Grid Connection European Stakeholders Committee
Stakeholders' webinar on RoCoF related considerations

1st February 2022

entsoe

Reliable Sustainable Connected

Introduction

ENTSO-E: Mario Ndreko

Problem Background & Motivation

RES is Changing the Power System

the power **system is gradually evolving from the classical centralised power system** where large synchronous generation units (type D) ensure power system stability and robustness, **towards a decentralised power system** where the generation shifts into the distribution level (type A and B).

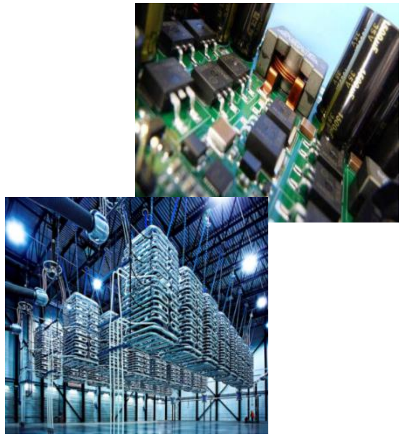
the **observability of the generation fleet** in the medium and low voltage networks becomes **challenging for System Operators.**

the **load flow patterns become volatile among transmission and distribution networks**, resulting in increased reverse flows and faster voltage variations

RES variability increases the need for **larger and more variable power transits across the transmission corridors**

Problem Background & Motivation

More Power Converters



On **generation side**, **a massive installation of power converters based power sources** throughout the **distribution and transmission** system

On the demand side, similar trends are being observed with the load being increasingly interfaced with power converters, e.g. industrial motors or EVs

On the high voltage transmission system, increased HVDC transmission capacity is expected by 2030 (70GW embedded HVDC links)

different power system ***dynamic profiles***

primarily caused by the **displacement of the synchronous generation** fleet

secondarily caused by the **fast time constants introduced by power electronic converters** and actuators

Problem Background & Motivation

TSOs View on Power System Stability Challenges

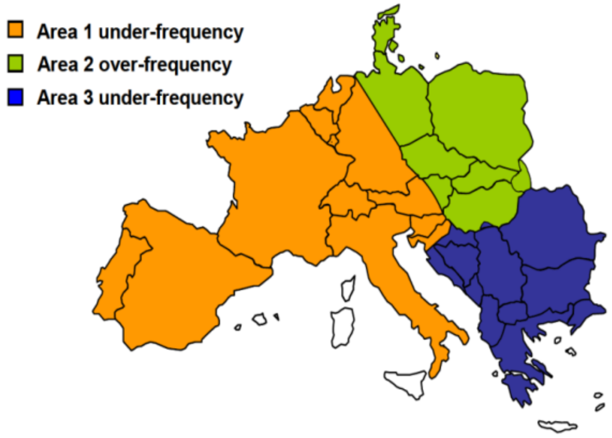
The EU-Horizon-2020 funded project **MIGRATE conducted a survey among 21 European TSOs aimed at identifying power system stability challenges** as perceived by the industry under high penetration of PEIPSs.

Ranking	Score	Issue
1	17.35	Decrease of inertia
2	10.16	Resonances due to cables and Power electronics
3	9.84	Reduction of transient stability margins
4	8.91	Missing or wrong participation of PE-connected generators and loads in frequency containment
5	8.19	PE Controller interaction with each other and passive AC components
6	7.50	Loss of devices in the context of fault-ride-through capability
7	7.00	Lack of reactive power
8	6.91	Introduction of new power oscillations and/or reduced damping of existing power oscillations
9	6.09	Excess of reactive power
10	4.27	Voltage Dip-Induced Frequency Dip
11	3.87	Altered static and dynamic voltage dependence of loads

A recent report from the sub-group **System Protection and Dynamics (SPD) working group of ENTSO-E** has ranked the increase of **RoCoF as a top power system stability challenge** for the CE system

Problem Background & Motivation

Decrease of Inertia and System Split



System split is identified as **a grid extreme contingency leading to separation of the system** into asynchronous zones.

Events such as **system splits** (usually experienced once in decades), becomes **critical under high penetration levels** of renewable generation sources.

Exports and imports before the system split event become **power imbalances** for the separate islands after the split.

A **system split is more likely** to occur across **highly loaded weak transmission corridors.**

The **potential imbalance after a rare system split which the systems need to survive is expected also to increase**, bringing the system to its **physical limits** in terms of balancing capability.

Developments of the **European Electricity Markets are leading to the transit flows** gradually increasing in magnitude, making system split cases in future more difficult to handle.

Agenda

In the content of GC ESC, ENTSO-E would like to open a dialogue with stakeholders on the topic of inertia challenges that the CE SA will face

- We aim to clarify how RoCoF values are selected and used in technical requirements for connection network codes and identify potential follow up actions

Timeslot	Topic	Presenter
13:00-13:15 *[15 min]*	Welcome/Introduction	ENTSO-E (Mario Ndreko)
13:15-14:00 *[45 min]*	ENTSO-E study: Frequency stability in long-term scenarios and relevant requirements	ENTSO-E (Joao Moreira, Vincent Sermanson, Francesco Celozzi)
14:00-15:00 *[60 min]*	System split 24 July report and RoCoF conclusions Analysis of VGB's questions and replies	ENTSO-E (Walter Sattinger) Stakeholders/all
15:00-15:15 *[15 min]*	Break	-
15:15-16:00 *[45 min]*	Examples of RoCoF national implementations	ENTSO-E (Johannes Weidner)
16:00-17:00 *[60 min]*	Questions and AOB	Stakeholders/all ENTSO-E

ENTSO-E study: Frequency stability in long-term scenarios and relevant requirements

ENTSO-E: Joao Moreira, Vincent Sermanson, Francesco Celozzi

Frequency stability in long-term scenarios – framework (1/3)

WHAT

Cross–committee project set up by System Development Committee and System Operation Committee. It involves:

- TF Planning Standards; StG Connection Network Codes; WG System Protection and Dynamics

The aim is to **assess the decreasing level of inertia and its impact on the future Continental Europe synchronous area**

WHY

- The system trends show a **decrease in the level of Inertia**
- Following an ordinary generation loss, **large RoCoF and frequency excursions** are not expected in Continental Europe. However, these **can be observed in case of a system split**
    - System splits are **realistic and serious disturbances**
    - System split events are **not a new issue**, but the trends show that the **underlying assumptions are shifting to a situation more challenging to withstand**
- It is **important** to **assess the expected RoCoF** values in a **system split** and **discuss the possible mitigation measures**
    - A high RoCoF reduces the available time for deploying the necessary fast balancing actions for preventing high frequency excursions leading to unstable behavior in the subsystems or even blackout

Frequency stability in long-term scenarios – framework (2/3)

HOW

Starting from the **market data of TYNDP2018**, the study defined a **methodology** to enable a comprehensive perspective of the possible Continental Europe synchronous area split cases and the **essential causes** at the base of the **RoCoF values**

- Calculation of **all possible system split combinations** considering a subset of the TYNDP 18 market nodes
- For each split combination, the **initial subsystems RoCoF is calculated based on the imbalance and inertia for every hour and every TYNDP scenario**
- **The study does NOT assess the probability of occurrence of a system split!**

The study considered **initial RoCoF values higher than 1 Hz/s as not manageable,** as per to System Operation Committee WG SPD "Inertia and Rate of Change of Frequency (RoCoF)*"

*https://eepublicdownloads.azureedge.net/clean-documents/SOC%20documents/Inertia%20and%20RoCoF_v17_clean.pdf

Frequency stability in long-term scenarios – framework (3/3)

To assess the RoCoF, the following boundary conditions are assumed:

a) The report considers the initial RoCoF value of the relevant island after the split.

b) Local phenomena can be more severe than the global RoCoF.

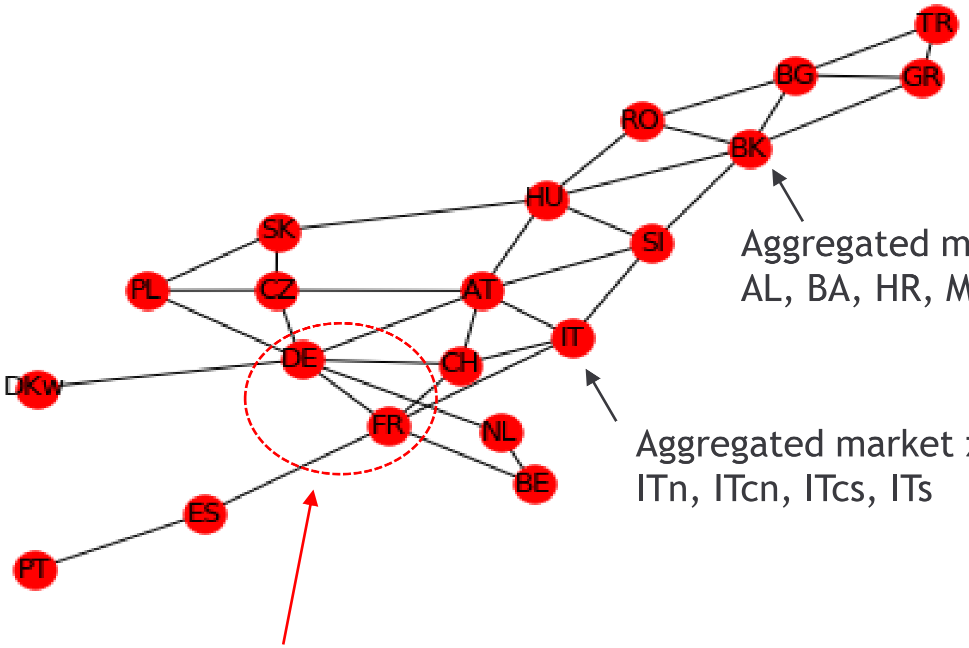
c) The initial RoCoF value can be significantly higher than the average value of 500-ms.

Based on the above, the analysis assumes that the global initial RoCoF provides an objective indicator of the scale and range of the challenge.

Objective and principle of the methodology

Define and characterize the consequences of possible system splits in terms of frequency stability

Method : a simplified approach based on the computation of the RoCoF from market data



Aggregated market zone BK:
AL, BA, HR, ME, MK, RS

Aggregated market zone IT:
ITn, ITcn, ITcs, ITs

2 subsystems only: the separation of France and Germany from the rest of the synchronous area is not considered for it would create four sub-systems: ES+PT/FR+DE/DK/the rest

- 20 aggregated market zones
- 457 possible system splits in 2 subsystems only
- 8736 hours
- 6 scenarios from TYNDP 2018

→ **24 million cases** (system split x hours x scenarios)

6 scenarios:
- BE2025: Best Estimate 2025
- ST2030: Sustainable Transition 2030
- DG2030: Distributed Generation 2030
- ST2040: Sustainable Transition 2030
- DG2040: Distributed Generation 2040
- GCA2040: Global Climate Action 2040

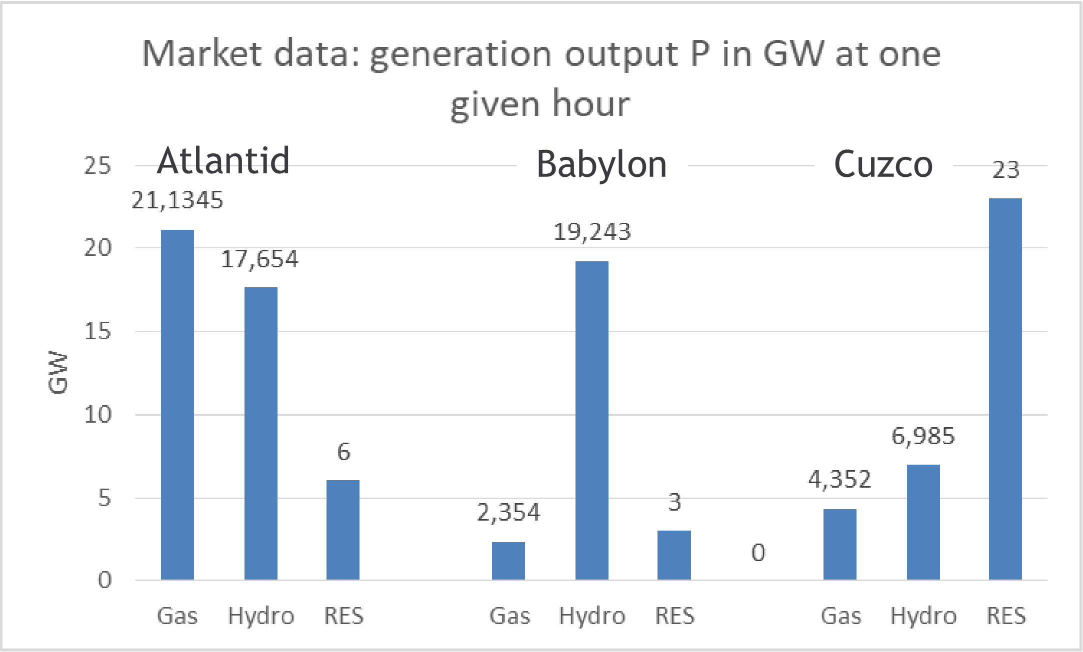
Methodology through a simple example (1/4)

Computation of running capacity Smax (MVA), Inertia H (sMW/MVA) and kinetic energy (MWs) by market zone and by hour

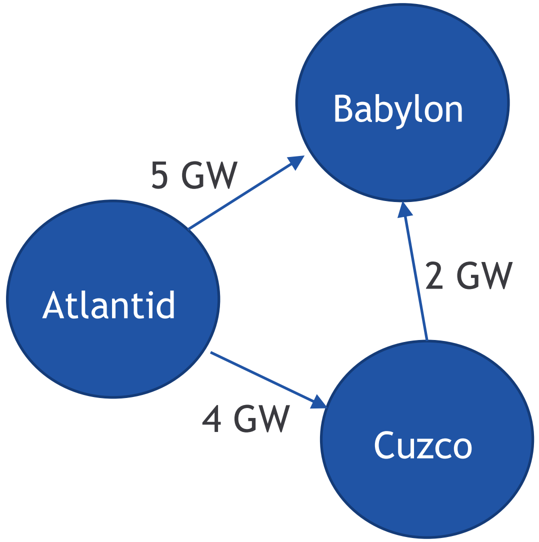
Input 1: TYNDP 2018 market data

For each hour the market simulation provide generation output in MW by market zone and by fuel type and power flows between market zones:

Example: 3 fuel types: Gas, Hudro, RES (wind and PV), 3 market zones: Atlantid, Babylon, Cuzco



Market data: power flow exchanges at one given hour



Methodology through a simple example (2/4)

Computation of running capacity Smax (MVA), Inertia H (sMW/MVA) and kinetic energy (MWs) by market zone and by hour

Input 2: all TSOs provided by country and fuel type

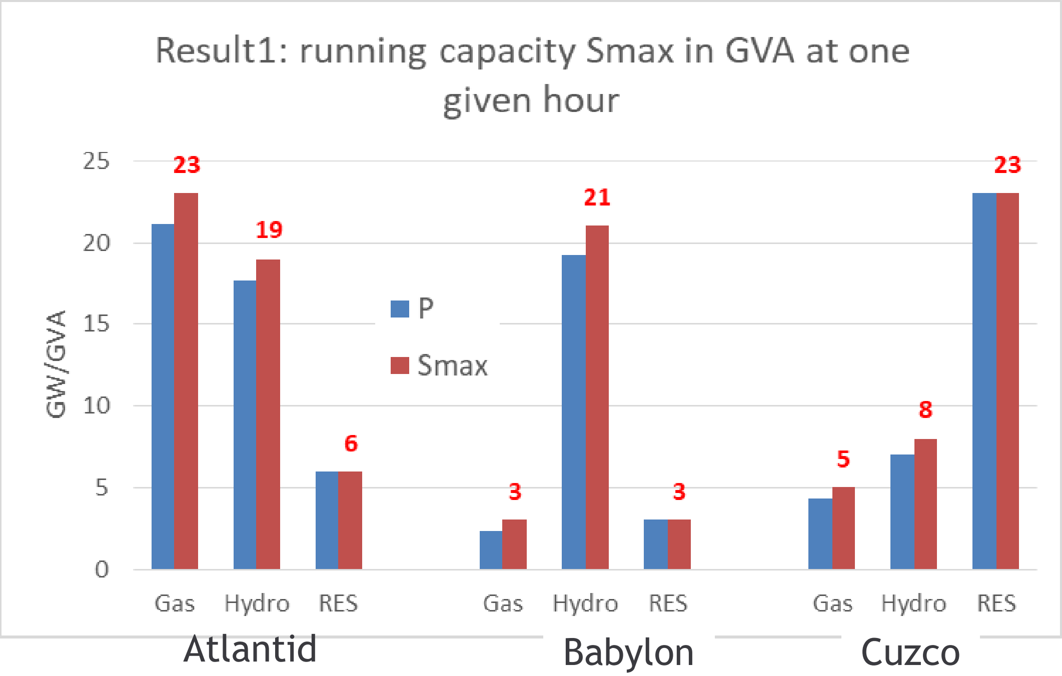
- Inertia (H in sMW/MVA),
- average size (in MVA)
- typical loading factor

Generator Technology Type	Max Loading	Average Rated Capacity	Average Inertia Constant
Fuel Type			
Nuclear	1	868,7	6,0
Lignite old 1	0,95	228,2	4,2
Lignite old 2	0,95	320,4	4,0
Lignite new	0,95	390,4	3,7
Lignite CCS	0,95	300,6	3,6
Hard Coal old 1	0,95	315,2	3,8
Hard Coal old 2	0,95	293,7	3,9
Hard Coal new	0,95	558,2	4,6
Hard Coal CCS	0,95	276,4	4,2
Convent. Gas old 1	0,95	156,3	3,9
Convent. Gas old 2	0,95	220,3	3,9
CCGT old 1	0,95	139,0	4,2
CCGT old 2	0,95	222,9	4,4
CCGT new	0,95	296,0	5,6
CCGT CCS	0,95	129,9	4,8
OCGT old	0,95	88,9	3,7
OCGT new	0,95	91,4	3,9
Light oil	0,95	114,6	4,2
Heavy oil old 1	0,95	274,6	4,5
Heavy oil old 2	0,95	129,2	4,2
Oil shale old	0,95	69,5	4,0
Oil shale new	0,95	175,3	4,5
Run-of-river (turbine)	0,95	16,5	2,8
Pump Storage Annual (pump)	0,95	139,4	3,5
Pump Storage Annual (turb.)	0,95	69,3	4,0
Pump Storage Daily (pump)	0,95	186,0	3,1
Pump Storage Daily (turb.)	0,95	208,1	4,2
Pump Storage Weekly (pump)	0,95	129,0	3,1
Pump Storage Weekly (turb.)	0,95	109,5	3,5
Swell RoR & Daily Stor. (turb.)	0,95	39,7	2,7
Battery Storage charge (load)	0	0,0	0,0
Battery Storage discharge (gen.)	0	0,0	0,0
Wind Onshore (MW)	0	0,0	0,0
Wind Offshore (MW)	0	0,0	0,0
Solar Photovoltaic (MW)	0	0,0	0,0
Solar Thermal	0	0,0	0,0
Others renewable	0,95	67,7	3,7
Others non-renewable	0,95	103,7	3,7
Lignite biofuel	0,95	150,0	5,0
Hard Coal biofuel	0,95	188,6	4,0
Gas biofuel	0,95	200,0	5,5
Light oil biofuel	0,95	200,0	1,6
Heavy oil biofuel	0,95	134,7	2,2
Oil shale biofuel	0,95	200,0	1,6

Result 1: Smax by market zone and by hour

Ex.: running capacity at one hour

- Atlantid: 48 GVA
- Babylon: 27 GVA
- Cuzco: 36 GVA



Methodology through a simple example (3/4)

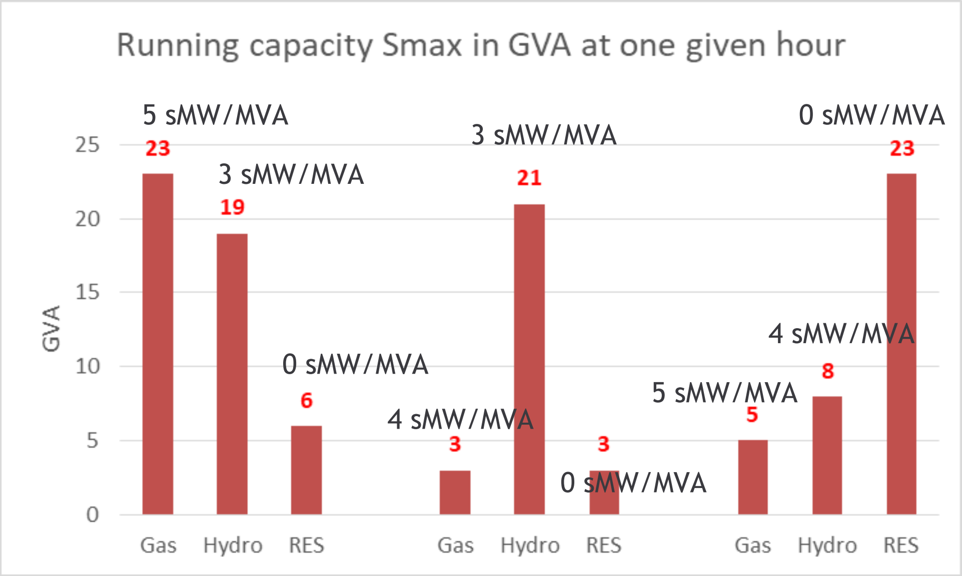
Computation of running capacity Smax (MVA), Inertia H (sMW/MVA) and kinetic energy (MWs) by market zone and by hour

Result 2: Inertia H and kinetic energy by market zone and hour

- H=barycentre of H weighted by Smax
- Kinetic energy E_k=H.Smax (in MWs)

Ex.: inertia, Smax and kinetic energy Ek at one given hour

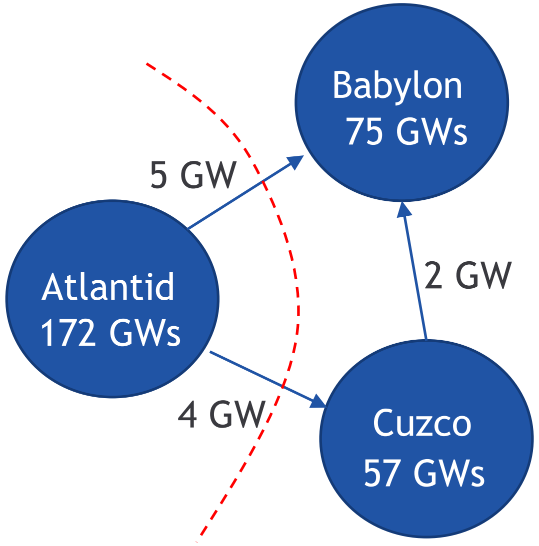
- Atlantid: E_k=(5*23+3*19)=172 GWs Smax= 48 GVA H=+3.6 sMW/MVA = 172/48
- Babylon: E_k= (4*3+3*21)= 75 GWs Smax= 27 GVA H=+2.8 sMW/MVA = 75/27
- Cuzco: E_k= (5*5+4*8)= 57 GWs Smax= 36 GVA H=+1.6 sMW/MVA = 57/36



Methodology through a simple example (4/4)

Computation of imbalances (MW) and RoCoFs (Hz/s) by system split, market zone and by hour

Market data: power flow exchanges at one given hour



RoCoF (A/BC)=(50/2).(9/172)=1,3 Hz/s
RoCoF (BC/A)=(50/2).(-9/132)=-1.7 Hz/s

Result 3: Computation of the **possible system splits** in two sub-systems (457 possible splits for 20 nodes) and the **imbalances**:

Ex.: imbalances

- Split Atlantid/B+C: +9000 MW
- Split Babylon/A+C: -7000 MW
- Split Cuzco/A+B: -2000 MW

Result 4: RoCoF by subsystem then by market zone (single busbar model, instantaneous response)

$$RoCoF\left(\frac{Hz}{s}\right) = \frac{50\ (Hz)}{2H\ (sMW/MVA)} \frac{Imbalance\ (MW)}{Smax_{subsystem}(MVA)} = \frac{50\ (Hz)}{2} \frac{Imbalance\ (MW)}{E_k(MWs)}$$

RoCoF at one given hour	Atlantid	Babylon	Cuzco
Split Atlantid/B+C	+1.3 Hz/s	-1.7 Hz/s	-1.7 Hz/s
Split Babylon/A+C	+0.8 Hz/s	-2.3 Hz/s	+0.8 Hz/s
Split Cuzco/A+B	+0.2 Hz/s	+0.2 Hz/s	-0.9 Hz/s

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Limitations and advantages of the approach

In real life:

- **System splits never follow the borders of market zones** and a split within a country may be **worse than the hypotheses** considered;
- The **RoCoF close to the disturbance** can be significantly **higher than the single busbar** model **approximation**, the approach is then also optimistic;
- The **impact of a system split** does not only depend on the instantaneous response. Other **frequency response controls** (LFDD, generators protections, other fast frequency response systems…) play a major role in the **containment or aggravation** of the frequency instability. Nevertheless, if the RoCoF is too high the controls do not have the time to react, notably due to the minimum time required for measurement.
- The probability of a system split is very low ;however, the system split events of 2003, 2006 and 2021 demonstrate that the real probability of such an event is not negligible. In the approach, **the probability of such an event is not considered, only the different possibilities and there consequences are studied**.

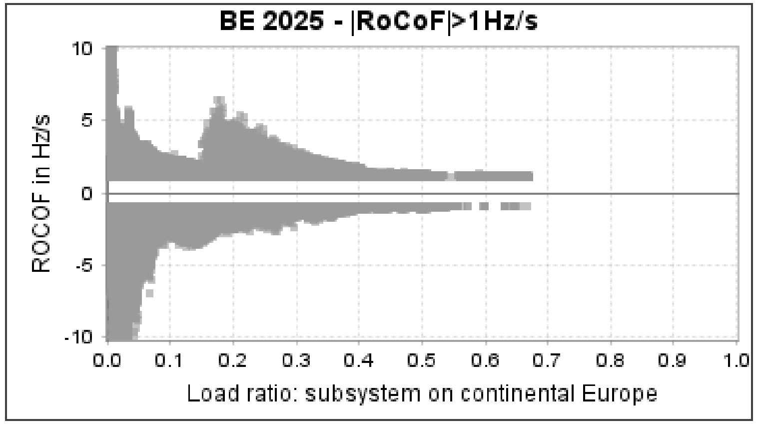
The benefit of a simplified approach first lies in a broad view on the phenomenon and its evolution, not possible with more detailed modelling:

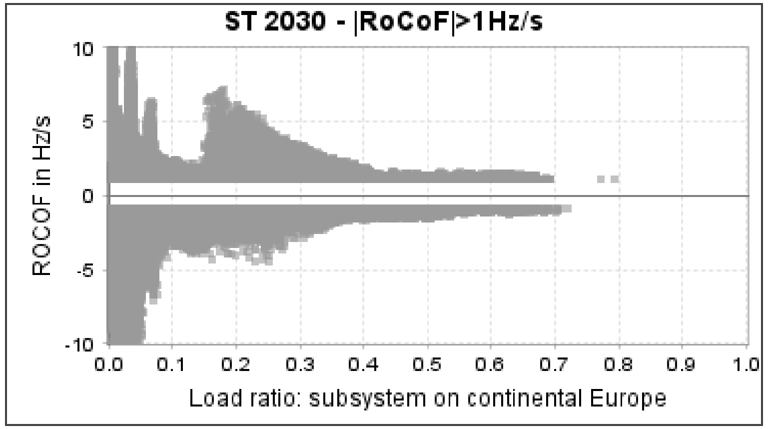
- 6 scenarios of TYNDP2018 (BE 2025, ST2030, ST 2040, DG 2030, DG 2040 and GCA 2040)
- 457 system splits
- In total, 24 million situations (scenarios x system split x hours)

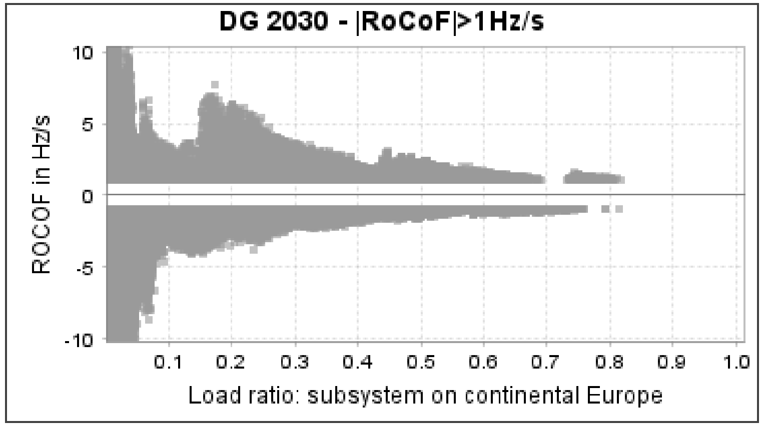
Despite the approximations, the approach captures the main drivers and the evolution of the phenomenon.

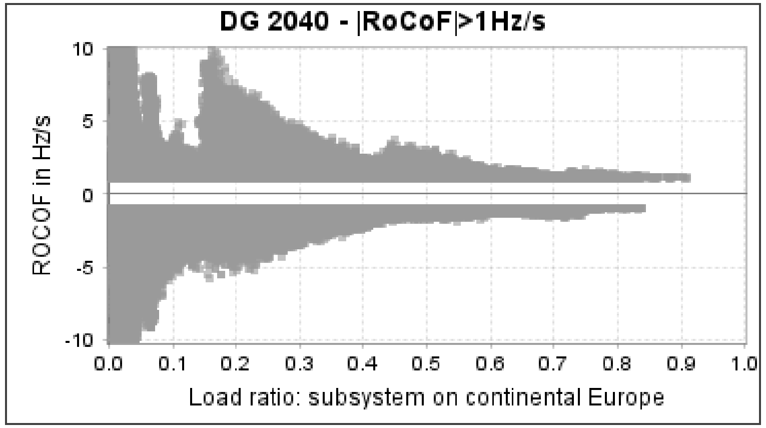
From the quantitative results, further discussion can take place on the level of risk and the mitigation actions

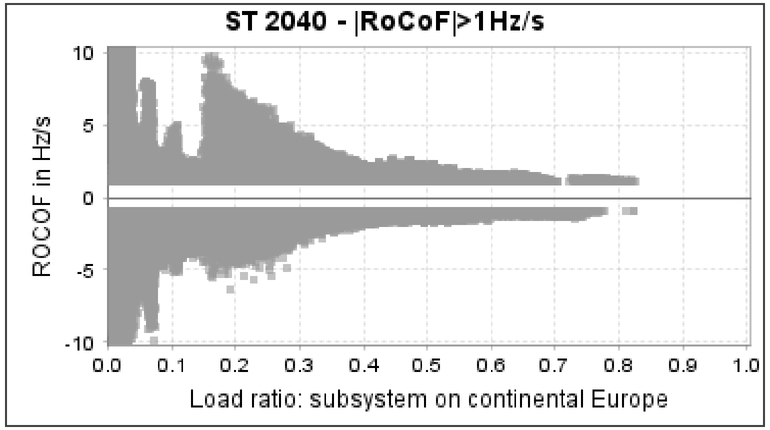
Subsystem RoCoF wrt load ratio: potentially unmanageable cases

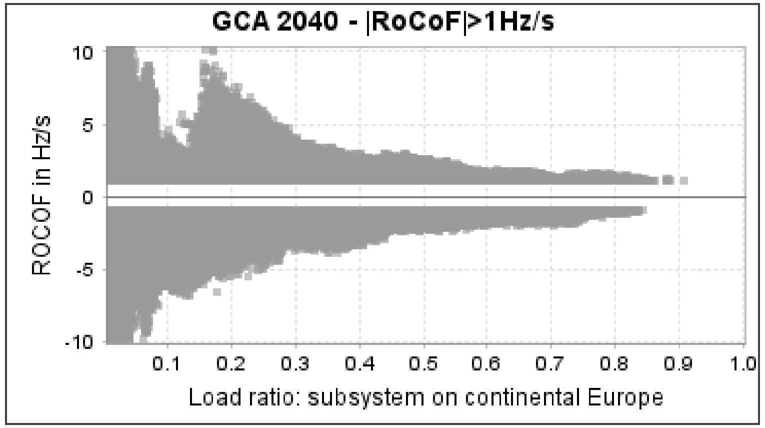






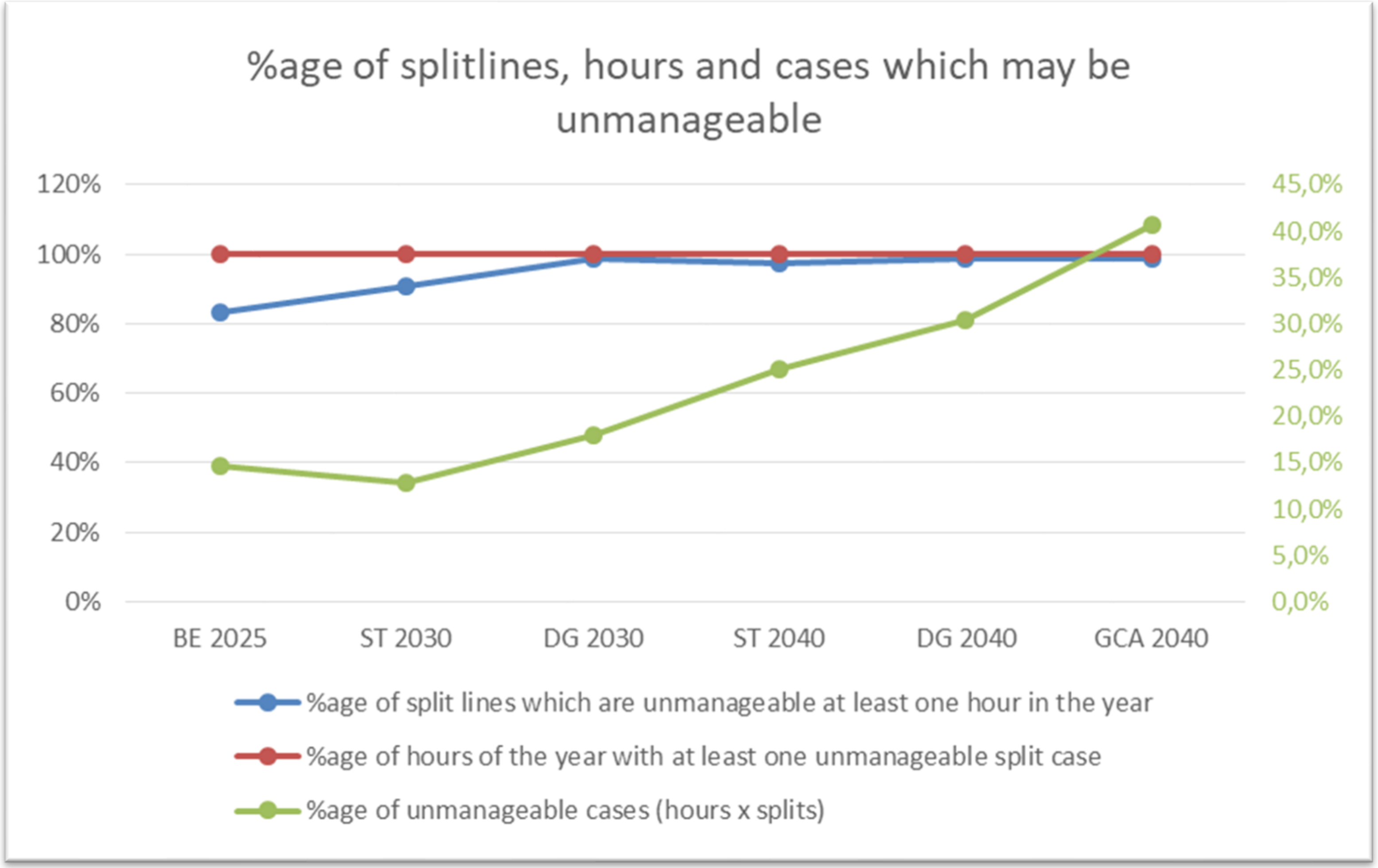






- The highest RoCoFs are related to smaller subsystems
- From 2025 to 2040 there is a RoCoF increase for all sizes of subsystems, an increasing size of the subsystems exposed to |RoCoF|> 1 Hz/s and more cases exceeding |RoCoF|> 1
- **In 2040, 3 times more cases (case= one hour and one split) create RoCoFs higer than 1Hz/s**

Subsystem RoCoF wrt load ratio : potentially unmanageable cases

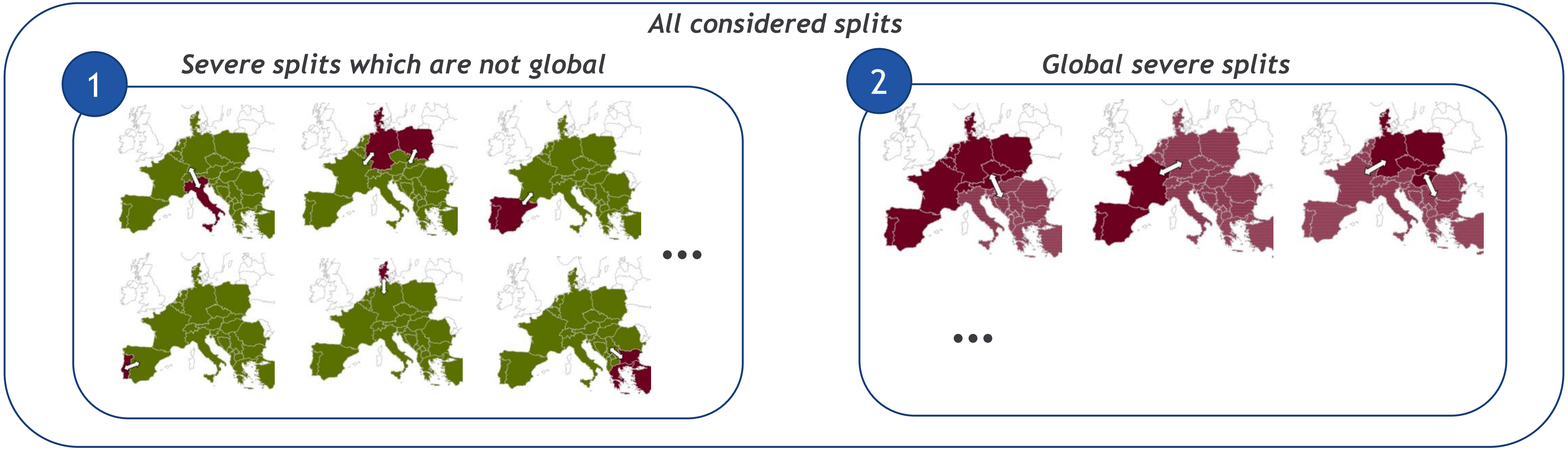


The red line at 100% shows that at any hour of the year at least one split can be unmanageable (RoCoF higher than 1Hz/s)

The blue line between 80% and 100% indicates that almost all splits can be unmanageable at least one hour of the year

The green line means that on all of the 3 800 000 cases (hours x splitlines) from 13% to 41% can be unmanageable depending on the scenario and time horizon

Digging further: The *global severe splits* approach allows a focus on the split cases that affect everyone in the Continental Europe system



System splits that could lead to a RoCoF > 1 HZ/s in one subsystem (red)
- A partial blackout could occur in the CE system

Global severe splits could lead to a RoCoF > 1 HZ/s in both subsystems
- A blackout could occur in the entire CE system

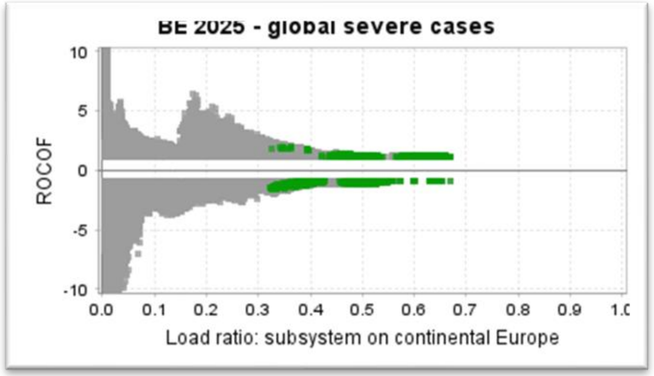
- Global severe splits represent only a subset of the total challenge, but provide visibility to the global scale of the issue
- Severe splits which are not global are also relevant

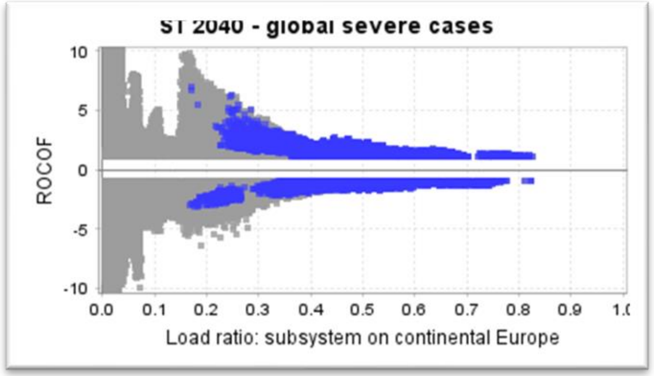
RoCoF WRT load ratio : global severe splits

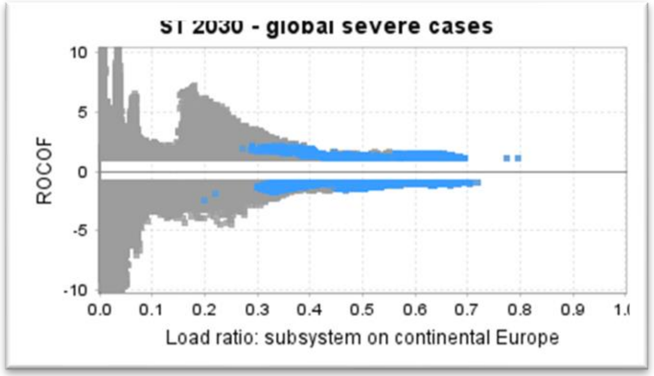
Global severe splits: both island with a |RoCoF| higher that 1 Hz/s. Potential risk for CE blackout

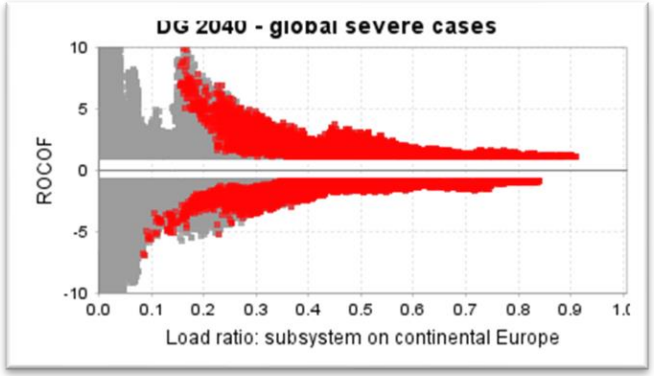
- The **number of cases is much lower than unmanageable cases** but the **consequences are much more serious** (Continental Europe blackout) and the numbers are still significant
- In GCA2040, all the splits isolating more than a third of the CE are globally severe, meaning they would affect the whole CE

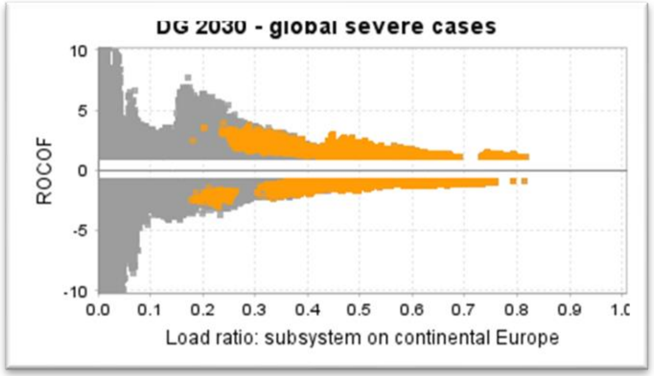
Each global severe case corresponds to two dots: each of the two dots relates to one of the two split subsystems, showing its load ratio and RoCoF for one specific hour and one system split. Obviously, the two load ratios are complementary to 1 and the RoCoF are of opposite sign.

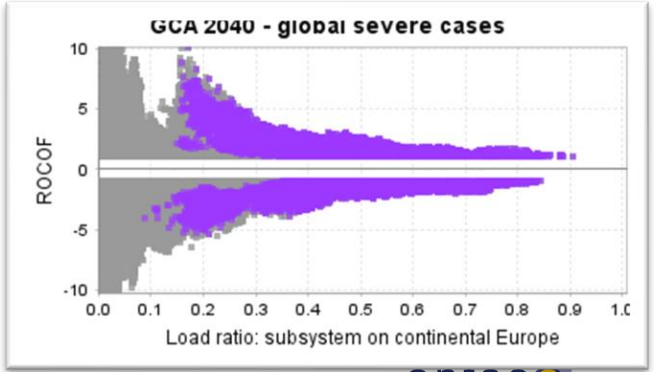




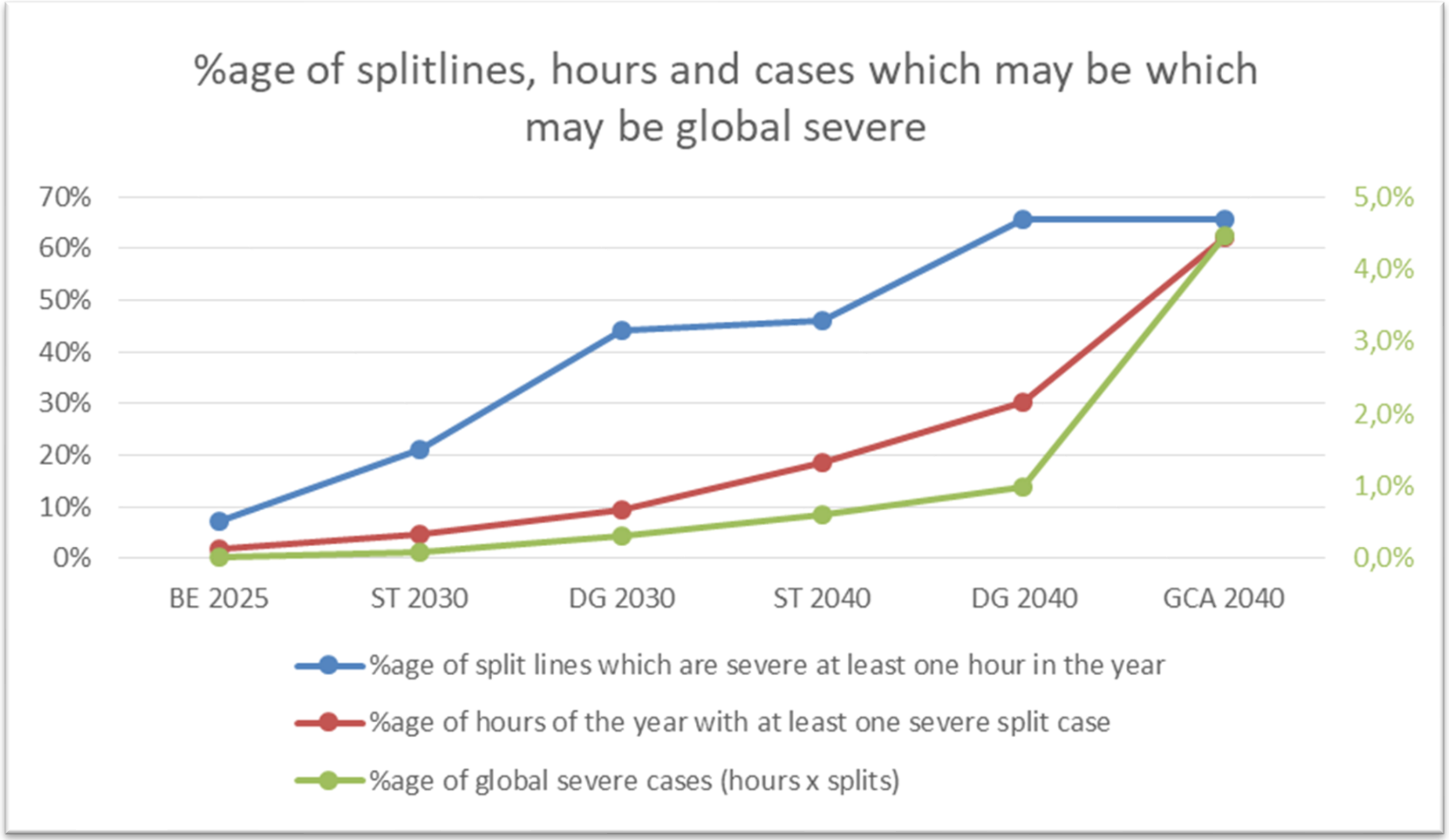








RoCoF WRT load ratio : global severe splits



The red line shows that from 2% to 62% of the hours of the year at least one split can be global severe depending on the scenario and time horizon

The blue line indicates that from 7% to 66% of splitlines can be global severe at least one hour of the year depending on the scenario and time horizon

The green line means that on all of the 3 800 000 cases (hours x splitlines) from 0% to 4% can be global severe depending on the scenario and time horizon

How to address the challenge?

OPTIMAL SET OF SOLUTIONS AND APPROACHES TO BE ASSESSED IN FUTURE STUDIES

Not a single solution: several measures should be considered and weighed

Provide additional inertia by renewable energies and battery storages (the precondition are grid forming and energy storage)

Provide additional inertia through STATCOM (the precondition are grid forming and energy storage), synchronous condenser or market-based procurement

Measures to **avoid a system split** (e.g. grid reinforcement, increased use of DC technology)

Countermeasures to **mitigate the effects of the system splits** (e.g. Special Protection Schemes, …).

As a last resort: **Market restrictions** as reduction of the power exchange or must run

Main conclusions

The assessment demonstrates that the **challenge posed by the decreasing level of inertia exists and, in the case of global severe splits, might involve the entire CE synchronous area.**

To cope with this challenge, different solutions should be assessed for the future system. **The installation of additional inertia is only one of the solutions.**

Making the system stronger against the impact of these events would mean implementing, even in the current planning phase of European grid, additional measures to **increase the robustness of the system** (infrastructure development and protection systems).

The decision on what is the 'acceptable' risk is not for the TSOs only, but involves all the stakeholders, industrial and institutional.

Possible follow up of the study and synergies with Planning processes

The work developed in the project "Long term frequency stability scenarios" is just a first step

What's next?

Continuing the investigation of the issue and identification of relevant steps in relation to the operation and development of the power system

- Assessment of the risks of a system split (updating the input data with the one from more recent TYNDPs)
- Evaluation of the most appropriate set of solutions to cope with the consequences of a system split

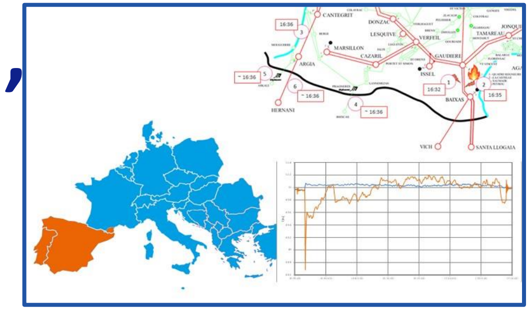
How does ENTSO-E plan to use this study?

The IoSN already include in its package an assessment of system dynamic and operational challenges. ENTSO-E is discussing how to integrate the work performed in the TYNDP with the methodologies and results developed in the framework of Project Inertia.

System split 24 July report and RoCoF conclusions Analysis of VGB's questions and replies

ENTSO-E: Walter Sattinger

Report on the 24 July 2021 system separation in Spain, parts of France from CE synchronous area



Internal Task Force

- An **internal ENTSO-E Task Force** has been created
- Task Force focused its efforts on gathering necessary data and concluding technical analysis
- ENTSO-E has published a factual report prepared by the Task Force on 12th November 2021

Expert Panel

- Since it is an ICS Scale 2 incident, an **Expert Investigation Panel** consisting of TSOs, ACER and NRAs representatives has been established and the work commenced on 22nd October (press release)
- Expert Panel will prepare a final report on the incident, including recommendations and lessons learnt
- The interim report prepared by internal ENTSO-E Task Force will be the bases for Expert Panel's work
- The final report shall be published in **first quarter of 2022**

24 July
Day of the incident

26 July
Task Force first meeting

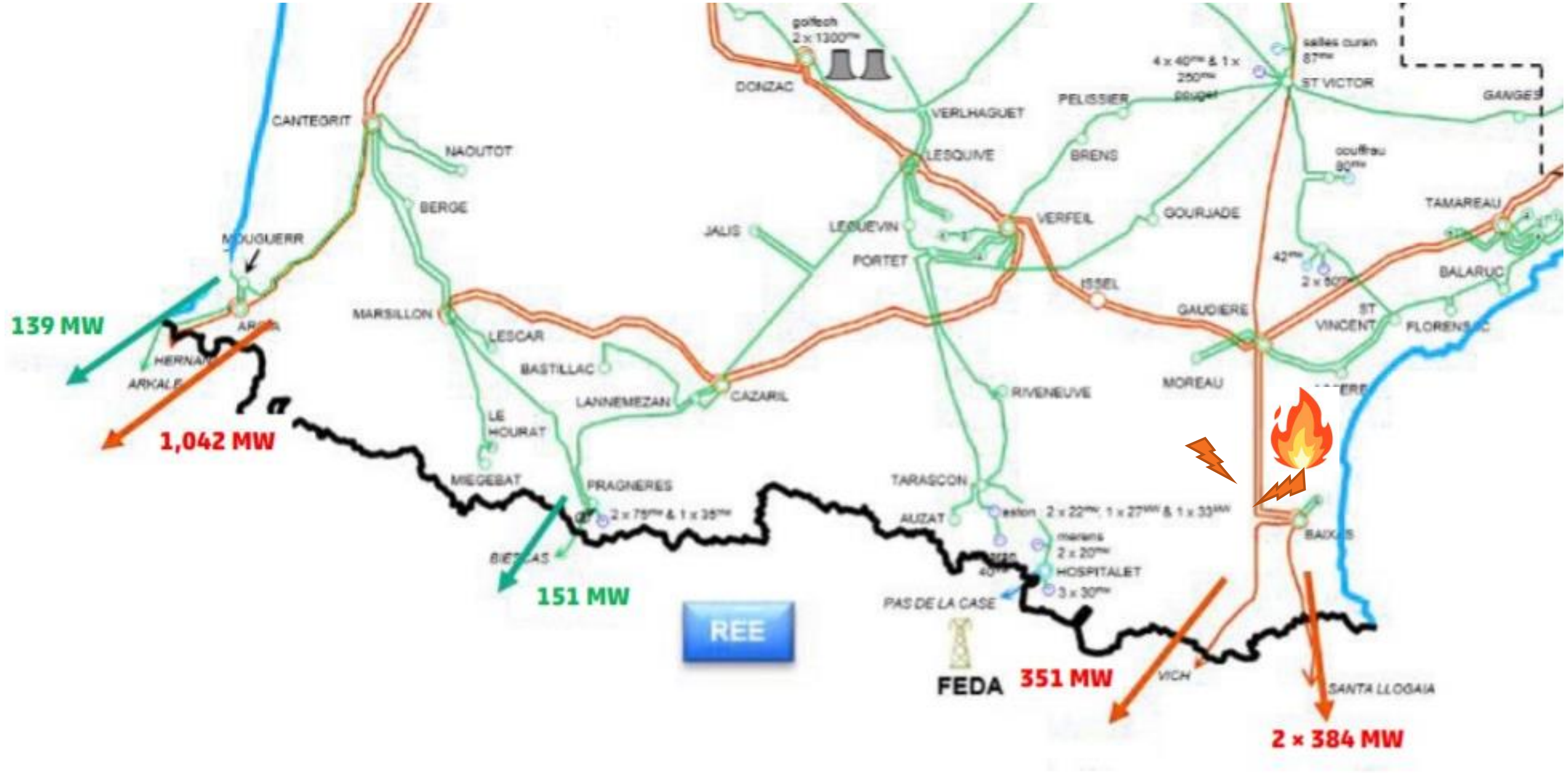
17 September
Completion of the technical analysis

22 October
Kick-off meeting of the Expert Panel

12 November
Publication of interim report

Q1 2022
Publication of final report

EVOLUTION OF THE SYSTEM CONDITIONS DURING THE EVENT



- On 24 July 2021 ca. 13:30, a severe fire broke out in the South of France.
- At first, RTE was not informed about the fire.
- From the start of the fire to the first line trip, at 16:33, RTE was not aware of the fire. **During this phase, the usual system operation rules were applied.**

- Power was flowing from France (FR) to Spain (ES), in line with the day-ahead and intra-day market scheduled exchanges and well below the calculated net transfer capacities.
- At 16:30, physical exchanges between FR and ES reached 2,451MW from FR to ES, distributed across two 220kV interconnection lines, two 400kV and two HVDC links. The eastern interconnection accounted for 1,119MW.
- The power plan productions and the load consumptions matched the forecasted values. There were no planned outages or dangerous power flows in grid elements in the surrounding area.

EVOLUTION OF THE SYSTEM CONDITIONS DURING THE EVENT

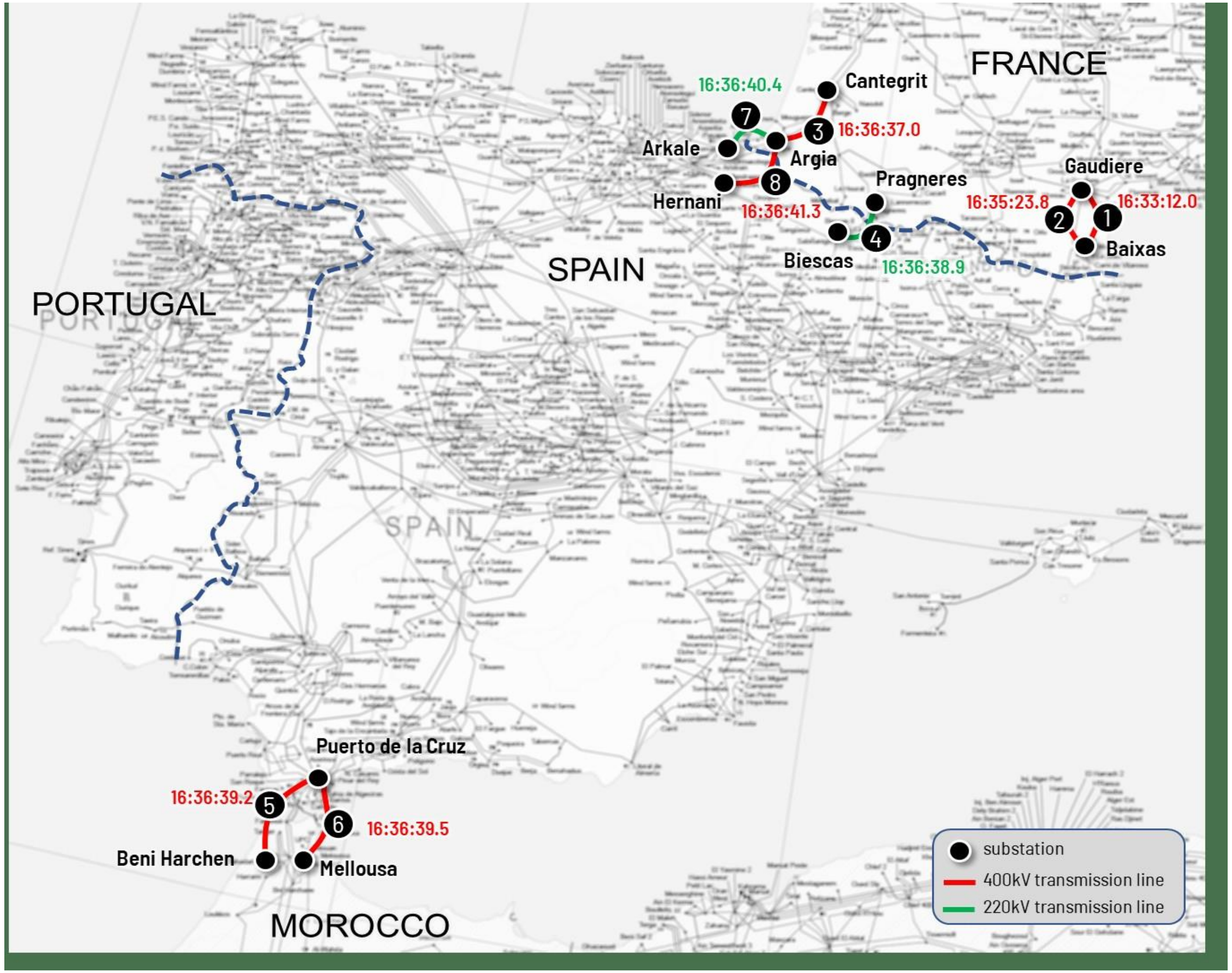
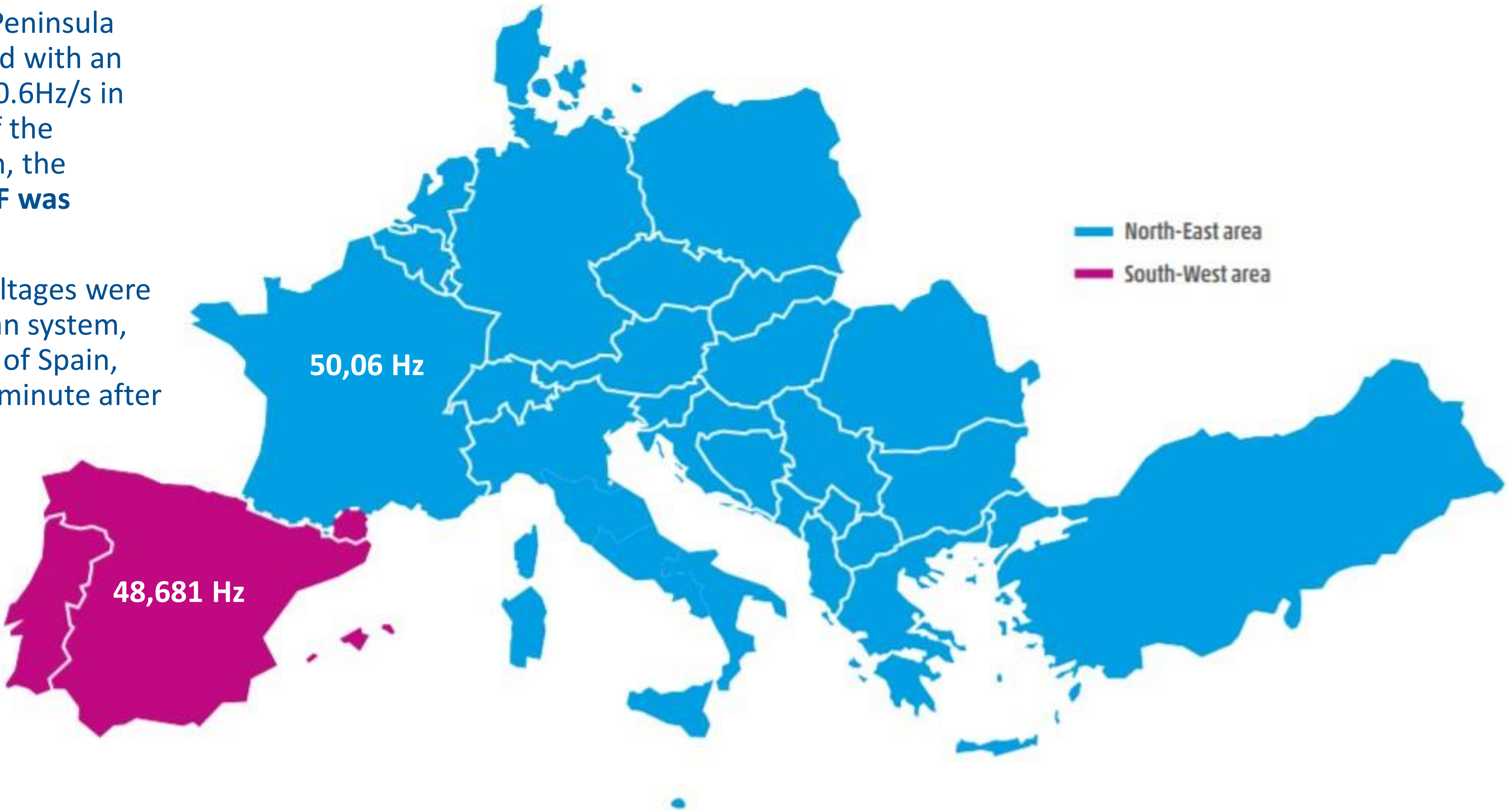


Figure 10: Geographical location of main tripped transmission system elements

- At 16:33:11 the wildfire caused a two-phase short circuit on circuit 2 of the 400kV Baixas-Gaudière line -> tripping of the line at 16:33:12.
- RTE and REE ordered a reduction of **exchange from 2,500 MW** to 1,200 MW at 16:34. The system split took place before the reduction became effective.
- At 16:35:23, circuit 1 experienced a similar fault and tripped. The eastern corridor was lost.
- The loss of the eastern corridor caused the western (400 kV Argia (FR)–Cantegrit (FR) line at 16:36:37) and central interconnection corridors to overload.
- The third tripping represents the point of no return that caused a loss of synchronism between the FR and ES systems, with the last line opening at 16:36:41.

EVOLUTION OF THE SYSTEM CONDITIONS DURING THE EVENT

- The lowest frequency in the middle of the Iberian Peninsula was **48.681 Hz**, reached with an estimated ROCOF of −0.6Hz/s in the centre of inertia of the underfrequency region, the **maximum local ROCOF was −1.03Hz/s**.
- After the split over-voltages were registered in the Iberian system, especially in the north of Spain, reaching 451.2kV one minute after the split.
- In Spain and Portugal, a total, **4,872 MW of loads were shed**, 2,302MW of pumps disconnected, and 3,764 MW of generators disconnected.



PERFORMANCE OF THE PROTECTION SYSTEM DURING THE INCIDENT

- An analysis was conducted for each line to describe the type of fault, the acting time of the protection, and the estimated location of the fault by dedicated fault location devices.
- The analysis proves that all **line protections** acted according to their settings and **demonstrated their correct behaviour**. Particular focus is given to the protection against loss of synchronism, as part of the defence protection scheme implemented by RTE and REE, that demonstrated the ability to protect the system, minimising the impact of disturbances.

FREQUENCY SUPPORT AND ANALYSIS

- The frequency deviation in the Iberian Peninsula was much higher than the predefined 200mHz**. Spain and Portugal activated the full amount of frequency containment reserve** within 30 seconds (380 MW and 50 MW, respectively).
- The activation of several manual frequency restoration reserves that took place only in Spain (REE is frequency leader), for a total requested power of 1,602 MW upward and 3,162 MW downward

COORDINATION ACTIVITIES BY THE REGIONAL SECURITY COORDINATOR

- The 5 services (CGM, OPC, STA, CCC and SA) were executed by Coreso in view of the incident with increasing timeliness of data without identifying any problems.
- No additional coordination or analysis services were provided by Coreso during or directly after the incident.
- The Critical Grid Situation Procedure was not triggered by TSOs.
- Some communication took place between Coreso, TSOs and RSCs regarding the frequency deviation and the resolution of the incident.

TSO-DSO COORDINATION – FREQUENCY PLAN AND LOAD SHEDDING

- The underfrequency condition on the Iberian Peninsula caused the activation of the first two load-shedding steps in Spain and Portugal, and the first load-shedding step in the southeast of France.
- To restore the generation – demand balance, **3,561 MW** were disconnected in Spain, **680 MW** in Portugal, and **65 MW** in France.
- Prior to the incident, **1,995 MW** of pumped storage were connected in Spain and **422 MW** in Portugal. Due to the underfrequency condition, all of them tripped (automatic disconnection) during the frequency drop.
- The details of the system defence plans of Portugal and Spain have been analysed, including **the unintentional loss of generation units** and loads.

RESYNCHRONISATION PROCESS

- The Iberian Peninsula frequency was gradually brought back close to 50 Hz by reconnecting loads previously disconnected in steps of 200 MW maximum each.
- **The reconnection was performed at 17:09 CET** by energizing the 400 kV Hernani (ES)–Argia (FR) line from Argia 400kV and synchronising from Hernani 400kV using its synchrocheck functionality.
- At the time of reconnection, the frequency difference was still large (218mHz), and therefore a power oscillation was observed for approximately 30 seconds with a frequency of 0.20Hz and an amplitude of 1,840 MW peak-to-peak.

N-1 SECURITY EVALUATION

- The analysis shows that the contingency analysis was rationally implemented and is well-tuned. **The N-1 security calculations performed by RTE, were in accordance to the valid legal framework (SO GL)**

COMMUNICATION OF COORDINATION CENTRES AND BETWEEN TSOs

- **Close coordination took place between RTE and REE.**
- Amprion (Germany) and Swissgrid (Switzerland) in their role as Coordination Centres North and South and in their role as Synchronous Area Monitor in Continental Europe were responsible for the procedures and coordinated countermeasures.
- They were **in contact with the affected TSOs** right after the separation and regularly throughout the entire event. They kept all other TSOs informed throughout the event.

entsoe answers

VGB POWERTECH

DEMAND FOR A MORE REALISTIC RATE OF CHANGE OF FREQUENCY (RoCoF) VALUE BASED ON RECENT SYSTEM SPLITS

ON 8 JANUARY & 24 JULY

GC ESC 22 SEPTEMBER 2021

Requirements in RfG NC regarding RoCoF

Art.13.1.b : With regard to the rate of change of frequency withstand capability, a power-generating module shall be capable of staying connected to the network and operate at rates of change of frequency up to a value specified by the relevant TSO, unless disconnection was triggered by rate-of-change-of-frequency-type loss of mains protection. The relevant system operator, in coordination with the relevant TSO, shall specify this rate-of-change-of-frequency-type loss of mains protection.

Comments by VGB:
This requirement has to take into account that some processes in a PGM will trip as a consequence of a too high RoCoF value. In several Member States the TSO has determined the RoCoF value without consensus / agreement from generators or consumers.

In the codes the withstand capability is defined. For system operation a limit which is smaller was specified too. Withstand limit = 2-2.5 Hz/s; CE power system operation limit = 1 Hz/s

Requirements in some Member States

According to the European Commission and FGH study dated February 2021

Value [Hz/s]	MS+	Number of MS+	Comments
0,5 (n/a for SW)	IS*	1	* Defined for type B and D
1 (for 0,5s)	GB, NIE, IE, 50549*	3	* EN 50549-1/-2, here SPGM
1,5 (for 1s)	NO	1	
2 (n/a for SW)	AT, DK	2	
2 (for 0,5s)	CZ, ES, HR, HU*, PL, SI, SK, FI, SE, PT, 50549**	10	* Defined for type B, C and D ** EN 50549-1/-2, here non-SPGM
2,5 (n/a for SW)	EE	1	
2,5 (for 0,5s)	HU*, LT, LV	3	* Defined for type A
2,5 (for 0,1s until 1s)	IT	1	
1,25 (for 2s) or 1,5 (for 1s) or 2 (for 0,5s)	DE, LU, NL, RO	4	
Over - and underfrequency profile	BE, GR	2	
n/a	CY, BA, BG, CH, FR, ME, MK, RS	8	

In the past, ENTSOE has explained several times that in IE the worst incident is a loss of generation, in Continental Europe (CE) a system split.

This should explain the difference between IE (1 Hz/sec) and CE (2 Hz/sec)

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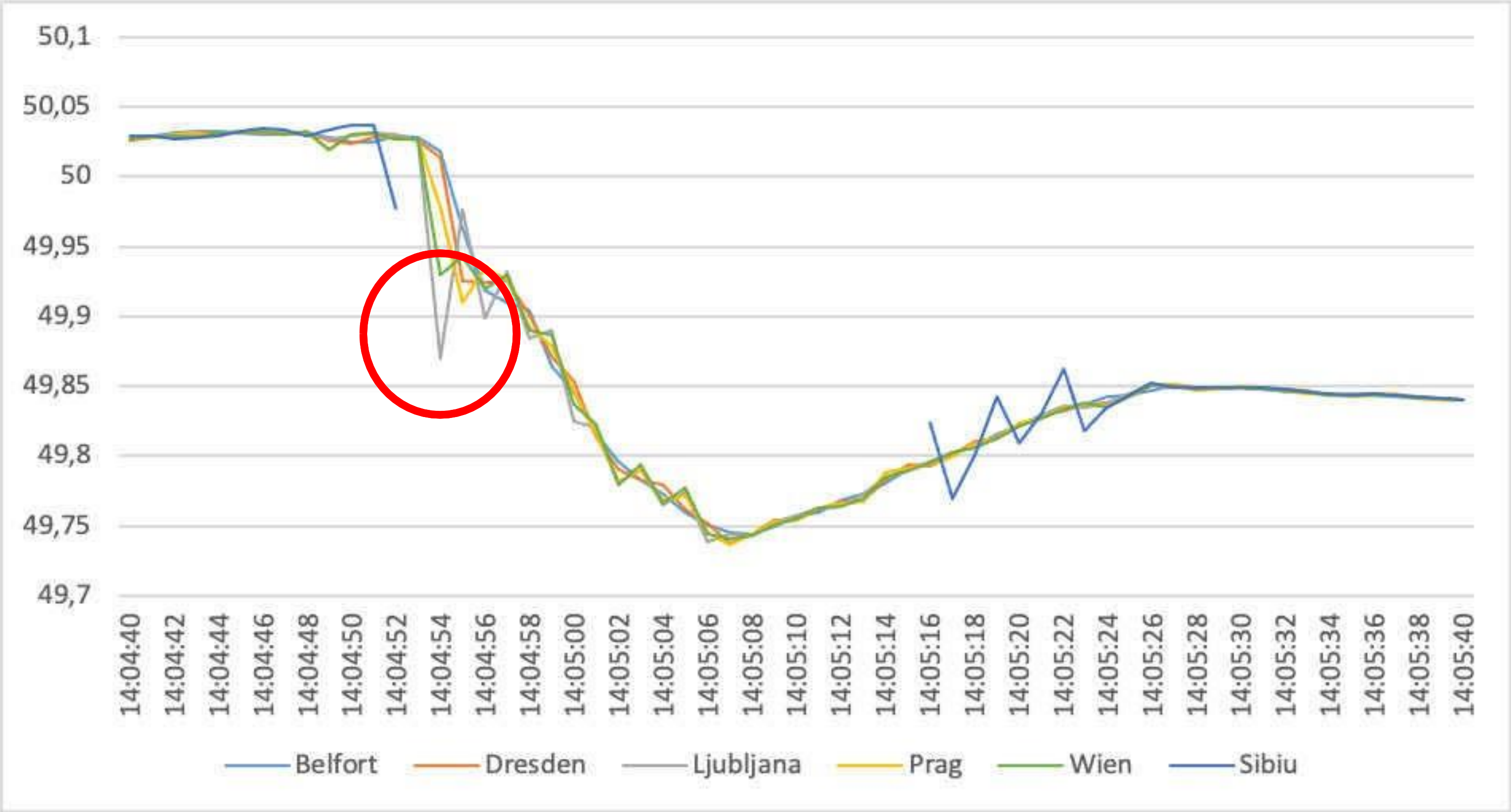
Frequency data on 8/1/2021 (according to www.gridradar.net)



Average RoCoF during 13 sec : 20 mHz/sec

Please be aware that these measurements are performed on the low voltage level (0.4 kV) with not certified measurement devices. However, the values are credible by comparing them with e.g. PMU measurements on the high voltage level (220 kV, 380 kV). While assessing RoCoF a few details are required, as:
a) accuracy of measurement
b) exact location of measurement - distance from centre of inertia c) time resolution, size of sliding window for RoCoF calculation

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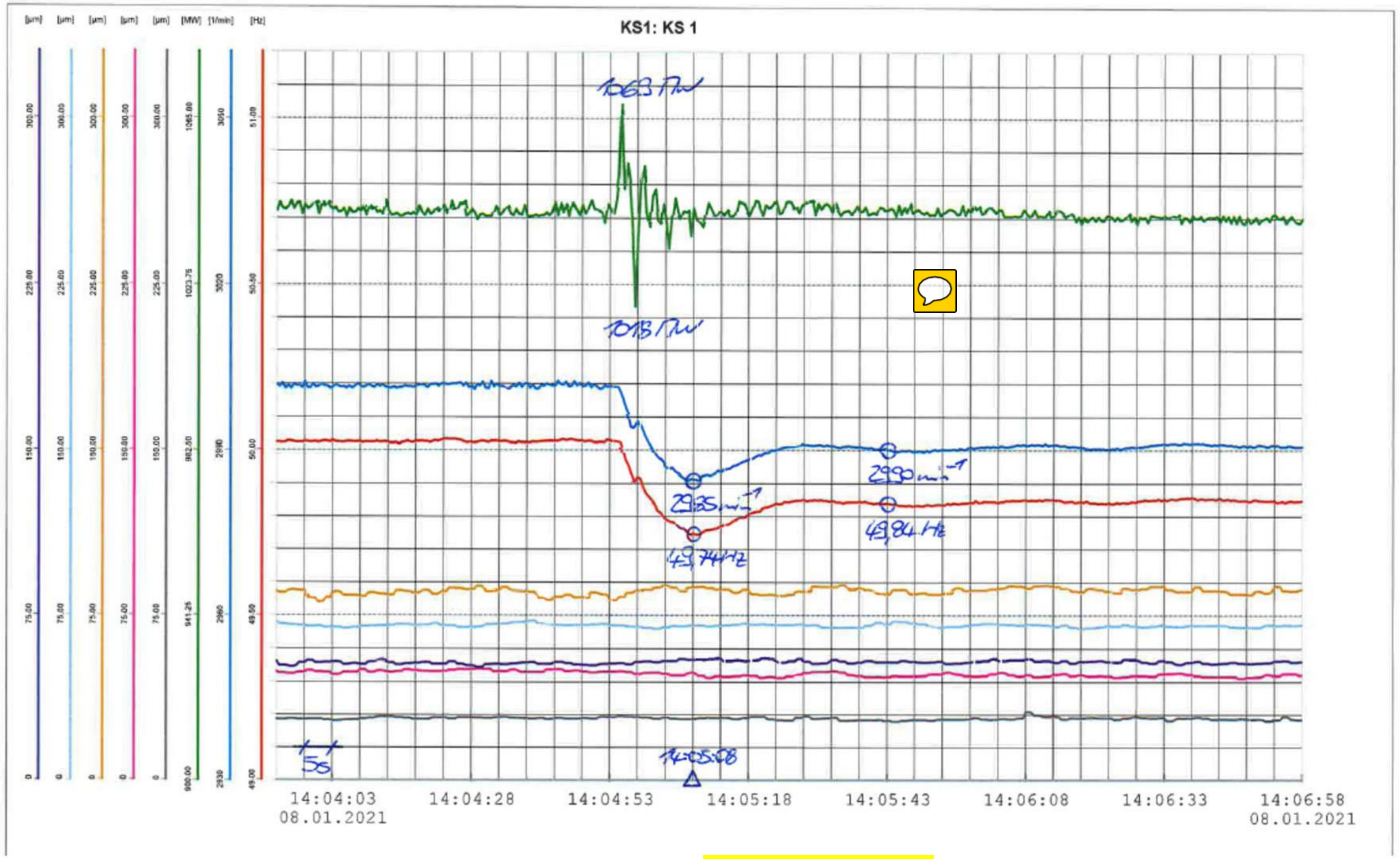
Frequency data on 8/1/2021 (registered at a Swiss power station)



Average RoCoF during 15 sec : 20 mHz/sec
Max RoCoF during 500 ms: 55 mHz/sec

This measurement and RoCoF estimation is much more better as the previous one and closer to the center of inertia - see related measurement result in the ENTSO-E report too. With other words this measurement does not contain as the previous one the effect of close to measurement local transients.

Some quotes from the final report (1)

On 15 July 2021, ENTSOE has published its final report about the system split dated 8 January 2021.
See https://eepublicdownloads.azureedge.net/clean-documents/SOC%20documents/SOC%20Reports/entso-e_CESysSep_Final_Report_210715.pdf

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3.2.1 Disconnection of generation units or loads close to the separation line due to high transients

*Due to the high transients of voltage and frequency, a significant number of generation units and industrial or domestic loads were disconnected in both areas. The detailed breakdown of generation and load disconnection by country is presented in Section 3.3. The RoCoF at the centres of inertia in the North-Western area was – 60 mHz / s and in the South-Eastern area + 300 mHz / s (RoCoF values are deduced from the frequency measured at the centre of inertia and is a mean value for the complete area). Both values were quite far from the **current considered critical** limit of 1 Hz / s (for higher RoCoF values most of the current devices and schemes which protect the power system are too slow to react).*

Correct, but locally, close to the separation line and the related high transients the there existent local RoCoF is much more higher - this effect was reproduced by dynamic model simulations and could also be proved by related measurements. In fact this was also the reason why along the separation line a certain number of generation units have disconnected exactly due to this reason.

Some quotes from the final report (2)

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RoCoF values of – 60 mHz / s and + 300 mHz/s were measured in the north-western and south-eastern areas, respectively. These values and related transients confirm the limit value of 1 Hz / s as a pragmatic sustainable RoCoF reference for the system. System separation events can serve as a valuable input to define normative incidents to be used in the dynamic system studies.

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Based on the recorded dynamic behaviour of the system it is observed that the RoCoF values after the separation were within the generation withstand capabilities. The event will be used to evaluate frequency stability evaluation criteria for Continental Europe and to verify the dynamic stability models.

Those values correspond to the centre of inertia! Local values might differ a lot!

These studies are ongoing and with the additional event from July 24th continued as in that case we have also observed a high number of not expected disconnections of generation units too.

VGB interpretation of the final report.

This report does not describe the consequences of a high RoCoF value on PGMs and consumers.

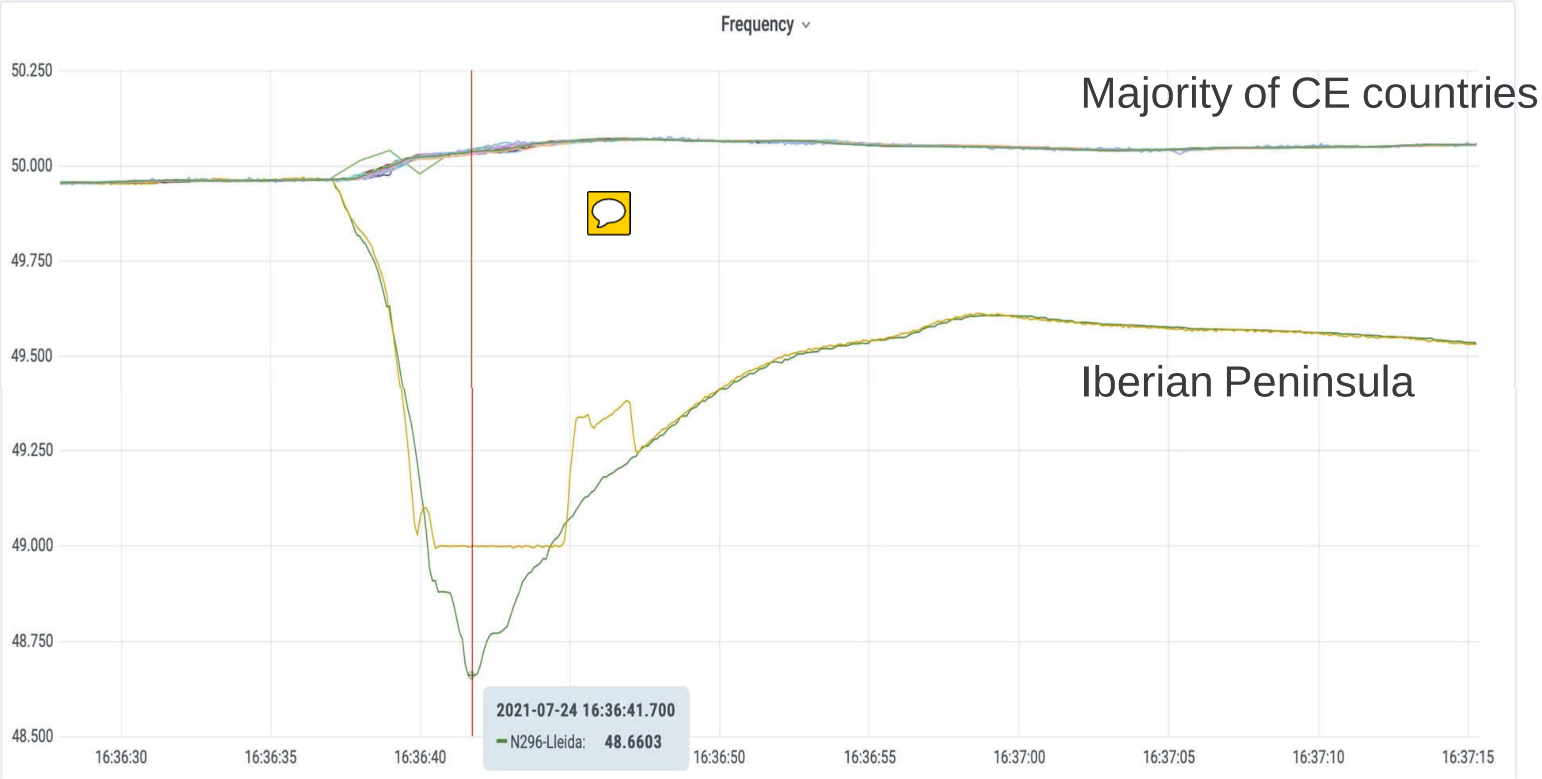
VGB experts are convinced that this report confirms a RoCoF withstand capability for grid users of 1 Hz/sec as appropriate.

A detailed analysis of the RoCoF is missing in the report.
More information is needed about:

- Technical details about the registrations of the frequency made by TSOs
- Specifications of the TSO's measurement equipment or processes to define the RoCoF including the size of the measuring window because 3 sizes of the measuring window considered in the requirements of Member States:
  0,5 sec / 1 sec / 2 sec (see FGH study slide).
- Any intention from ACER or ENTSOE to harmonise the measuring window. The FGH study mentions values of 0.5 sec, 1 sec and 2 sec.
  This is not an indication of a unique European level playing field for grid users.

Valid observation. However, we have to distinguish between RoCoF estimation: a) during operation, e.g. within protection equipment
b) dynamic model calculation results analysis
c) evaluation of measurements from different sources as WAMs, transient recorders etc.
c

Frequency data (according to www.gridradar.net)



Average RoCoF during 3,6 sec : 280 mHz/sec

See previous comments: measurement on low voltage level, not certified measurement equipment, unknown accuracy and time resolution - for qualitative assessment fine, but for qualified and professional use we have to agree on common accepted and verified tools and equipment.

Conclusions

The size of the sliding window (SW) of the frequency measurement in previous graphs is not specified.
Also in the ENTSOE report the size of the SW is not specified.

Recorded RoCoF figures in real life:

- \- 20 mHz/sec for the 8/1/ system split (average value over 13/15 sec)
- \- 60 mHz/sec and + 300 mHz/sec according to the ENTSOE report
- \- 280 mHz/sec for the 24/7 system split (average value over 3,6 sec) To compare with the 2000 mHz/sec requirement in some Member States

The huge difference between reality and requirement is not justified.

VGB asks for a detailed RoCoF analysis in all reports about system splits. This analysis should be used for a discussion in a GC ESC about a RoCoF requirement that is justified by experience and based on Recital 25 of RfG NC.

A sliding window of 500ms was used for the ENTSO-E reports for RoCoF estimation.

VGB proposal

To start a working group to solve following issues:

- To distribute frequency data around the moment of the system split
- To specify details for the frequency measurements usable for the definition of the RoCoF including the size of the measuring window or the mathematical procedure to define the RoCoF
- To specify if the above mentioned RoCoF definition is used in the ENTSO-E reports.
- To harmonise the measuring window. The FGH study mentions values of 0.5 sec, 1 sec and 2 sec. This is not a sign of a unique European level playing field for generating companies.
- To define an acceptable RoCoF for the CE synchronous area based on real criteria in collaboration with ALL stakeholders, especially the generating companies.

ENTSO-E (SPD) is open for all related discussions and clarifications.

Examples of RoCoF national implementations

ENTSO-E: Johannes Weidner

Executive Summary

Executive Summary – Motivation

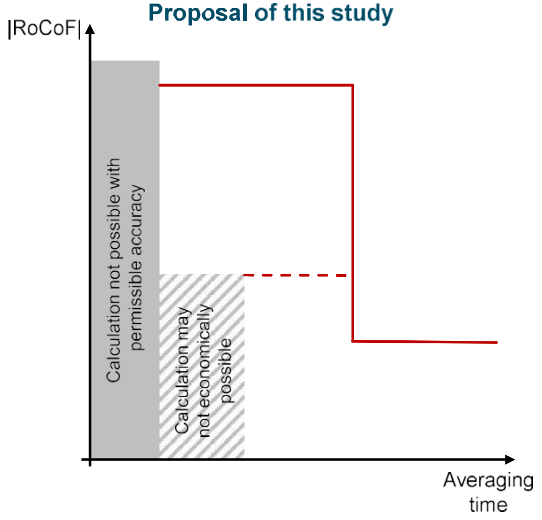
Development of the power plant portfolio and increasing load flows

- Shut-down of conventional power plants lead to a decreasing system inertia and thus to higher rate of change of frequencies in case of contingencies
- In these contingencies, grid users like wind farms must not prematurely disconnect from the grid because of the high RoCoFs, but rather manage higher RoCoFs for a certain time
- Measurements of the system split in January 2021 have shown that the ratio between the average RoCoF and local RoCoFs can go up to a factor of 6

Goals of the project

- ➢ Establishment of design-relevant system split configuration that meet specific criteria
- ➢ Deriving ratios between local and global RoCoF in the grid segments for the before defined cases
- ➢ Determining robustness requirements for generation units in regard to controllable RoCoFs

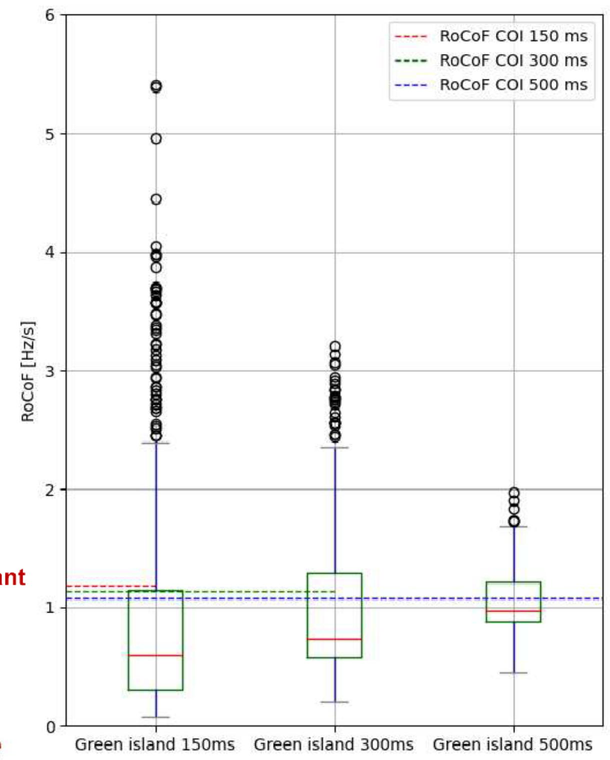
Source: entso-e



Executive Summary – Quintessence of the simulation results

- In total, three different European system splits have been investigated – one dimension-relevant case, an extreme scenario and the system split of the Iberian Peninsula of July 2021
- The dimension-relevant case has been determined with a global RoCoF of 1.07 Hz/s for an averaging time of 500 ms in the green island
- The investigation shows that the local RoCoFs can be many times over the global RoCoF
- For 150 ms averaging time window for the RoCoF calculation immediately after the system split, the ratio is
  - $^{RoCoF_{\max,150}}/_{RoCoF_{\mathrm{COI}}} = {}^{5{,}36}/_{1{,}18} = 4{,}54$
- For 500 ms the spread decreases significantly and the influence of the geographical distance to the split line is lower
- The ratio between the global and local RoCoF is
  - $^{RoCoF_{\max,500}}/_{RoCoF_{\mathrm{COI}}} = {}^{1{,}99}/_{1{,}07} = 1{,}85$

Results of the 1 Hz/s scenario

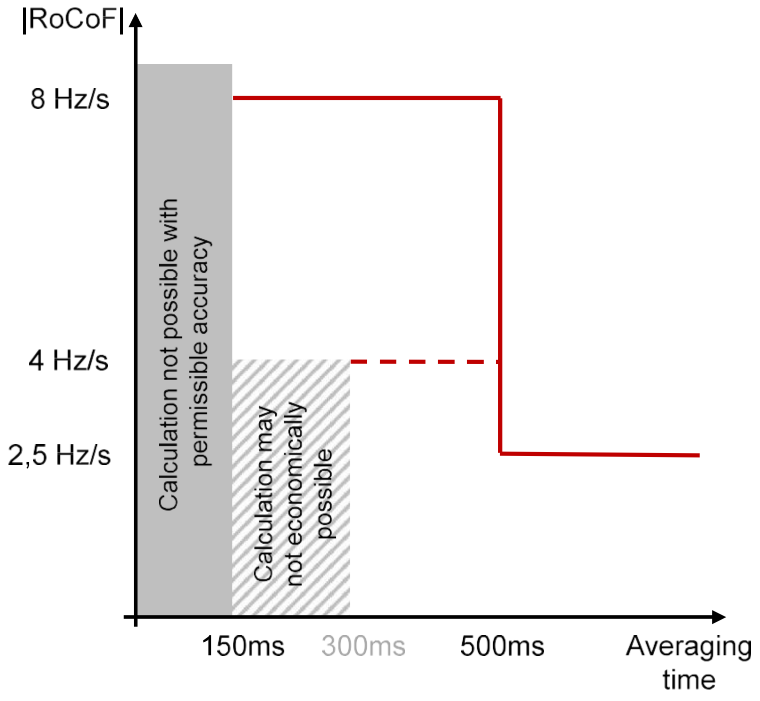


Proposed dimensioning-relevant system split

Executive Summary – Identification of robustness requirements for generation units

Generators should stay connected to the grid below the curve and not disconnect prematurely

- Proposed values according to the respective averaging times:
  - **150 ms: 8 Hz/s**; 300 ms: 4 Hz/s; **500 ms: 2,5 Hz/s**
- We propose a phased characteristic curve with the averaging times of 150 ms, as the technical shortest possible determination and 500 ms
- The proposed RoCoF values are based on the analyses of the three investigated scenarios. For a final decision on the values itself, a discussion with the manufacturers and operators is necessary



Executive Summary – Key results

Plausibility and model evaluation

- Global RoCoF (averaged over 500 ms) in the center of inertia in the dynamic model corresponds with the results from the analytical single point model.
- Both the validation against the analytical single point model and the validation against the system split scenario of the Iberian Peninsula prove that reliable results can be achieved with the enhanced dynamic grid model.
- The realistic system split scenario of the Iberian Peninsula in July 2021 was able to produce plausible results, which correspond to the real measured values.

Local vs. global RoCoF

- The frequency gradient at the center of inertia (global RoCoF) does not differ significantly in an averaging time window in the range of 150 ms to 500 ms.
- Local RoCoFs can be many times higher than the global RoCoF.
- Local RoCoFs differ significantly depending on the averaging time window (150-500 ms) and show a large dispersion, which decreases with increasing averaging time windows.
- Basically, the factor between local and global RoCoF increases with smaller averaging time window (also due to geographical extension).

Factors influencing the RoCoF

- Geographically closer measurement points to the edge of the system split have a higher local RoCoF than those further away. However, this difference decreases with increasing averaging time windows. When averaging over 500 ms, only a small scatter is observed, while this is particularly large when averaging over 150 ms.
- Even with larger power deficits and associated higher global RoCoFs, the factor between local and global frequency gradients remains of similar magnitude. The investigations therefore suggest that the findings obtained for the analyzed three scenarios with regard to the factors can also be qualitatively applied to other scenarios.
- When averaging over 500 ms, the spatial distribution of the RoCoFs has largely decayed and an approximately homogeneous distribution can be observed.

Questions and AOB

Thank you very much for your attention