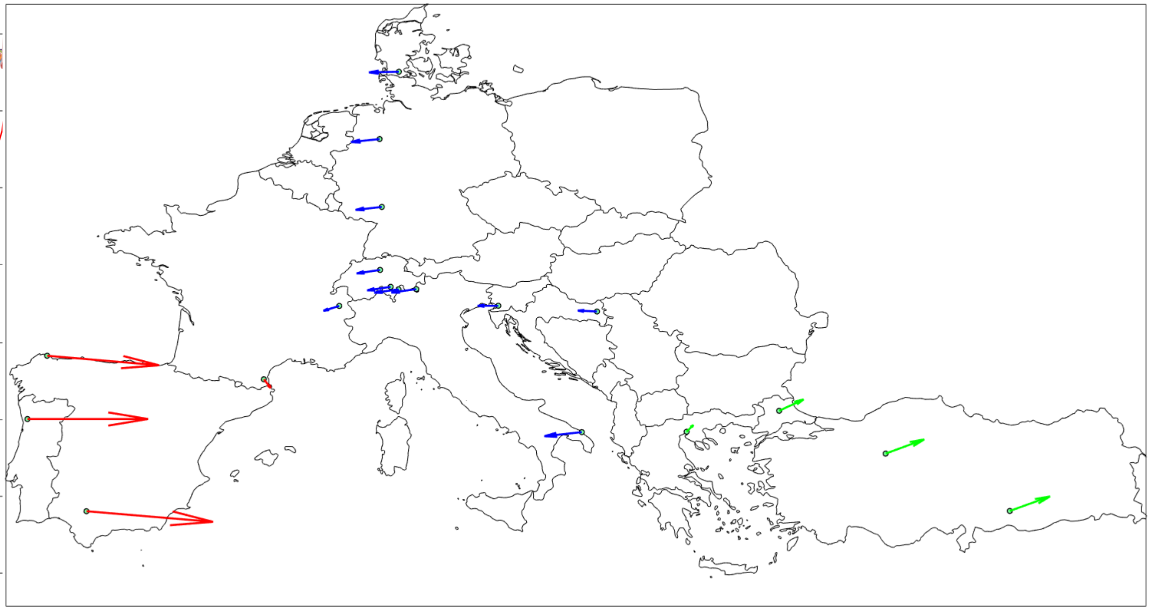


Grid stability challenges with increasing renewable energy penetration, examples

East & West Oscillation in Continental Europe: Hybrid interconnected system with **HVDC link in AC mode** keeps the system oscillation (for ever…)

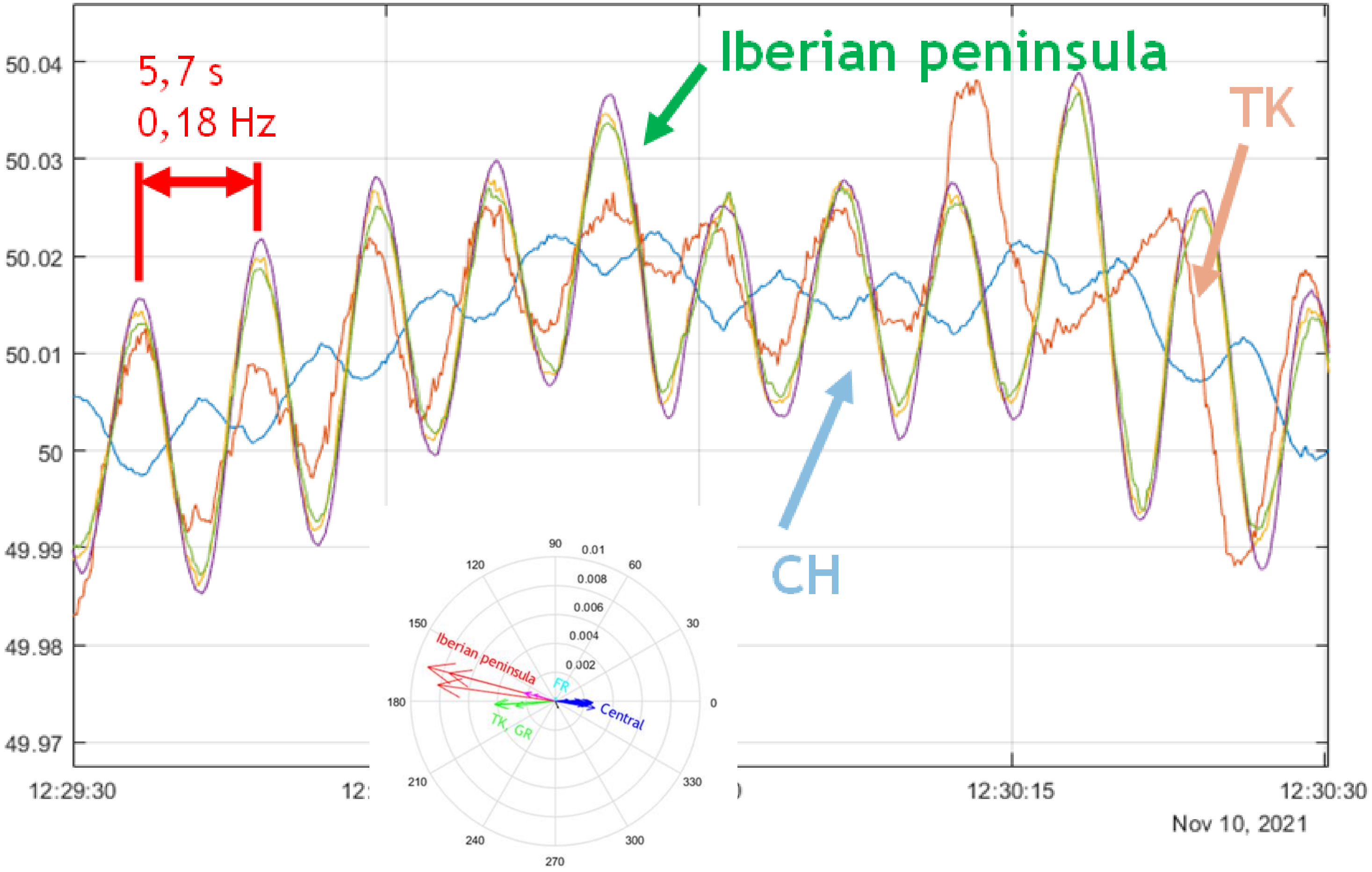


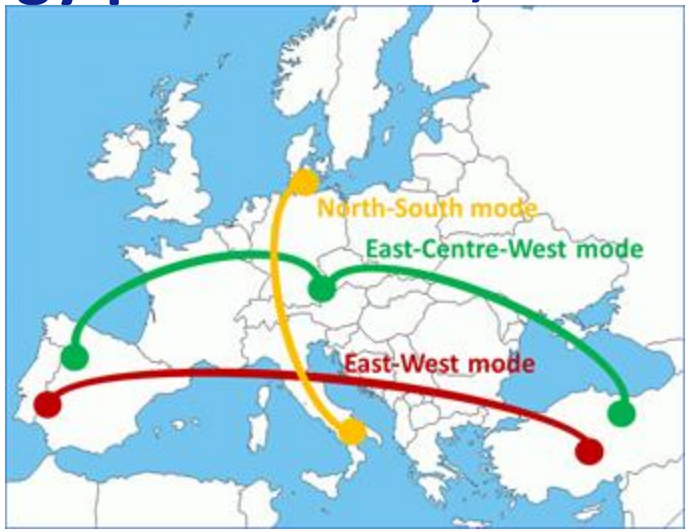
Alarms from the WAMS to SCADA are needed to alert the operators



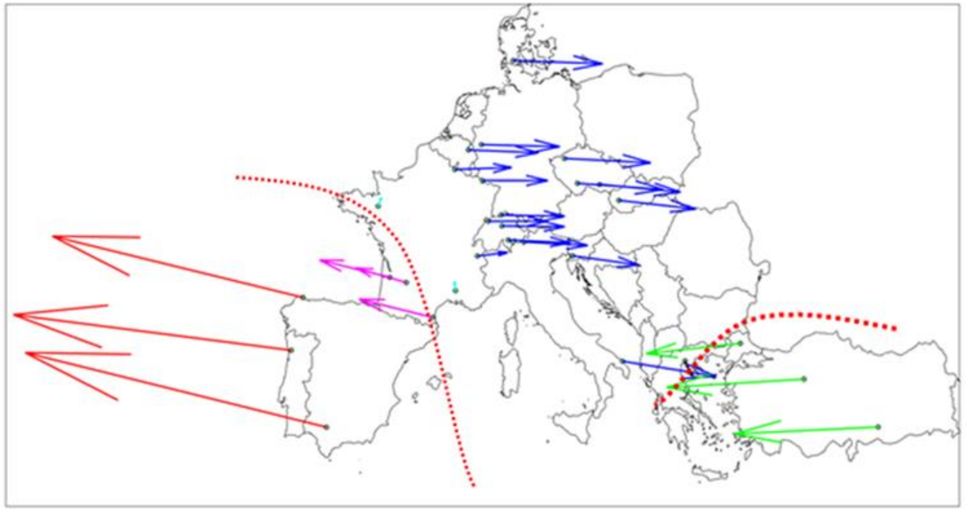
Grid stability challenges with increasing renewable energy penetration, examples

The East & **Center** & West mode has became the most frequent oscillation mode after the expansion of CE to Ukraine



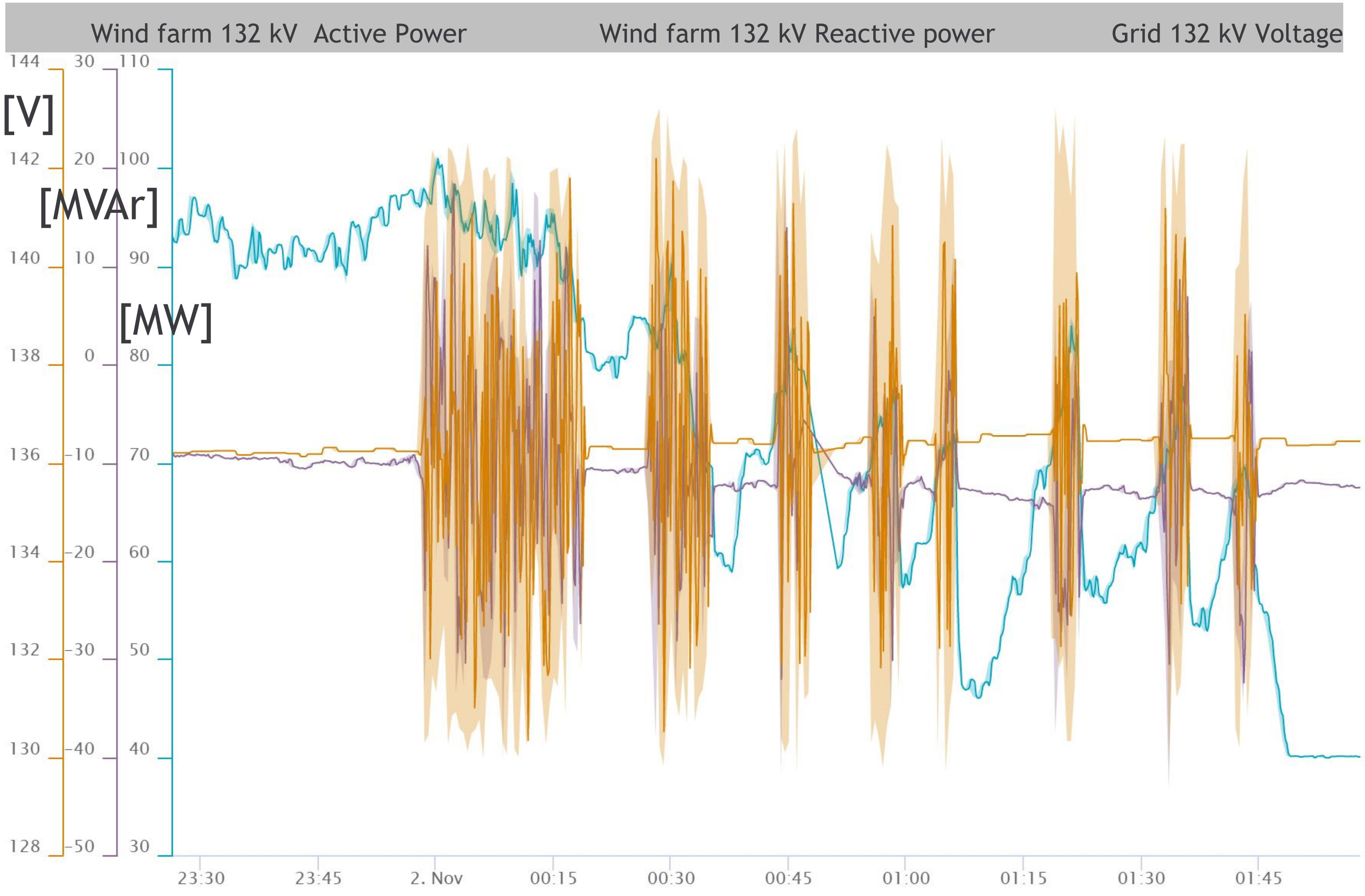


Portugal and Turkey are in the same mode



Grid stability challenges with increasing renewable energy penetration, examples

Windfarm in Norway



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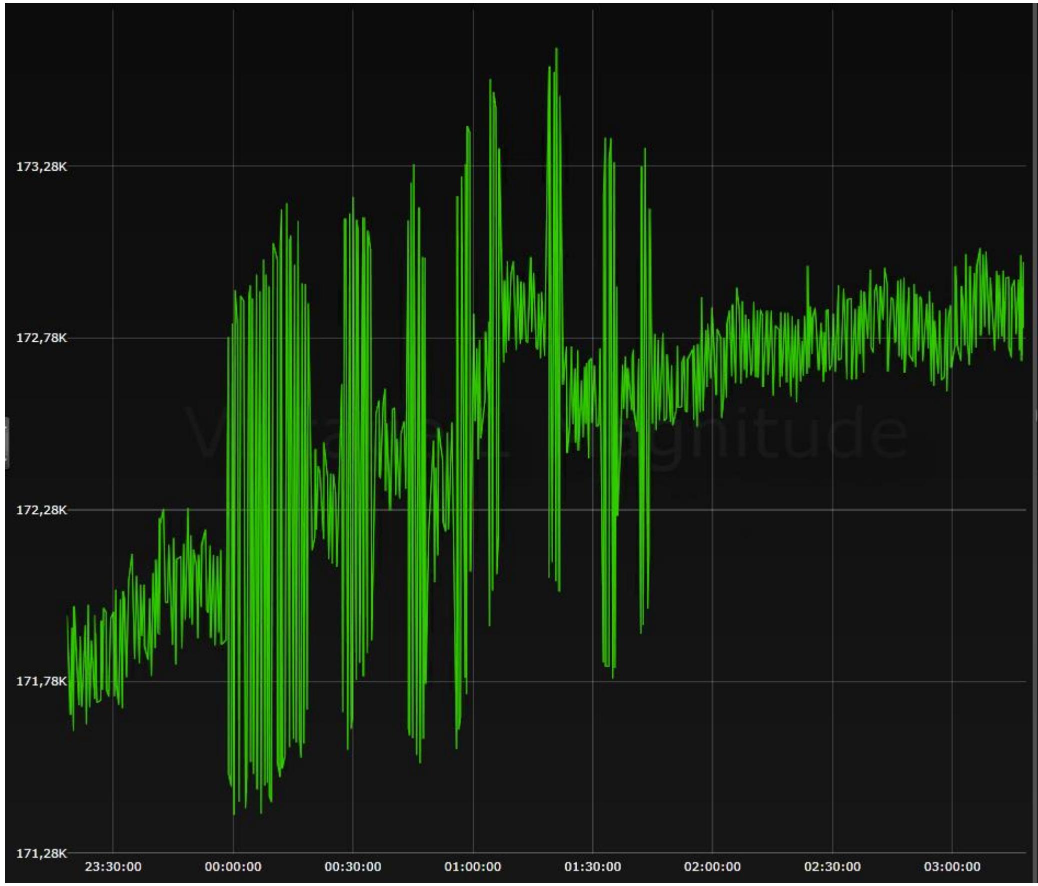
Grid stability challenges with increasing renewable energy penetration, examples

Windfarm in Norway

Impact 300 kV transmission grid

Voltage oscillations [kV]



Power flow [MW]

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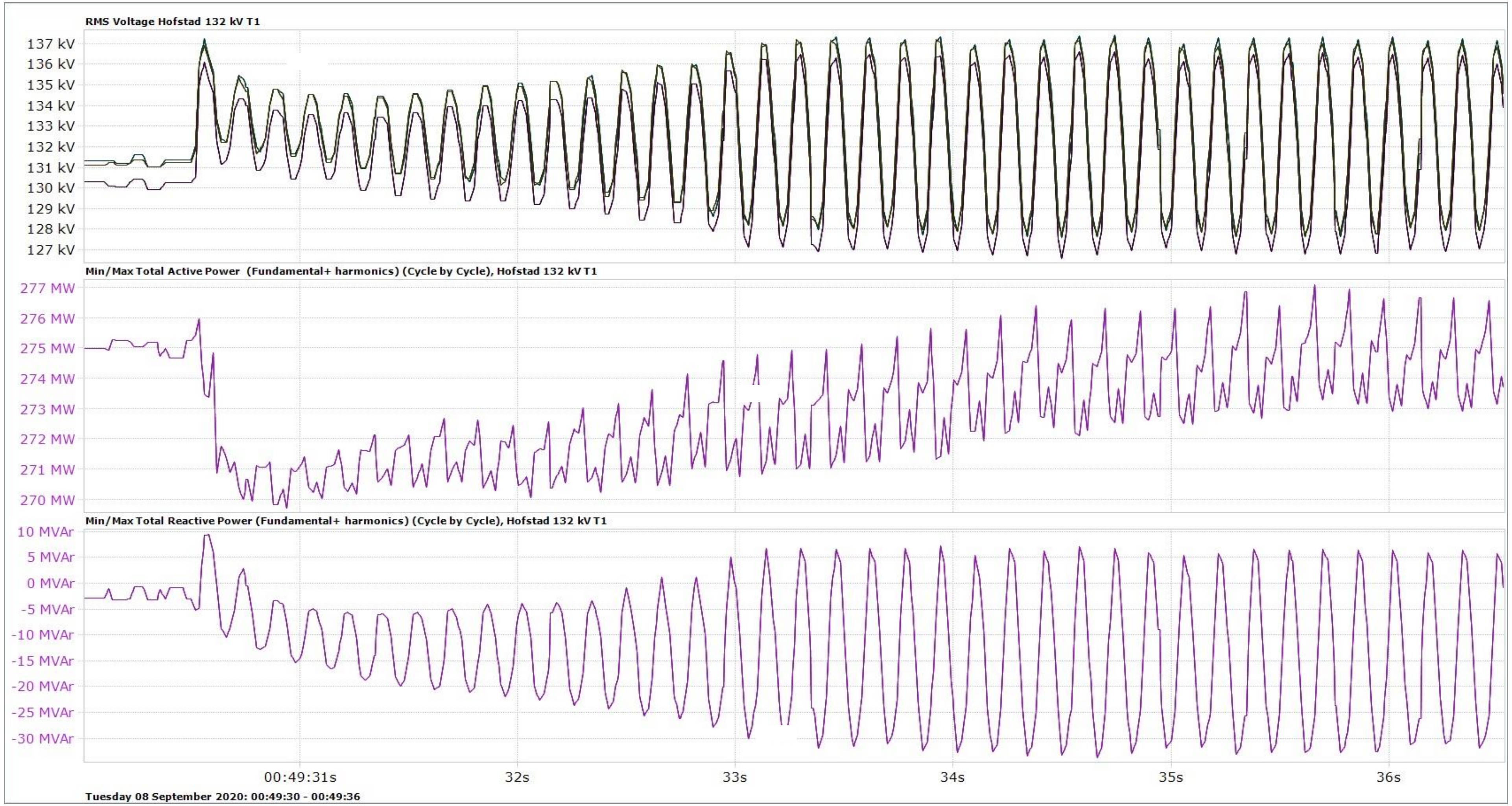
Grid stability challenges with increasing renewable energy penetration, examples

Windfarm in Norway

Instability in windfarm voltage regulator



6,25 Hz

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Part II: ENTSO-E RDI actions

ENTSO-E initiatives and interests in tackling stability challenges

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ENTSO-E Research, Development and Innovation Roadmap 2024 - 2034

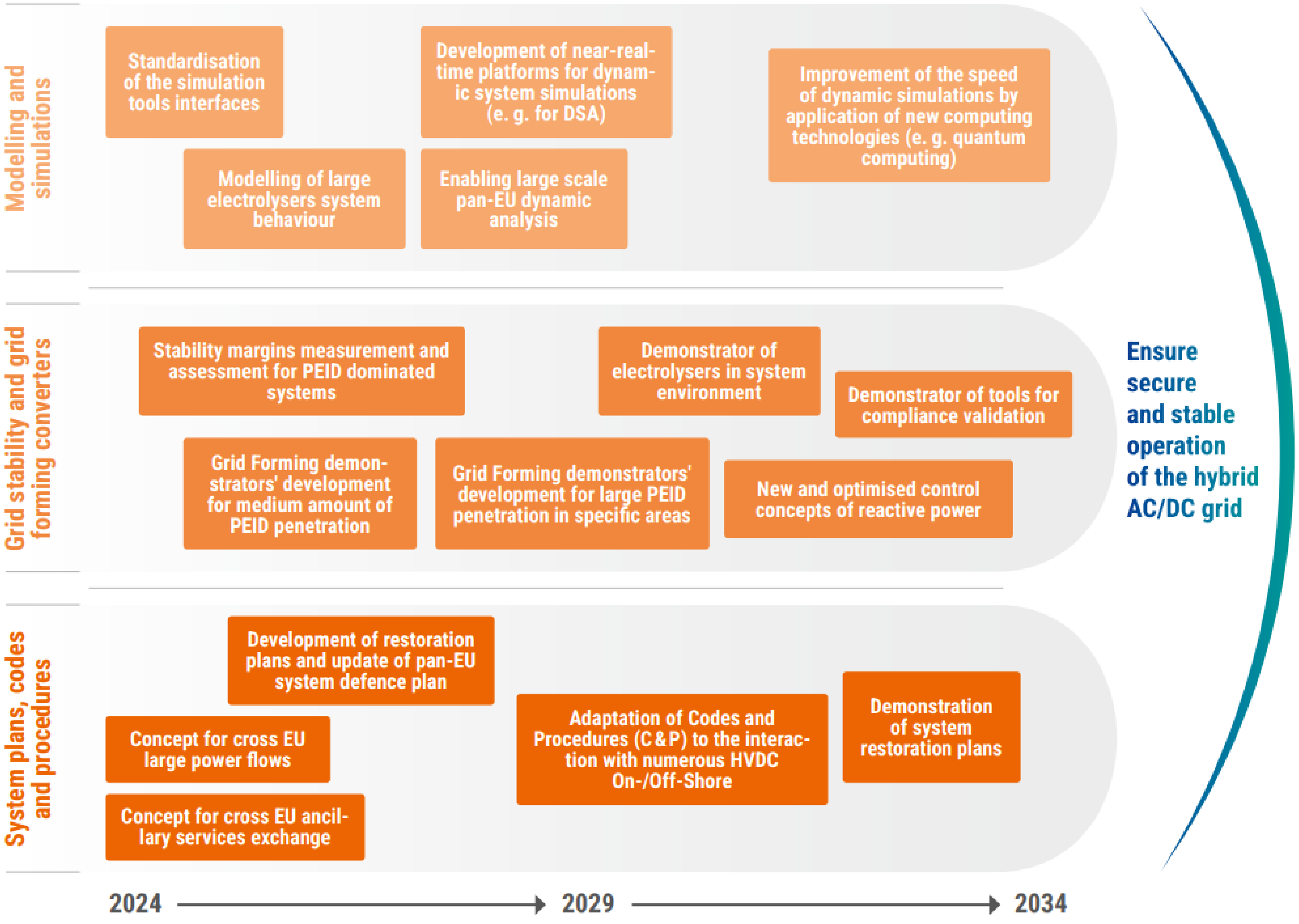

Figure 9: Mission 3 – Ensure secure and stable operation of the hybrid AC/DC grid

ENTSO-E RDI Roadmap 2024-2034 (eepublicdownloads.blob.core.windows.net)

"A Roadmap to accelerate the development of the future power system, a system that needs to be sustainable, flexible, digitalised and at the core of the European energy system of systems."

- Mission 3 under Cluster 2 tackles stability challenges in AC/DC grids through:
  - Simulation and measurement tools
  - Grid forming considerations for PEID penetration
  - Stability margins measurements for PEID dominated systems

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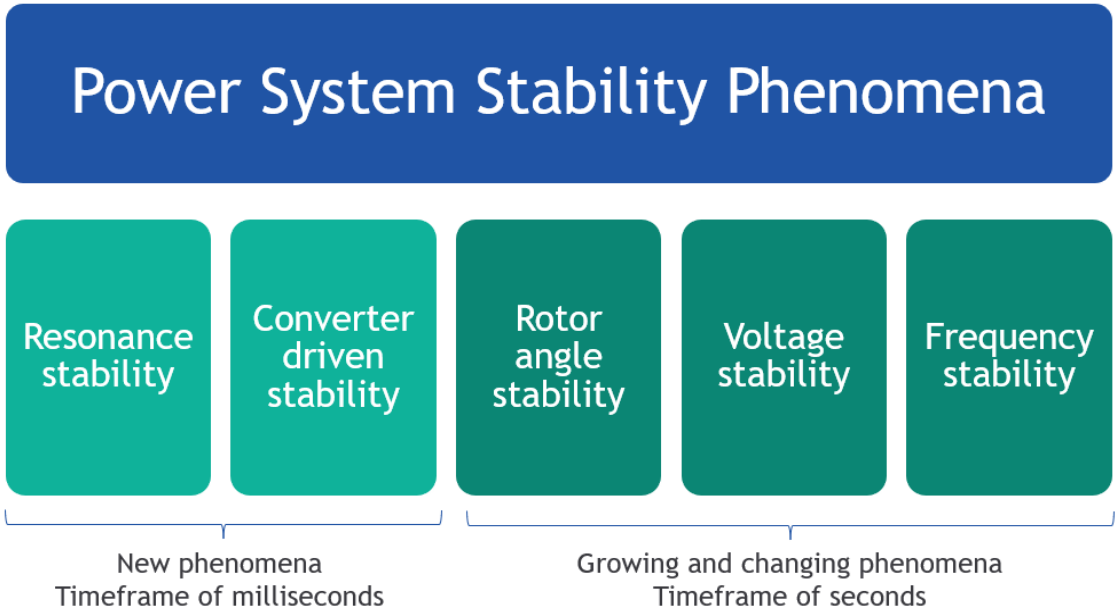
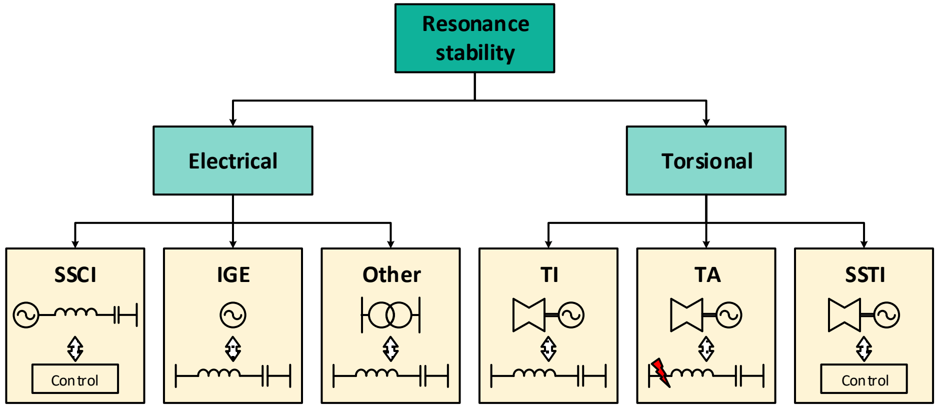
Modelling and simulation techniques - Modelling and Simulation Tools for New Stability Phenomena

Simulation and measurement tools





To maintain a reliable and resilient future power grid, detection of instability phenomena through wide area monitoring is needed. Predicting, detecting and tracking onset of instability is needed, as well as actional operational insights to deal with these issues.

What questions did the project answer?

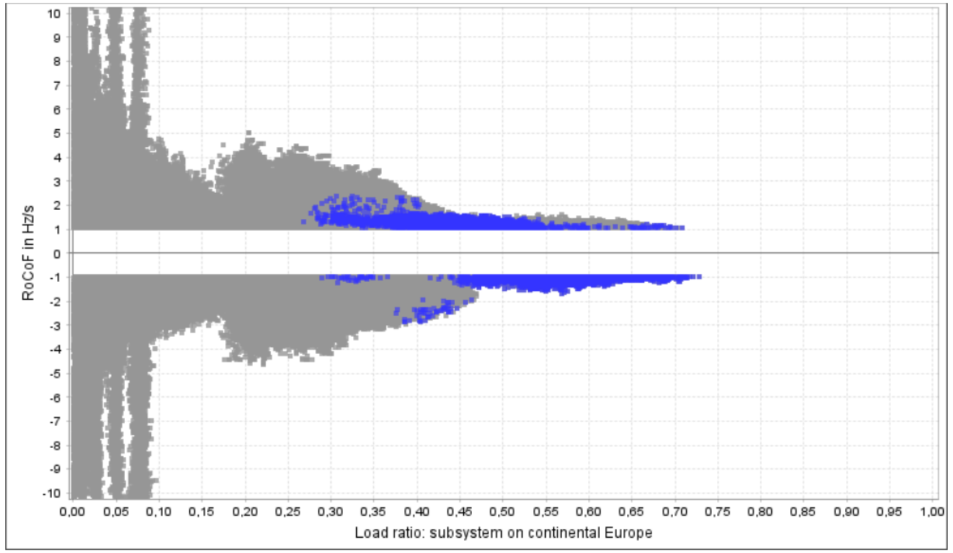
- What are the relevant models and simulation tools to be assessed to tackle new stability phenomena?
- What specific phenomena can be evaluated? (for example: control system dynamics, SSCI etc)
- What degree do the modelling and simulation tools cover the listed phenomena?

Grid forming converters and their role in enhancing stability – Project Inertia

Grid forming considerations for PEID systems

- project inertia phase I and phase II both analyzed global severe splits (GSS); these are system splits that would lead to a blackout of whole CE (e.g., both resulting subsystems after a system split exceed an absolute RoCoF of 1 Hz/s and/or absolute frequency thresholds) [Project Inertia Phase I] [Project Inertia Phase II]
- ongoing discussion about necessity of minimum level of inertia within CE, to maintain a certain level of resilience and survive the most severe disturbances (e.g., GSS)
- conventionally, inertia is mainly provided by synchronous generation units
- in the future, inertia shall be provided also by power electronics as well (some units symmetric and for some units unsymmetric)
- inertia can only be provided in combination with grid forming (GFM) controls, where the power electronic unit shows an inherent active power reaction in case of faults or significant network changes (change of frequency, RoCoFs, phase angle …)

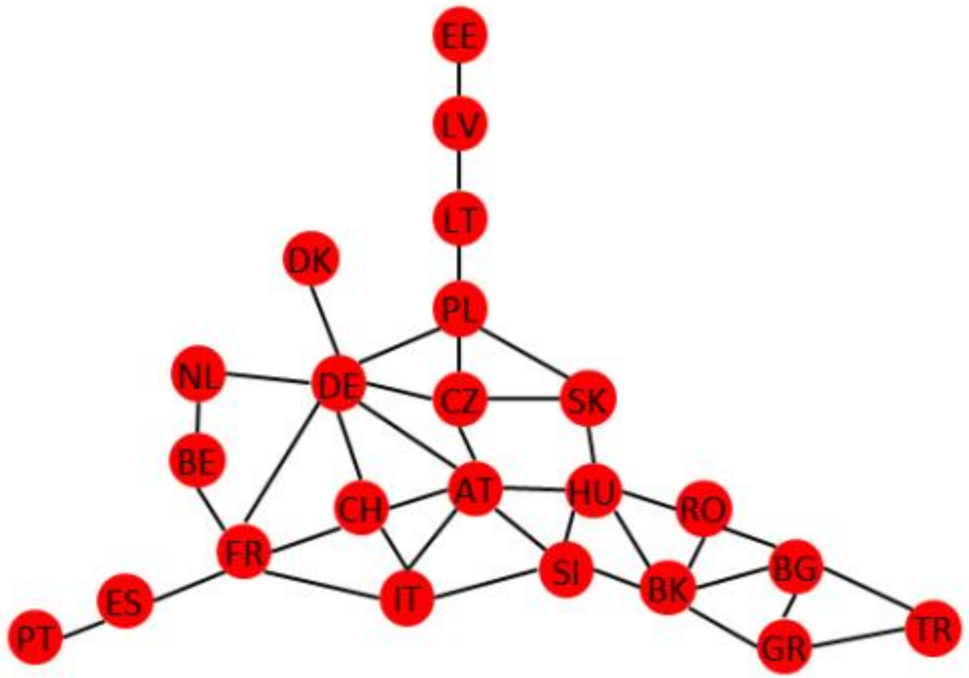
GA2040



Project Inertia Phase II – Interim Report, Fig. 11 [Link]

Grid forming converters and their role in enhancing stability – Project Inertia

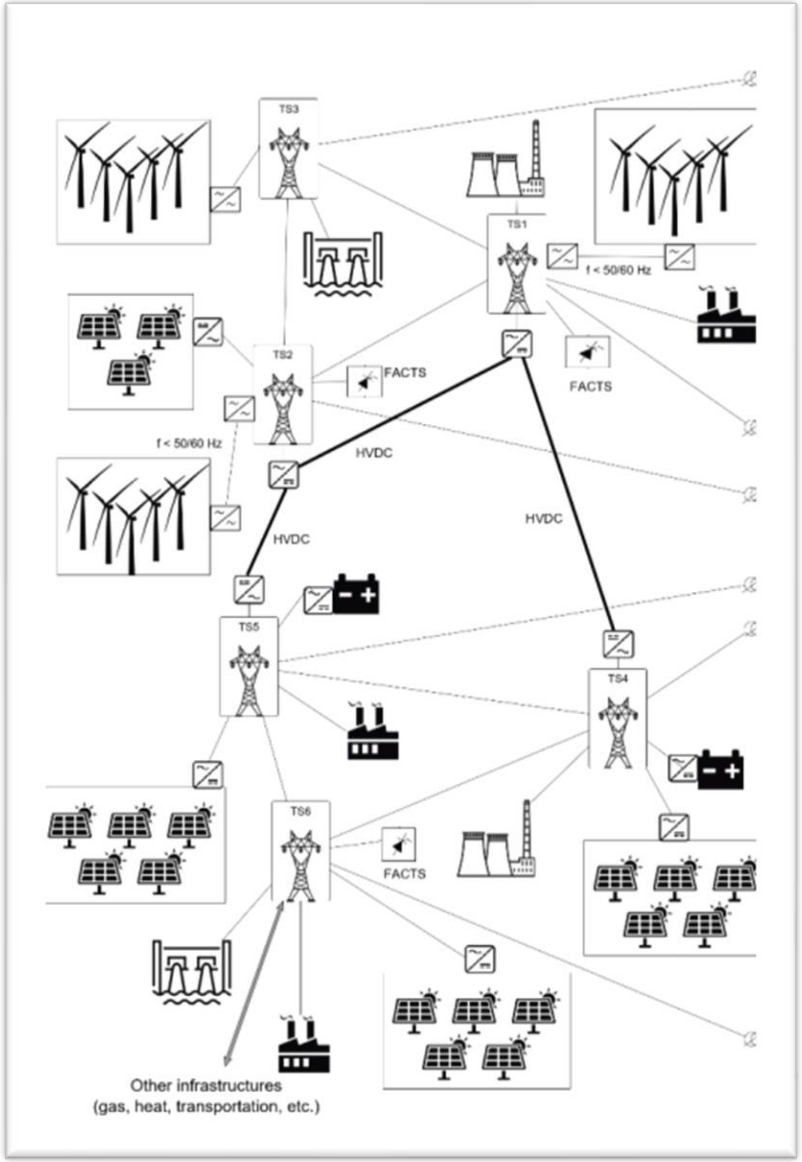
Grid forming considerations for PEID systems



- Project Inertia II analyses system splits on future "low inertia" configuration of Continental Europe following different TYNDP 2022 scenarios.
- Cases where subsystems both exceed 1Hz/s operational threshold shows significant increase from 2030 to 2040.
- To avoid blackouts from global severe splits:
  - Additional kinetic energy of a minimum 72.7 GWs in a first no-regret step is required for the RGCE synchronous area level. (equivalent to 42 SC of 250Mvar and H = 7MWs/Mvar)
  - PPMs with grid forming capabilities as well as synchronous condensors and STATCOMS with grid forming capabilities and storage are necessary.

Instability Analysis - Instability Detection Technologies in PEID systems

Stability margins measurements for PEID dominated systems



To maintain a reliable and resilient future power grid, detection of instability phenomena through wide area monitoring is needed. Predicting, detecting and tracking onset of instability is needed, as well as actional operational insights to deal with these issues.

What questions does the project try to answer?

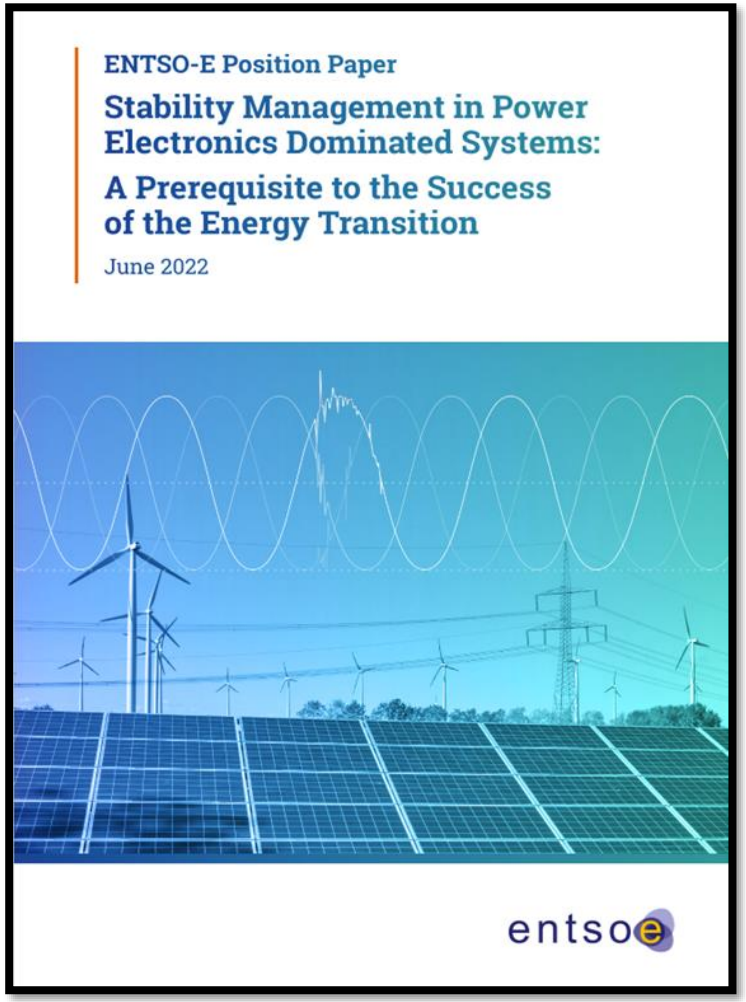
- What measurement-based detection technologies can be identified and evaluated for better detection of grid instability?
- What are the strengths and weaknesses of measurement-based detection technologies employed for different stability phenomena?
- What are the key factors that influence the effectiveness of these technologies?
- What are the future areas of research and development within instability detection technologies?

Source: Mevludin Glavic, Scott Greene, in Encyclopedia of Electrical and Electronic Power Engineering, 2023

Future direction and research needs

Future RDI actions mapped to actions proposed under Stability management in PE dominated system position paper

	Actions to tackle stability challenges	Status
Medium Term (2-3 years)	Propose methods for identification and analysis of thresholds	Covered in Project Inertia II
	Propose methods to predict and monitor system stability	To be covered in ongoing (internal) project Instability Detection Technologies
	Identify and specify the required technical capabilities of invertor-based assets	To be considered
	Develop high level specifications of power system models and simulation tools	Covered in Modelling and Simulation Tools for New Stability Phenomena (internal)
	Develop market mechanisms appropriate for ensuring the availability of necessary system services	To be considered
	Analyse roles and responsibilities with regards to the stability management of the pan-European grid	*Ongoing work on building awareness on stability challenges to non-technical stakeholders*
Long term (>3 years)	Deploy prediction, monitoring and communication systems for system stability on a pan-European level	To be considered
	Ensure that system stability issues are considered in the planning process of system development	*Evaluate grid stability issues in HVDC systems*
	Support vendors and manufacturers in development and deployment of new capabilities in inverter-based assets	*Evaluate electrolysers and grid forming capabilities (GFC) impact on system stability*
	Develop and verify power system models, asset models and simulation tools	To be considered
	Ensure liquidity in markets for new system services where applicable	To be considered



ENTSO-E Position Paper on Stability Management in Power Electronics Dominated Systems (eepublicdownloads.azureedge.net)

28

European
Commission

#HorizonEU

THE EU RESEARCH & INNOVATION PROGRAMME 2021 – 27

This presentation is based on the political agreement of 11 December 2020 on the Horizon Europe. Information on some parts is pending revision.

19 March 2021

Research and Innovation

Future direction and research needs

Horizon Europe Projects TSO members are involved in, and progress is followed by ENTSO-E RDI

Project	Description	Relevance to ENTSO-E RDI roadmap 2024-2034
InterOPERA	By **defining technical frameworks and standards**, aims to make future HVDC **systems mutually compatible and interoperable by design**, to improve the grid forming capabilities of offshore and onshore converters and pave the way for the first HVDC **multi-terminal, multi-vendor, multi-purpose** real-life projects in Europe.	*Mission 2* *Development and test of critical MT HVDC components, Demonstration of interoperability of HVDC converters, Demonstration of multi-vendor MT HVDC.*
HVDC WISE	The project **proposes, designs, and validates HVDC-based grid architecture concepts**, enabling the deployment of reliable, resilient, widespread AC/DC transmission grids to achieve the European energy transition.	*Mission 2* *Alignment of reliability and maintenance concepts* *Mission 3* *Adaptation of Codes and Procedures (C&P) to the interaction with numerous HVDC On-/Off-Shore*
PROSECCO	The overarching aim is to remove barriers to the development of reliable and efficient hybrid AC/DC grids through a systematic approach to increase knowledge in the fields of i) **DC protection relay testing and integration**, ii) **AC protection near DC grids** and iii) **optimal use of DC infrastructure through power flow control**.	*Mission 2* Simulation tools, compliance tests and test facilities for HVDC converters
InterSCADA	**The project has devised a comprehensive strategy to address the challenges** faced by TSOs and DSOs, involving the development of the **modular InterSCADA platform**, the implementation of **advanced algorithms for real-time monitoring, control, and ancillary services**, rigorous **testing and validation** methodologies, as well as services through **real-life demonstrators**, and providing **recommendations for grid codes**.	*Mission 3* *Development of near-real time platforms for dynamic system simulations*
DAEDALOS	The overall goal of the project is to **develop and test in realistic demonstrators' environment**, **innovative tools granting grid stability and reliability** within the complex context of hybrid AC/DC systems and HVDC power grids. The project aims at realising **two demonstrators**, one will be built in the campus facility of University of Aachen and the other will be hosted in the University of Catalunya facility.	*Mission 2* *Alignment of requirements for HVDC, cable and monitoring systems*

Our values define who we are, what we stand for and how we behave.
We all play a part in bringing them to life.

EXCELLENCE

We deliver to the highest standards. We provide an environment in which people can develop to their full potential.

TRUST

We trust each other, we are transparent and we empower people. We respect diversity.

INTEGRITY

We act in the interest of ENTSO-E

TEAM

We care about people. We work transversal and we support each other. We celebrate success.

FUTURE THINKING

We are a learning organisation. We explore new paths and solutions.

We are ENTSO-E