» Continental Europe Synchronous Area Separation on 24 July 2021

Technical Report

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EXECUTIVE SUMMARY

On Saturday, 24 July 2021 at 16:36 CET, the Continental Europe Synchronous Area was separated into two areas due to cascaded trips of several transmission power system elements. Specifically, the Iberic Peninsula, comprising the systems operated by REE and REN, was separated from the rest of the Continental European power system. Immediately after the incident occurred, European TSOs started to resolve it, resynchronising the Continental European power system at 17:09 CET. Due to their fast, coordinated approach, no major damage was observed in the power system.

In the immediate aftermath of the system separation, European TSOs, in close collaboration through the ENTSO-E, decided to start a joint process to collect all relevant facts regarding the incident. This process was launched with the clear mission to deliver these facts to national and European authorities and ENTSO-E members as well as to any interested party in a transparent and complete way. This factual report presents the first collection of the gathered facts, while the incident is still under further investigation. The report is structured into several parts, which are briefly summarised on the next pages.

Environmental conditions before the incident

Section 2 describes the environmental conditions before the incident. The focus is on the severe fire that broke out in South France on 24 July at approximately 13:30 in the vicinity of two parallel 400 kV Baixas–Gaudière lines. RTE was not informed of the wildfire and therefore did not electrically isolate the affected area in a timely manner or consider the dangerous environmental conditions in their N-1 security evaluation. The double circuit represents a key corridor for the eastern interconnection between France and Spain, because it topologically links the French 400 kV system to the Spanish system through the 400 kV Baixas (FR)–Vich (ES) tie-line and from the Baixas (FR)–Santa–LLogaia (ES) HVDC interconnection link.

System conditions before the system separation

Section 3 gives details on the CE power system conditions before the system separation, with a focus on South West Europe and the three mainly affected TSOs: RTE, REE and REN. As regards cross-border flows, power was flowing from France to Spain, 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 France and Spain reached 2,451 MW from France to Spain, distributed across two 220 kV interconnection lines, two 400 kV and two HVDC links. In particular, the eastern interconnection accounted for 1,119 MW. 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.

Dynamic behaviour of the system during the event

Section 4 analyses the dynamic behaviour of the system during the event. First, it provides the details of the sequence of events that led to the system split. Specifically, at 16:33:11 the wildfire caused a two-phase short circuit on circuit 2 of the 400 kV Baixas-Gaudière line, in the vicinity of the Gaudière substation. The protection system detected the fault and responded correctly by opening the circuit breaker and tripping the line at 16:33:12. RTE and REE promptly ordered a reduction of exchange from 2,500 MW to 1,200 MW at 16:34; however, the system split took place before the reduction became effective. At 16:35:23, circuit 1 experienced a similar fault and tripped. The automatic reclosure of both circuits was unsuccessful; therefore, both circuits were out-of-service: the Baixas substation was separated from the rest of the French transmission system and the eastern corridor was lost.

The loss of the eastern corridor caused the western and central France–Spain interconnection corridors to become overloaded. These overloads caused the tripping of the 400 kV Argia (FR)–Cantegrit (FR) line at 16:36:37 due to overload protection. This third tripping represents the point of no return that caused a loss of synchronism between the French and Spanish systems, which subsequently led to the complete loss of interconnection between the two systems. Within four seconds, the rest of the tie-lines went out of service thanks to the loss of synchronism protections, with the last line opening at 16:36:41.

Section 4 further analyses the main dynamic stability criteria throughout the event. Already after the trip of the first 400 kV Baixas–Gaudière line, the remaining interconnection corridors between France and Spain became overloaded, and the voltage phase angle between France and Spain increased to values close to the stability margin of 90 degrees. The lowest frequency measured in the middle of the Iberian Peninsula was 48.681 Hz, which was reached with an estimated ROCOF of −0.6 Hz/s in the centre of inertia of the underfrequency region, while the maximum local ROCOF was −1.03 Hz/s. As regards voltage stability, after the split, over-voltages were registered in the Iberian system, especially in the north of Spain, reaching 451.2 kV one minute after the split.

Finally, this Section gives a general overview of the overall energy balance, considering automatic frequency restoration reserves that were correctly activated in Spain and Portugal, the manual frequency restoration in Spain, and the unintentional disconnections across the system. Specifically, in Spain and Portugal in total, 4,872 MW of loads were shed, 2,302 MW of pumps disconnected, and 3,764 MW of generators disconnected. In Spain and France, coil reactors and capacitors were also disconnected and reconnected. These key figures are supported by preliminary dynamic simulation results.

Performance of the protection system during the incident

Section 5 describes the performance of the protection system during the incident, analysing each of the seven high voltage lines that tripped. For each line, this section describes the type of fault that was detected, 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. The section illustrates the evolution of the signals during the transients as measured by digital fault recorders. 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

Section 6 describes the frequency support activated during the event. First, it provides details regarding the activation of frequency containment reserves (also known as primary control) that acted quickly enough and delivered the predefined power quantities. The frequency deviation in the Iberian Peninsula was much higher than the predefined 200 mHz; therefore, Spain and Portugal activated the full amount of frequency containment reserve within 30 seconds (380 MW and 50 MW, respectively). Then, this Section analyses the activation of automatic frequency restoration reserves (also known as secondary control) and the activation of manual frequency restoration reserves that took place only in Spain, for a total requested power of 1,602 MW upward and 3,162 MW downward between 16:29 and 17:30. Finally, Section 6 analyses the impact of regional coordination during the incident.

Resynchronisation process

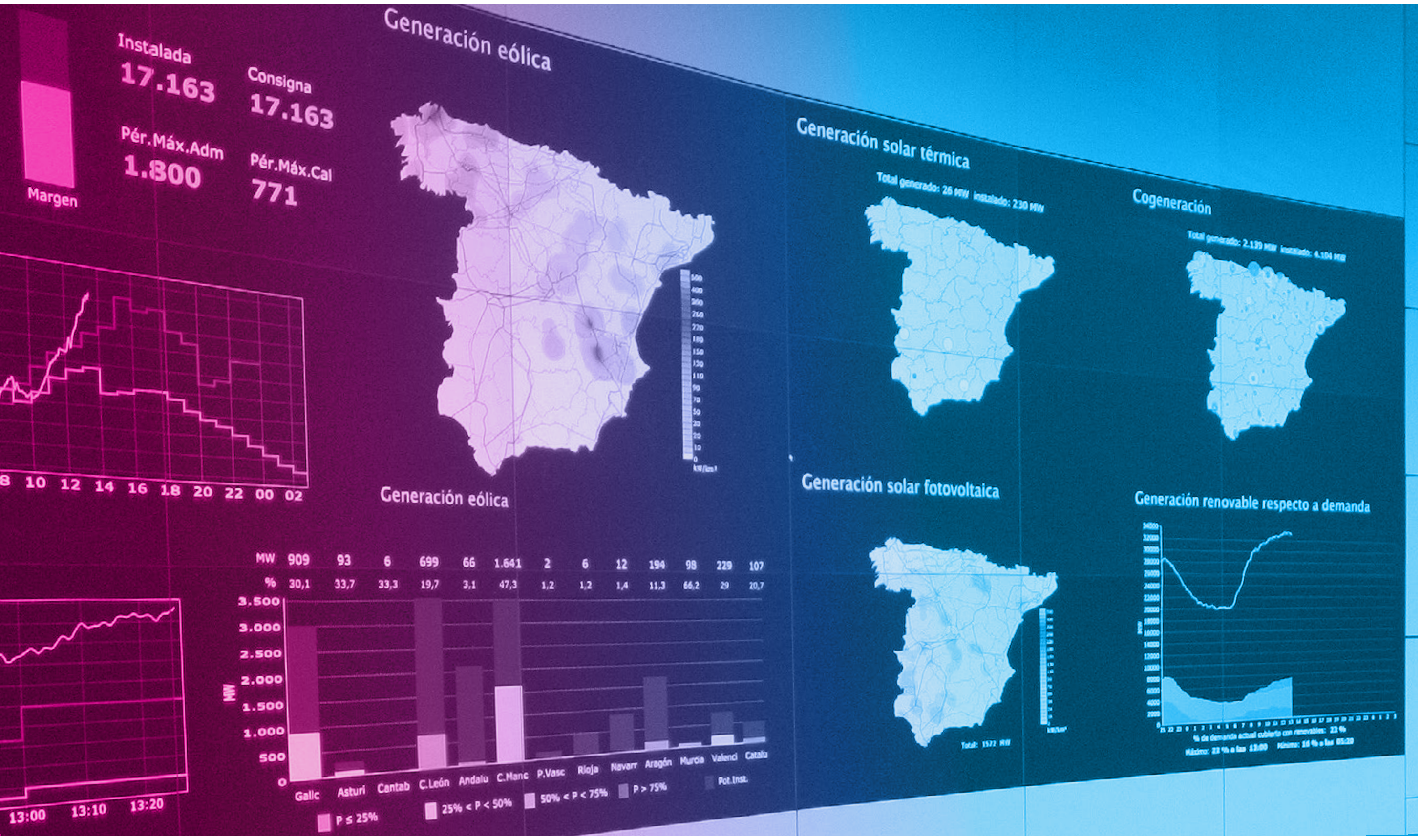
Section 7 describes the resynchronisation process. First, the Iberian Peninsula frequency was gradually brought back close to 50 Hz by reconnecting loads previously disconnected in steps of 200 MW maximum each. The reconnection was performed at 17:09 CET by energizing the 400 kV Hernani (ES)–Argia (FR) line from Argia 400 kV and synchronizing from Hernani 400 kV using its synchro-check functionality. At the time of reconnection, the frequency difference was still large (218 mHz), and therefore a power oscillation was observed for approximately 30 seconds with a frequency of 0.20 Hz and an amplitude of 1,840 MW peak-to-peak.

N-1 security evaluation

Section 8 evaluates the N-1 security calculations performed by RTE, according to the valid legal framework, i. e., the System Operation Guideline (SO GL). The analysis shows that the contingency analysis was rationally implemented and is well-tuned.

Communication of coordination centres/SAM and between TSOs

Section 9 describes communication of coordination centres/SAM and between TSOs. Throughout the event, close coordination took place between RTE and REE. Amprion (Germany) and Swissgrid (Switzerland) in their role as Coordination Centres (CCs) North and South, respectively, and in their role as Synchronous Area Monitor (SAM) in Continental Europe were responsible for the procedures and coordinated countermeasures. In other words, they were in contact with the affected TSOs (RTE and REE) right after the separation and regularly throughout the entire event. They also kept all other TSOs informed throughout the event.



Coordination activities by the regional security coordinator

Section 10 describes the coordination activities that were performed by Coreso/Brussels, the Regional Security Coordinator and the Coordinated Capacity Calculator of the South-West European Capacity Calculation Region. The section describes outage planning coordination, short-term adequacy assessment, day-ahead capacity calculation, day-ahead congestion forecast and intraday congestion forecast, and real-time snapshot calculations.

TSO–DSO Coordination – Frequency Plan and Load Shedding

Section 11 describes TSO–DSO coordination in terms of the frequency plan and load shedding. First, it provides the valid legal framework for the Low-Frequency Demand Disconnection scheme preparation, i. e., the network code on electricity emergencies and restoration. Then, it describes the TSO–DSO coordination after Low-Frequency Demand Disconnection scheme activation.

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 during the frequency drop.

Finally, this Section provides the details of the system defence plans of Portugal and Spain, including the unintentional loss of generation units and loads.

Classification of the incident based on the Incident Classification Scale (ICS) methodology

Section 12 describes the classification of the incident based on the Incident Classification Scale (ICS) methodology, carried out according to the valid legal framework, i. e., the System Operation Guideline (SO GL). According to the analysis, the most critical criterion is L2 (Incidents on Loads).

For incidents of this scale, a detailed report must be prepared by an expert panel composed of representatives from TSOs affected by the incident, the relevant RSC(s), a representative of subgroup ICS, regulatory authorities and ACER upon request. The ICS report must contain an explanation of the reasons for the incident based on the investigation according to article 15(5) of SO GL. The TSOs affected by the incident must inform their national regulatory authorities before the investigation is launched. The expert investigation panel was established on 22 October 2021 and will publish its final report in the first quarter of 2022.

Next steps

The final report will contain technical analysis, analysis of main causes, and critical factors and conclusions, recommendations, and internal actions.

1 INTRODUCTION

Background

On Saturday, 24 July 2021 at 16:36 CET, the Continental Europe Synchronous Area was separated into two areas due to cascaded trips of several transmission network elements. Specifically, the Iberic Peninsula, comprising the systems operated by REE and REN, was separated from the rest of Continental Europe. Immediately after the incident occurred, European TSOs started to resolve it, resynchronising the Continental European power system at 17:09 CET.

Continental Europe System Separation Task Force

In the immediate aftermath of the system separation, European TSOs, in close collaboration through ENTSO-E, decided to start a joint process to collect all relevant facts regarding the incident. This process was launched through the coordination of an ENTSO-E Task Force with the clear mission to deliver these facts to national and European authorities, ENTSO-E members as well as to any interested party in a transparent and complete way.

The Task Force, composed of the European TSOs, has been coordinating all relevant ENTSO-E bodies in analysing the event and is responsible for the development of the Technical Report and for overseeing the communication of facts to external stakeholders. This Technical Report presents the results of the investigation carried out by the Task Force.

The investigation has classified the event according to the ICS Methodology as a Scale 2 event, and therefore a relevant investigation expert panel was set up, starting its work on 22 October 2021. The Task Force will assist with the development of the work within this Expert Panel and deliver a final technical report in the first quarter of 2022.

Structure of the technical report

The report is structured as follows. Section 2 describes the environmental conditions before the incident, with a focus on the fire in the of South France. Section 3 gives details on the CE power system conditions before the system separation, with a focus on South West Europe and the three mainly affected TSOs: RTE, REE and REN. Section 4 analyses the dynamic behaviour of the system during the event, supported by preliminary dynamic simulation results. Section 5 describes the performance of the protection system during the incident. Section 6 deals with the frequency support activated during the event. Section 7 provides an overview of the resynchronization process. Section 8 evaluates the N-1 security calculations performed by RTE. Section 9 describes the communication of coordination centres/SAM and between TSOs. Section 10 analyses the coordination activities that were performed by Coreso/Brussels, the Regional Security Coordinator. Section 11 describes the TSO–DSO coordination and the frequency plan and load shedding. Section 12 describes classification of the incident based on the Incident Classification Scale (ICS) methodology.

Sources of data and information

The analysis presented in this report is based on information that was sent by all continental Europe TSOs and more detailed information from the most affected TSOs. An important source of information comprised recordings from Wide Area Monitoring (WAM) Systems, which have delivered, with their accurate and precise time stamping, valuable measurements for aligning all the events in the correct order. Another important source of information involved measurements from transient recorders and digital protection devices with precise GNSS time stamps.

2 ENVIRONMENTAL CONDITIONS BEFORE THE INCIDENT

This section analyses the environmental conditions in the South of France shortly before and at the time of the incident. The focus is on the fire that occurred on that day in the vicinity of the Spanish–French border.

Fire in the Moux area

On 24 July 2021, at approximately 13:30, a severe fire broke out in the vicinity of the city of Moux, in the South of France. A massive mobilisation of firefighting services was activated, with more than 850 firefighters, one helicopter and nine firefighting planes. In total, 850 hectares of vegetation were destroyed by flames during this two-day event; see Figure 1 to Figure 3.

At first, RTE was not informed about the fire. Based on bilateral exchanges between RTE and the fire department (SDIS: Service Départemental d'Incendie et de Secours) carried out after the event, the situation can be summarised as follows:

During the organisation of the firefighting efforts, the fire department became aware that two 400 kV lines are located in the fire area, as seen in Figure 4 and Figure 5. In such situations, a request to switch off these lines, in order to ease the intervention of planes and firemen, should be submitted to RTE. But in the present case, due to the intense situation, this communication did not happen. Lacking confirmation of the line outages, the fire services organised themselves to deal with the fire by keeping a safe distance from the lines (respecting their own safety rules for high voltage lines).

Requesting the outage of lines in order to allow an intervention is covered by an agreement between RTE and the french fire department. But in the current case, this communication did not happen.

Figure 1: Location of the fire on a large-scale map.

Figure 2 & 3: Picture taken during firefighting activities.

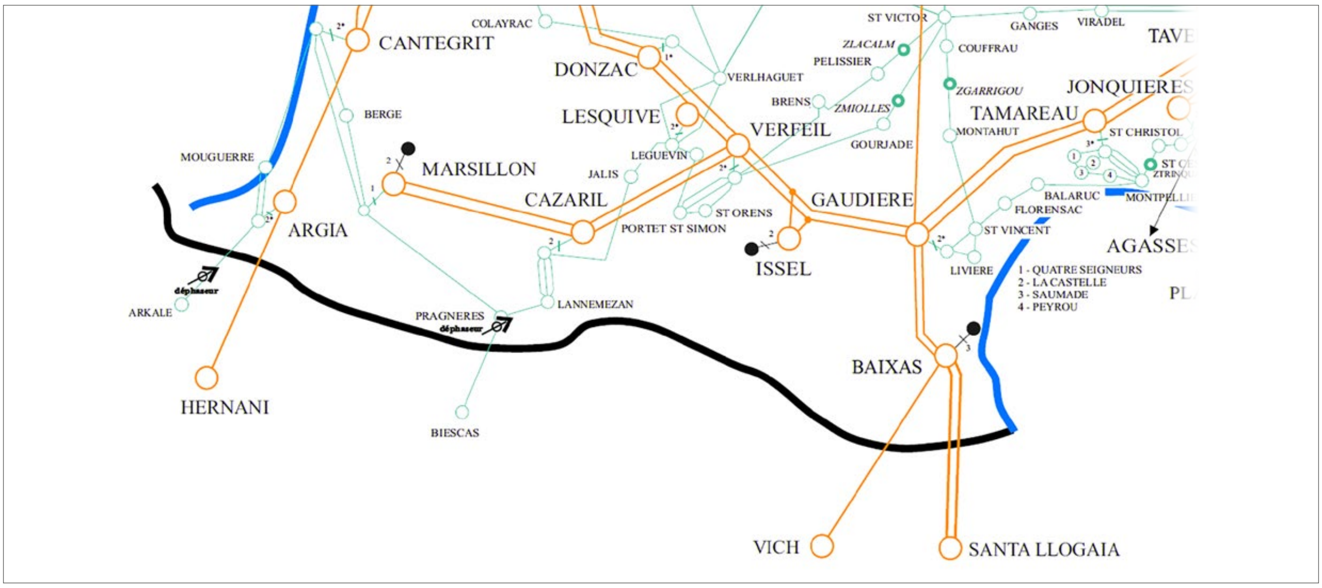


Figure 4: Grid map of the South of France (400 kV in orange; 225 kV in green).

Information about the fire

Thus, as explained before, 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.

At 16:57, ENEDIS, the DSO of the area, informed RTE that one of its employees has *seen* a fire, with *huge quantities of smoke*, close to transmission system installations. Through complementary exchanges, the DSO specified at 17:06 that one cable of the line *could* have fallen to the ground. At 17:10, RTE called the fire department (SDIS 11), to collect all information regarding the fire and its exact location. This exchange of information allowed for the confirmation of the event as well as a better understanding of the situation.

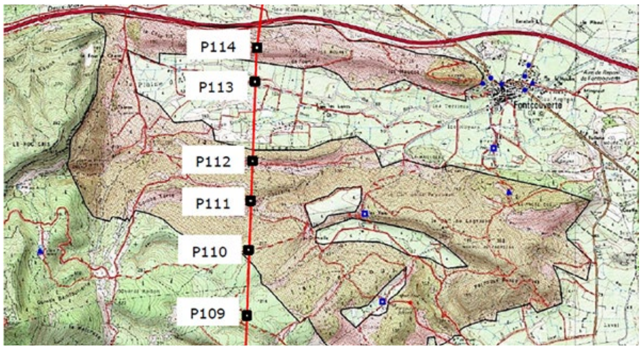


Figure 5: Fire area in Moux on 24 July and 400 kV Baixas-Gaudière line location (in red)

This information was provided after the grid separation, but it was used to analyse the grid conditions in the area, and to prepare actions on the lines.

Environmental conditions and operating rules

As detailed in Chapter 8, 'N-1 security evaluation', one criterion used in security assessment involves the environmental conditions in the vicinity of grid devices. On 24 July, the specific risk was not known thus not taken into account.

Usually, information on the environmental situation is shared and used. For instance, on 11 August 2021, a fire was detected by the fire department (SDIS 11) in the area of Sallèles Cabardes and Villegly villages. The fire services realised the fire was in the vicinity of RTE's lines and thus, at 14:16, called RTE to inform them of the situation and the fire's particular location. This allowed RTE to prepare for the potential consequences; therefore, at 14:38, when the fire department requested that RTE switch off the 400 kV Gaudière Issel lines 1 and 2, RTE was able to react accordingly. The fire was extinguished, and at 17:38, the 400 kV lines returned to operation. This illustrates the added value of providing proactive information on environmental conditions, to anticipate system operation conditions.

Following the 24 July event, RTE met with fire department SDIS 11 to discuss these elements, and to find a way to improve the communication chain to ensure that relevant information reaches the concerned entities.

3 EVOLUTION OF THE SYSTEM CONDITIONS DURING THE EVENT

3.1 System conditions before the system separation

3.1.1 System conditions in South West Europe

This section analyses the system conditions in South West Europe shortly before and at the time of the incident. The focus is on the market scheduled flows and on the measured cross-border (CB) physical flows between Portugal (PT), Spain (ES) and France (FR).

Market scheduled flows versus cross-border physical flows

The market schedules (see Table 1 and Table 2) reflect exchanges of energy between Continental Europe and the Iberian Peninsula, with important flows on the France → Spain Border. This reflects cheaper electricity in Continental Europe area used to feed-in the Iberian Area.

Focus on the France–Spain border

Table 3 provides information to compare the market scheduled exchanges between Spain and France on 24 July 2021 afternoon with those on similar days. This shows that on 24 July, market scheduled exchanges between Spain and France were not of unusual values.

Calculated NTC values

The net transfer capacities (NTCs) on the borders result from capacity calculations performed on D-2 (two days ahead) by the Regional Security Coordinator (RSC, CORESO for these countries); see Table 4. These calculations aim at covering different potential operating situations, while ensuring compatibility with real-time operation of the grid. In order to determine commercial capacities that are compliant with system security operation rules, the capacity calculation process is based on the principles, rules, and elements considered in the 'N-1 security evaluation', detailed in Section 8 of this document.

The commercial capacities are then offered to market parties, who use them to exchange energy between different areas. The market schedules resulting from these exchanges are thus compliant with operational security limits, whereas the emerging load flow values in real time might slightly exceed these values (see next paragraph on physical cross-border flows). Table 4 shows the NTC for 24 July on the France–Spain border. Market scheduled exchanges (Table 2) were well within this range of values.

Country	16:00–17:00	17:00–18:00	18:00–19:00	19:00–20:00
FR → ES [MW]	2,682	1,200	631	1,345
ES → PT [MW]	1,713	1,448	1,236	1,157

Table 1: Day-Ahead market scheduled exchanges for 24 July 2021.

Country	16:00–17:00	17:00–18:00	18:00–19:00	19:00–20:00
FR → ES [MW]	2,537	1,778	209	1,745
ES → PT [MW]	1,468	928	748	783

Table 2: Intra-Day market scheduled exchanges for 24 July 2021.

Market scheduled exchanges FR → ES	16:00–17:00	17:00–18:00	18:00–19:00	19:00–20:00
Saturday 17 July [MW]	3,000	3,237	2,547	2,490
Thursday 22 July [MW]	3,052	3,052	1,127	–530
Friday 23 July [MW]	2,914	713	–135	810
Saturday 24 July [MW]	2,537	1,778	209	1,745

Table 3: Comparison of market scheduled exchanges on FR-ES Border during various days in July 2021.

NTC FR → ES for 24 July	16:00–17:00	17:00–18:00	18:00–19:00	19:00–20:00
FR → ES [MW]	2,682	2,682	2,682	2,775
ES → FR [MW]	2,590	2,590	2,590	3,098

Table 4: NTC on France-Spain border on 24 July 2021.

Scheduled exchanges Fr → ES (MW)

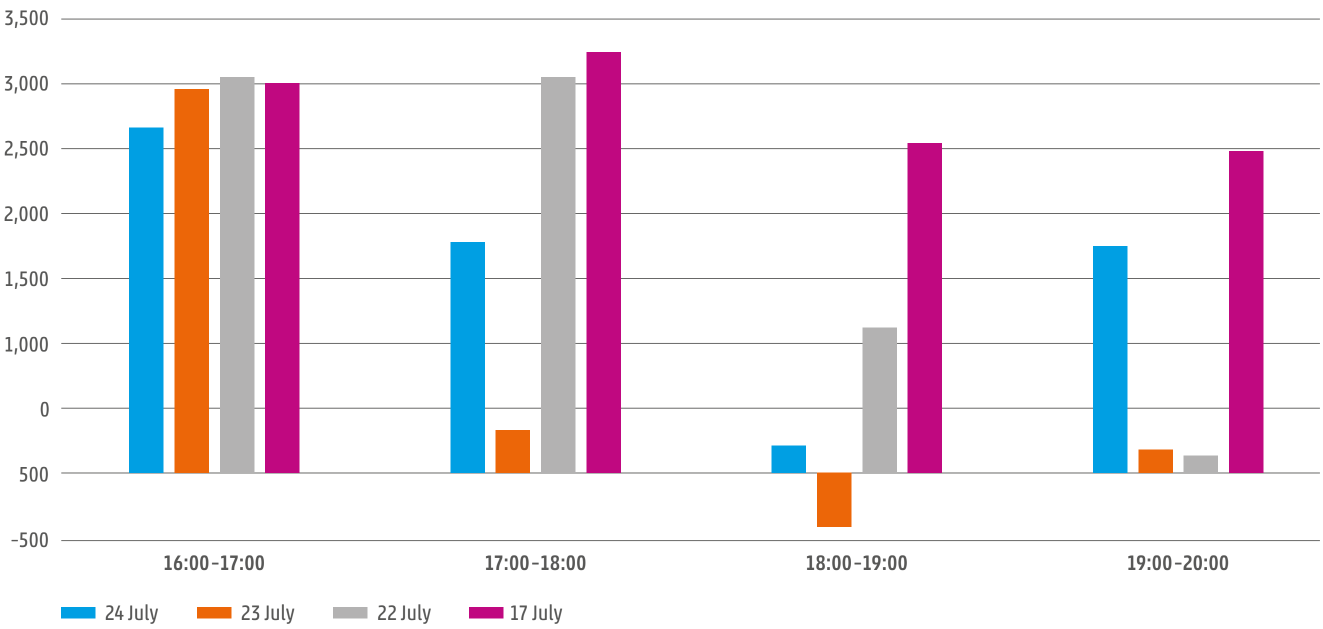


Figure 6: Comparison of market schedules on FR-ES Border.

Physical flows at 16:30 on the FR–ES border

Physical flows are the result of real-time operations, without the IGCC correction. At 16:30, physical exchanges between France and Spain reached 2,451 MW from France to Spain, carried on the different interconnection lines. This value is below the calculated NTC for the border (see Table 4) and fits the Intra-Day market scheduled exchange (Table 2). Figure 7 gives the details by lines.

Focus on the Portugal–Spain border

Calculated NTC values

Table 5 shows the NTC for 24 July 2021 on the Spain–Portugal border. Market scheduled exchanges (Table 2) were well within this range of values.

Physical flows at 16:30 on the ES–PT border

Physical flows are the result of real-time operations, without the IGCC correction. At 16:30, physical exchanges between Spain and Portugal reached 1,417 MW, carried on the different interconnection lines.

Overall system conditions in South West Europe

Table 6 presents the overall power exchanges in South West Europe.

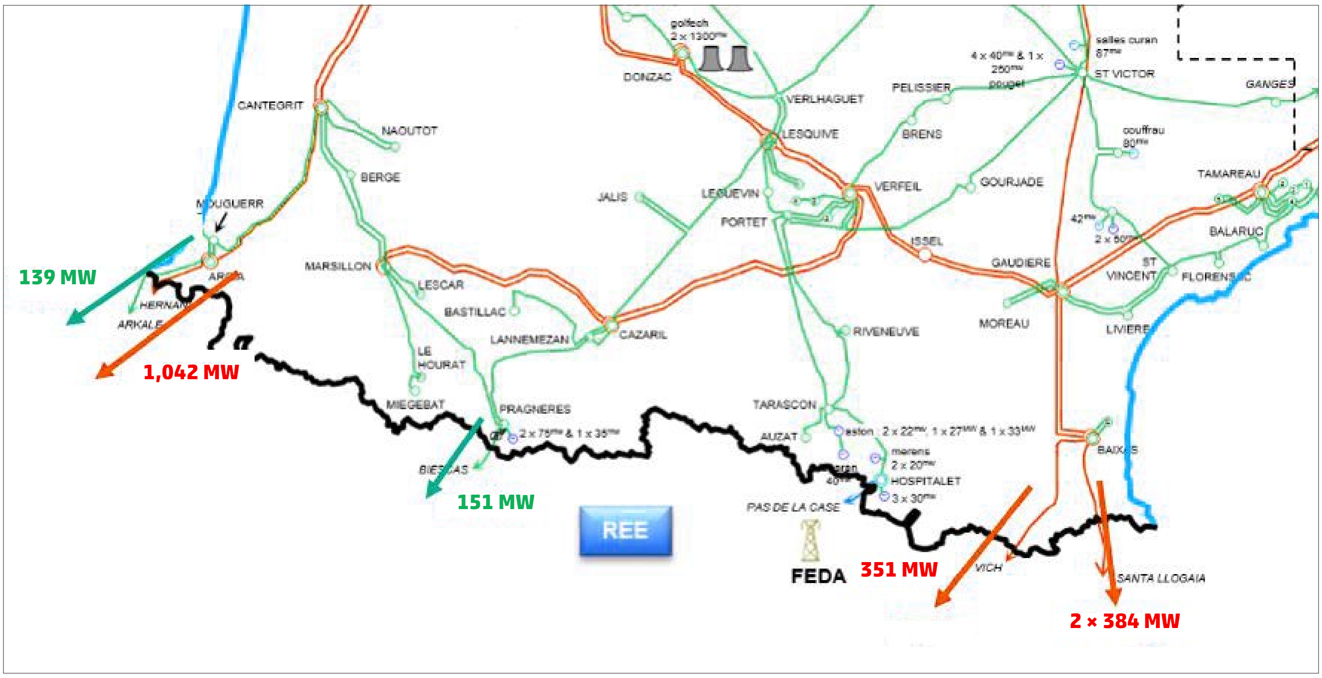


Figure 7: Simplified view (225 kV in green, 400 kV in red) of the south-west French transmission system and the exchanges with Spain before the event.

NTC ES–PT for 24 July	16:00-17:00	17:00-18:00	18:00-19:00	19:00-20:00
PT → ES [MW]	3,150	3,150	3,150	3,600
ES → PT [MW]	4,905	4,905	4,905	4,590

Table 5: NTC on Spain–Portugal border on 24 July.

Cross-border flows for 24 July at 16:30	NTC	Day-Ahead forecast	Intra-Day forecast	Real-Time snapshot CGM
FR → ES [MW]	2,682	2,682	2,537	2,451
ES → PT [MW]	4,905	1,713	1,468	1,417

Table 6: Cross-border power flows in different in different timeframes (NTC, Day-Ahead, Intra-Day, Real-Time) on 24 July.

3.1.2 System conditions in France

Production of power plants and renewables

The realised production of power plants corresponds to the scheduled production in France. The scheduled and actual productions in the hour from 16:00–17:00, before the system separation, are shown in Table 7.

Consumption

On the afternoon of 24 July, the forecasted load in France was the usual value for a summer saturday afternoon. Before the event, the realised load was close to the forecasted one, seen in figure 8. At 16:35, the French load was 42,086 MW.

Type of Power Plant	Scheduled [MW]	Realised [MW]
Nuclear power plants (NPPs)	38,420	38,046
Other thermal power plants (TPPs)	1,360	1,600
Hydro power plants (HPPs)	5,740	6,396
Solar power plants (SPPs)	5,070	4,665
Wind power plants (WPPs)	1,890	3,306
SUM	**52,480**	**54,013**

Table 7: Scheduled and actual generation in France at 16:00–17:00 summarised by powerplant or fuel type.

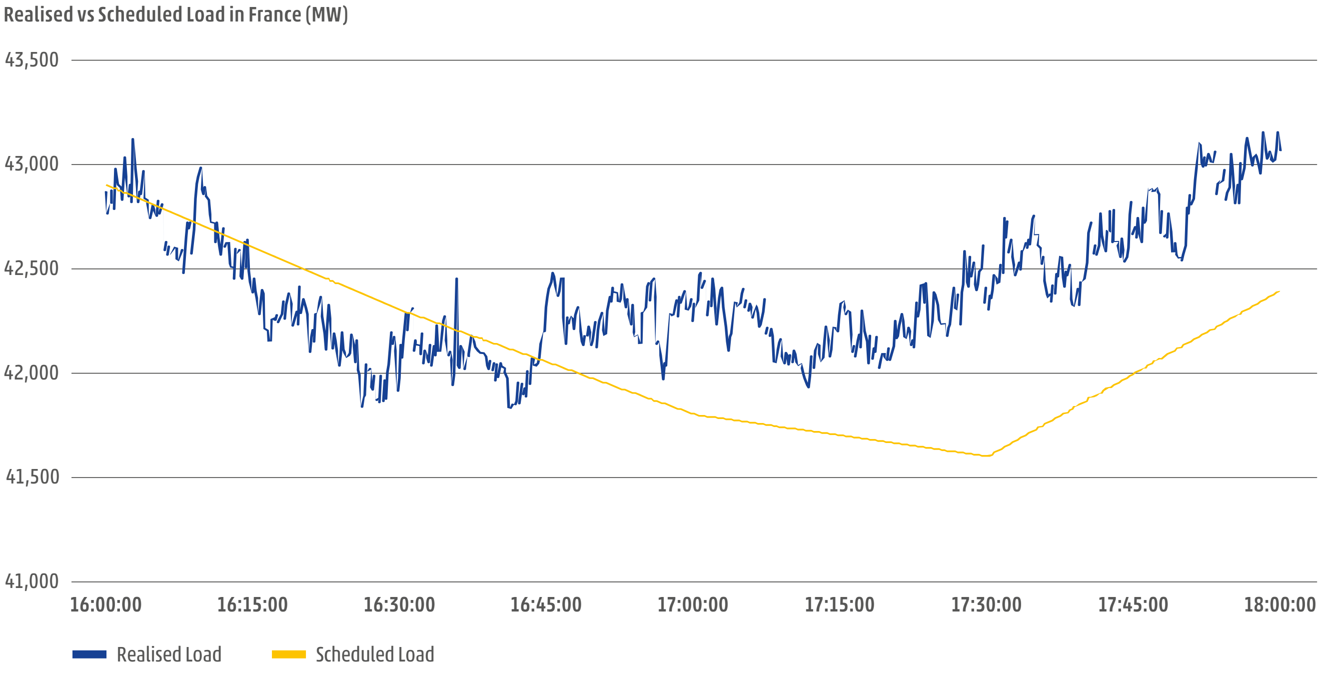


Figure 8: Comparison between realised and forecasted load in France.

Scheduled/planned outages of grid elements

All planned outages of transmission lines were considered during the planning phase for the Day-Ahead forecast. The following French transmission lines in the vicinity of the Spanish–French border were in planned outage:

» Cazaril Marsillon 400 kV n°2 and Cazaril Verfeil 400 kV n°1 (France): this grid action was set up to mitigate high voltage phenomena. These topologies are typical and do not create any constraints.

Power flows on surrounding grid elements in different timeframes (Day-Ahead, Intra-Day, Real-Time)

Transmission line		DACF		IDCF		Realised real-time flow [A] - 16:30	
	PATL [A]	flow [A]	PATL [%]	flow [A]	PATL [%]	flow [A]	PATL [%]
Argia-Hernani 400 kV	2,050	1,482	72	1,633	80	1,424	69
Argia-Arkale 225 kV	1,076	400	37	472	44	308	29
Argia-Mouguerre 225 kV n°1	1,172	60	5	60	5	131	11
Argia-Mouguerre 225 kV n°2	1,172	55	5	67	6	145	12
Argia-Cantegrit 400 kV	2,050	1,732	84	1,326	65	1,534	75
Biescas-Pragnères 225 kV	786	452	57	452	57	336	43
Marsillon-Pragnères 225 kV	565	192	34	205	36	188	33
Lannemezan-Pragnères 225 kV	737	252	34	242	33	143	19
Baixas-Vich 400 kV	2,179	440	20	421	19	362	17
Baixas-Gaudière 400 kV n°1	4,380	1,060	24	949	22	793	18
Baixas-Gaudière 400 kV n°2	4,380	1,060	24	949	22	793	18

Table 8: Flow on French transmission lines in the vicinity of the Spanish-French border at 16:30.

Focus on the HVDC lines

Due to their conception, it is technically not possible to overload these lines. However, Table 9 provides flows on both Baixas–Santa Llogaia HVDC lines.

Transmission line	DACF [MW]	Realised real-time flow [MW] - 16:30	Maximum transmission [MW]
Baixas-Sant Llogaia 400 kV n°1 - HVDC	527	385	1,000
Baixas-Sant Llogaia 400 kV n°2 - HVDC	527	385	1,000

Table 9: Active power flow on HVDC lines on the Spanish-French border.

Focus on security analyses on the 400 kV Baixas-Gaudière line

As detailed in Section 8 'N-1 security evaluation', continuous security analyses are performed on grid elements to ensure the respect of the N-1 principle. This computation is performed at different timeframes, from month-ahead up to real-time, where it is assessed every 15 minutes. Table 10 shows the results of this security analysis relative to the tripping of the 400 kV Baixas–Gaudière line, and the resulting flows in the remaining lines and respect of their permanent admissible transmission loading (PATL). The simulation of a trip of one of the two Baixas-Gaudière 400 kV does not show any violations on the other lines.

Transmission line		DACF		IDCF		Snapshot 16:30	
	PATL [A]	flow [A]	PATL [%]	flow [A]	PATL [%]	flow [A]	PATL [%]
Argia-Hernani 400 kV	2,050	1,583	77	1,415	69	1,492	73
Argia-Arkale 225 kV	1,076	441	41	506	47	332	31
Argia-Mouguerre 225 kV n°1	1,172	75	6	67	6	142	11
Argia-Mouguerre 225 kV n°2	1,172	80	7	74	6	156	13
Argia-Cantegrit 400 kV	2,050	1,834	89	1,723	84	1,602	78
Biescas-Pragnères 225 kV	786	540	69	531	68	395	50
Marsillon-Pragnères 225 kV	565	221	39	231	41	208	37
Lannemezan-Pragnères 225 kV	737	310	42	294	40	182	25
Baixas-Vich 400 kV	2,179	396	18	384	18	326	15
Baixas-Gaudière 400 kV n°1	4,380	1,982	45	1,771	40	1,463	33
Baixas-Gaudière 400 kV n°2	4,380	fault	NA	fault	NA	fault	NA

Table 10: Results of the simulation of a trip of one of the two 400 kV Baixas-Gaudière lines.

Transmission line	Flow [MW]	Maximum transmission [MW]
Baixas-Sant Llogaia 400 kV n°1 – HVDC	365	1,000
Baixas-Sant Llogaia 400 kV n°2 – HVDC	365	1,000

Table 11: Impact of the trip of one of the two 400 kV Baixas-Gaudière lines on the HVDC lines.

3.1.3 System conditions in Spain

Production of power plants and renewables

The realised production of power plants corresponds to the scheduled production in Spain. The scheduled and realised productions in the hour from 16:00–17:00, before the system separation, are shown in Table 12.

Type of power plant	Scheduled [MWh]	Realised real-time flow [MW]
Hydro	1,683	1,638
Solar (FV)	10,138	10,356
Nuclear	6,919	6,957
Combined cycles	1,658	1,462
Wind	6,437	6,543
Coal	320	310
Thermal renewable	475	475
Distributed thermal non renewable	3,342	3,136
SUM	**30,972**	**30,877**

Table 12: Scheduled and realised generation in Spain at 16:00 – 17:00 and real-time flow at 16:33.

Consumption

On the afternoon of 24 July, the forecasted load in Spain was in the usual range of values for a summer Saturday afternoon. Before the event, the realised load was close to the forecasted value. At 16:33, the Spanish load was 30,033 MW.

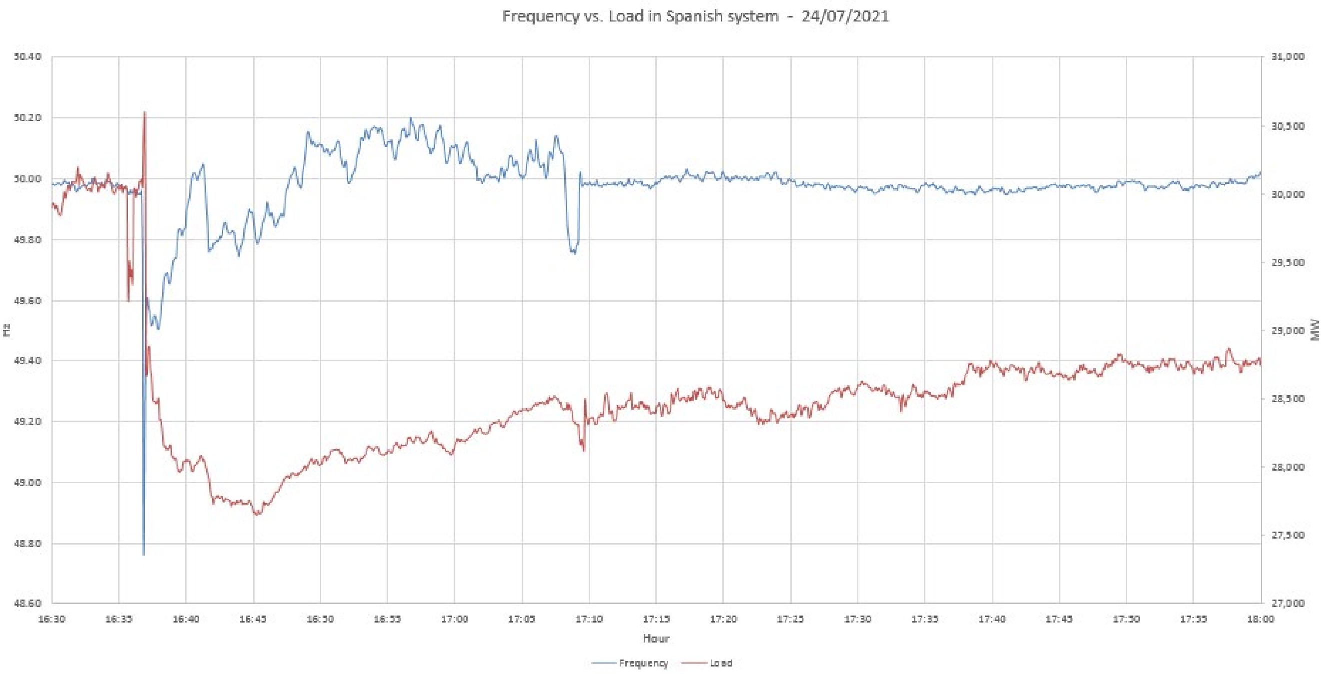


Figure 9: Comparison between realised load and frequency in Spain.

Scheduled/planned outages of grid elements

All outages of transmission lines were taken into account during the planning phase during day-ahead. There were no planned outages on Spanish transmission lines in the vicinity of the Spanish–French border.

Power flows on grid elements in different timeframes (Day-Ahead, Intra-Day, Real-Time)

		DACF	DACF	Snapshot 16:25	Snapshot 16:25
Transmission line	PATL (MVAs)	flow (MVAs)	% PATL	flow (MVAs)	% PATL
AT9 VIC 400/220 kV	300	89.6	29	80.5	27
VIC-BESCANÓ 400 kV	2,030	99.1	5	61.0	3
VIC-PIEROLA	1,510	212.9	14	114.8	8
VIC-BAIXAS	1,510	410.3	26	316.3	21
AT10 VIC 400/220 kV	600	143.5	23	***	***
AT4 VIC 400/220 kV	600	94.1	15	133.4	22
AT1 VIC 400/220 kV	200	87.4	43	88.2	44
AT1 LLOGAIA 400/132 kV	315	146.0	46	134.3	42
LLOGAIA-BESCANÓ 400 kV	2,030	375.7	18	290.0	14
LLOGAIA-LA FARGA 400 kV	2,030	516.5	25	416.8	20
HVDC LLOGAIA-ECLLOGAIA 1	1,140	512.3	44	418.3	36
HVDC LLOGAIA-ECLLOGAIA 2	1,140	512.3	44	13.9	33
BIESCAS-SABIÑÁNIGO 220 kV	270	197.9	66	165.4	57
BIESCAS-PRAGNERES 220 kV	300	182.5	55	151.6	47
HERNANI-AZPEITIA 400 kV	1,030	406.8	36	403.5	39
HERNANI-ICHASO 400 kV	1,590	420.5	24	411.5	26
HERNANI-ARGIA 400 kV	1,420	1,071.6	75	1,063.8	74
AT5 HERNANI 400/220 kV	600	84.1	13	102.6	17
PST ARKALE 220 kV	550	175.9	28	140.6	24
ARKALE-ARGIA 220 kV	410	175.9	38	140.6	32

Table 13: Flow on Spanish transmission lines in the vicinity of the Spanish-French border at 16:30.

*** AT10 VIC 400/220 kV was disconnected in real time due to topological reasons, to minimise the flow at L-220 kV VIC-SAN CELONI.

In real-time a security analysis was done every five minutes, and no risk was detected in the contingency list defined by the Spanish security procedures.

From 16:00–17:00, the value of the scheduled interchange between France, Spain and Portugal was very similar to the value in the previous hour.

3.1.4 System conditions in Portugal

Production of power plants and renewables

The realised production of power plants corresponds to the scheduled production in Portugal. The scheduled and realised productions during the hour from 16:00–17:00, before the system separation, are shown in Table 14.

Type of Power Plant	Scheduled [MW]	Realised real-time flow [MW]
Hydro power plants (HPPs)	372	334
Thermal power plants (TPPs)	1,012	1,011
Wind power plants (WPPs)	1,384	1,588
Solar power plants (SPPs)	668	804
All other power plants	395	393
SUM	**3,831**	**4,130**

Table 14: Scheduled and realised generation in Portugal from 16:00-17:00 and real time flow at 16:33.

Consumption

The quarter-hourly forecast and realised consumption levels in Portugal, from 16:00 to 18:00, are shown in Table 15.

Consumption	Forecast [MW]	Actual [MW]
16:00-16:15	5,230	5,175
16:15-16:30	5,230	5,145
16:30-16:45	5,154	4,511
16:45-17:00	5,154	4,088
17:00-17:15	5,122	4,233
17:15-17:30	5,122	4,331
17:30-17:45	5,166	4,522
17:45-18:00	5,166	4,654

Table 15: Comparison between forecasted and realised consumption in Portugal.

Power flows on grid elements in different timeframes (Day-Ahead, Intraday, Real-Time)

Transmission line		DACF		IDCF		Snapshot 16:30	
	PATL [A]	flow [A]	PATL [%]	flow [A]	PATL [%]	flow [A]	PATL [%]
Alto Lindoso-Cartelle 1,400 kV	2,132	210	10	223	10	179	8
Alto Lindoso-Cartelle 2,400 kV	2,132	211	10	224	10	179	8
Lagoaça-Aldeadavila 400 kV	2,120	465	22	485	23	311	15
Pocinho-Aldeadavila 1,220 kV	981	177	18	183	19	118	12
Pocinho-Aldeadavila 2,220 kV	981	180	18	185	19	119	12
Pocinho-Saucelle 220 kV	945	163	17	168	18	112	12
Falagueira-Cedillo 400 kV	2,000	352	18	389	19	454	23
Alqueva-Brovales 400 kV	1,848	346	19	359	19	535	29
Tavira-Puebla de Guzmán 400 kV	2,000	302	15	311	16	410	21

Table 16: Flow on Portuguese transmission lines in the vicinity of the Spanish-Portuguese border at 16:30.

4 DYNAMIC BEHAVIOUR OF THE SYSTEM DURING THE EVENT

This section gives an overview of the dynamic behaviour of the system during the event, by referring to the timeline of the various events, analysing the main dynamic stability criteria, and providing some details on the activated defence equipment.

The section is structured as follows:

- » Section 4.1 gives the timeline of the sequence of the events that led to the system split.
- » Section 4.2 analyses the dynamic stability margin of the system during the event.
- » Section 4.3 analyses the system from the voltage stability point of view, focusing on the risk of facing a voltage collapse.
- » Section 4.4 focuses on the HVDC link at the border between Spain and France, while led to keeping a small part of France connected to Spain during the event.
- » Section 4.5 describes the results of a preliminary dynamic analysis, which serves as an important basis to justify the registered ROCOF values and evaluate the overall inertia installed in the system.

Finally, in order to give an exhaustive figure on the overall energy balance, Sections 4.6 and 4.7 provide an overview of the intentional and unintentional disconnections across the system. In particular, Section 4.6 deals with the activated automatic defence plans, in terms of frequency support and low frequency demand disconnections (that are thoroughly discussed in Section 6). In addition, Section 4.7 deals with the unintentional loss of generation units and loads (which is thoroughly discussed in Section 11).

4.1 Sequence of events

The sequence of events was reconstructed thanks to WAMSs[1] that gather data from PMUs[2] , measurement devices equipped with precise time information and based on protection device recordings that usually provide GNSS synchronization (when available). The sequence of events is further detailed in Table 17 and Figure 10.

No	TSO	Delta [s]	Trip time	Substation 1	Substation 2	Voltage [kV]	Comments
1	RTE	0	16:33:12.0	Baixas (FR)	Gaudière (FR)	400	Two phase fault. Circuit 2
2	RTE	131.8	16:35:23.8	Baixas (FR)	Gaudière (FR)	400	Two phase fault. Circuit 1
3	RTE	205.0	16:36:37.0	Argia (FR)	Cantegrit (FR)	400	Overload protection 60 s
4	REE	206.9	16:36:38.9	Biescas (ES)	Pragneres (FR)	220	Distance protection zone 2 out-of-step condition
5	REE	207.2	16:36:39.2	Puerto de la Cruz (ES)	Beni Harchen (MA)	400	Underfrequency protection on Moroccan end that sent a direct transfer trip to Spanish end
6	REE	207.5	16:36:39.5	Puerto de la Cruz (ES)	Melloussa (MA)	400	Underfrequency protection on Moroccan end that sent a direct transfer trip to Spanish end
7	RTE/REE	208.4	16:36:40.4	Argia (FR)	Arkale (ES)	220	Out-of-step protection (simultaneous on both sides)
8	RTE	209.3	16:36:41.3	Argia (FR)	Hernani (ES)	400	Out-of-step protection

Table 17: Sequence of events.

The first two trips occurred in France roughly at 16:33 within a period of two minutes and were caused by two phase-to-phase faults in each line (events #1 and #2 in Table 17 and Figure 10). Before the tripping, the two lines were transporting 612 MW each from France to Spain. Due to the separation of substation Baixas from the rest of the French grid, these two trips resulted in the loss of the eastern interconnection between Spain and France. The Baixas substation remained supplied from Spain. The loss of the eastern corridor caused the western and central interconnection corridors to become overloaded. These overloads caused the tripping of the 400 kV Argia–Cantegrit line 73.2 seconds after the second tripping (event #3). This third tripping caused a loss of synchronism between the French and Spanish systems, which subsequently led to the complete loss of interconnections between the two systems. The tripping of the 220 kV Biescas–Pragneres line (event #4) was caused by the distance protection (zone 2) under out-of-step conditions. The tripping of the Morocco–Spain tie-lines was caused by the automatic action of an underfrequency protection on the Moroccan side (events #5 and #6). The Spanish side was also disconnected due to the reception of a transfer tripping from the Moroccan side. The remaining tie-lines between France and Spain tripped shortly afterwards due to their out-of-step protection systems (events #7 and #8).

It should be noted that this sequence of events reflects only the separations of transmission lines in the high and extra high voltage transmission system. In addition, on French side, ten 63 kV lines tripped during the event, due to distance and loss of synchronism protections. Some of these trips indicate that a few RTE substations were connected to the Spanish system. The resulting two synchronous areas are shown in Figure 11. It should be further noted that after the first line tripped, RTE and REE jointly decided to reduce by 1 GW the power flows from France to Spain (further details in Section 6.3).

1 Wide Area Monitoring Systems: a system that acquires real time-data from PMUs with wide location displacement and high level of time resolution

2 Phasor Measurement Unit (PMU): a measurement device that estimates and phase aligns phasors located in different locations of an electrical grid thanks to precise time synchronization (usually based on the GNSS) and reports these measurements at high rates (usually reporting time between 20 and 100 ms depending on TSO settings).

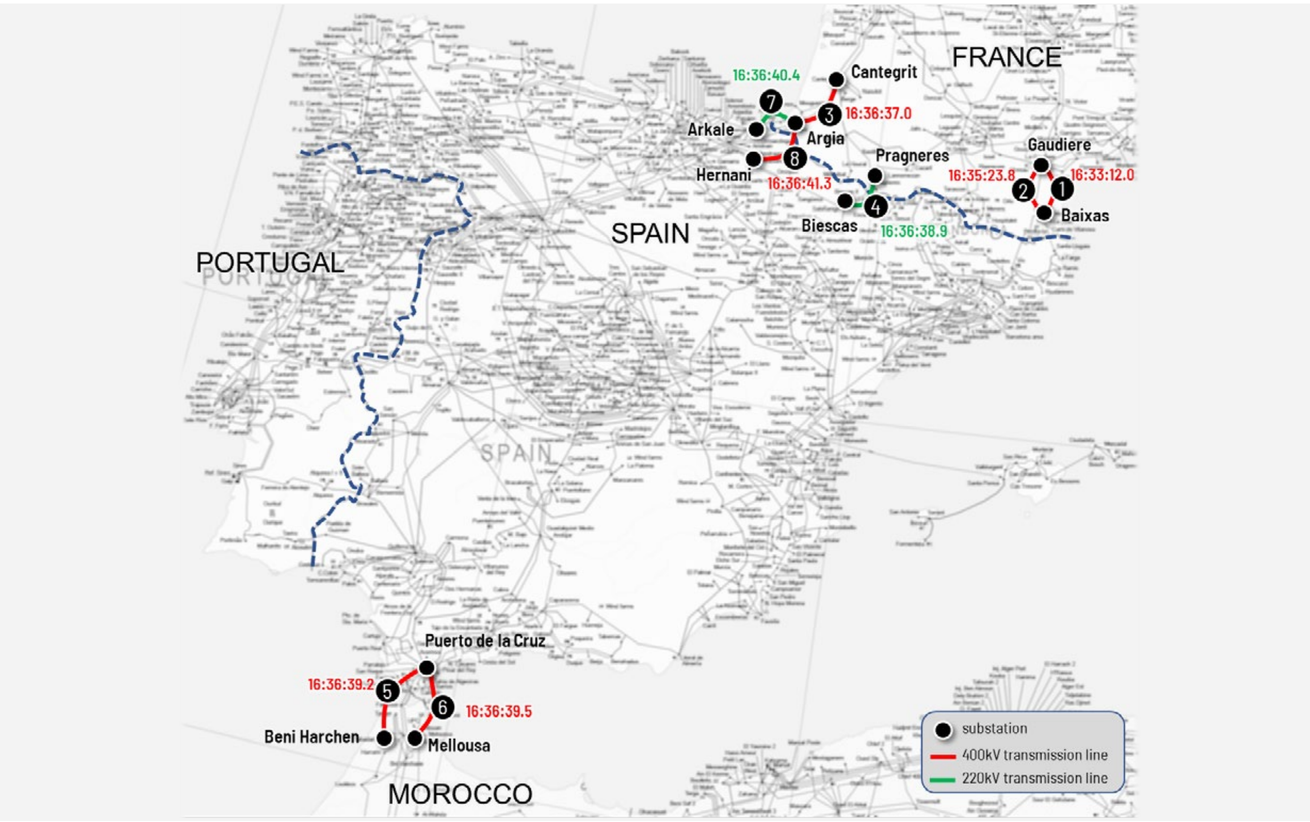


Figure 10: Geographical location of main tripped transmission system elements.

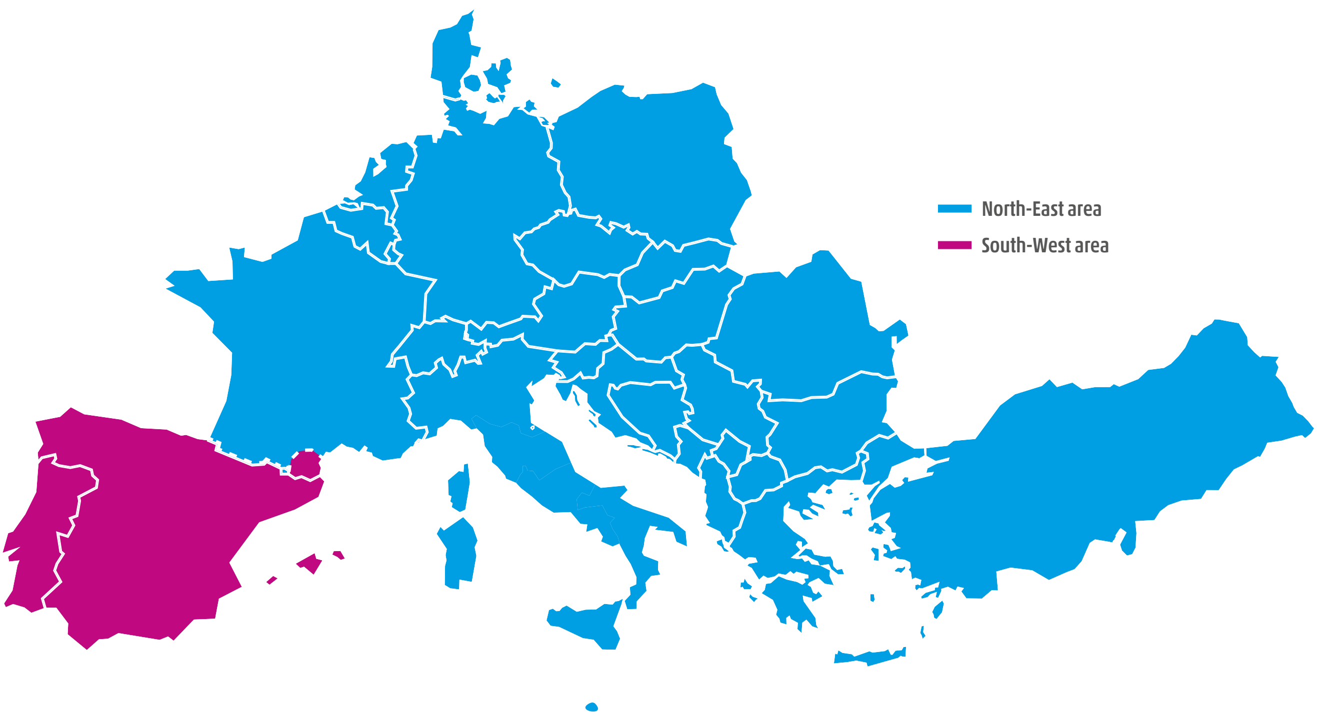


Figure 11: Resulting two synchronous areas after the system split.

4.2 Dynamic stability margin

The PMU recordings included in Figure 12 show how the separation took place.

» After the tripping of the 400 kV Baixas–Gaudiere 2 line (event #1) at 16:33:12.0, the frequency, voltage and load of the transmission elements remained within normal values, as is expected after an N-1. But after this event the N-1 criterion was no longer fulfilled, which is why REE and RTE agreed to reduce the exchange between France and Spain from 2,500 MW to 1,200 MW at 16:34. However, the next two trips (events #2 and #3) took place before this reduction became effective.

» After the tripping of the 400 kV Baixas–Gaudiere 1 line (event #2) at 16:35:23.8 the remaining interconnection corridors between France and Spain became overloaded and the voltage phase angle between France and Spain increased to values close to the stability margin of 90 degrees. Low voltages were observed in the substations close to the border. To mitigate these low voltages twelve coils reactors were disconnected in Spain, two of them automatically. In France, six capacitors were connected, five of them automatically, and two coil reactors were disconnected manually. The system was in a critical state, with high angle differences between the peninsular busbars and the rest of Europe and also with low voltages in the area close to the interconnection between Spain and France. Despite this critical situation, the system remained stable for over one minute until the following event occurred.

» Before the exchange reduction previously agreed by Spain and France became effective, the 400 kV Argia–Cantegrit line tripped (event #3) at 16:36:37.0 due to the automatic action of the overload protection implemented for this line. This tripping caused the loss of synchronism between France and the Iberian Peninsula. After the loss of synchronism, the only possible defence action was to split the system at the locations where it has been planned. Indeed, RTE and REE have installed loss of synchronism protections at both ends of each interconnection line between the countries as system defence protections.

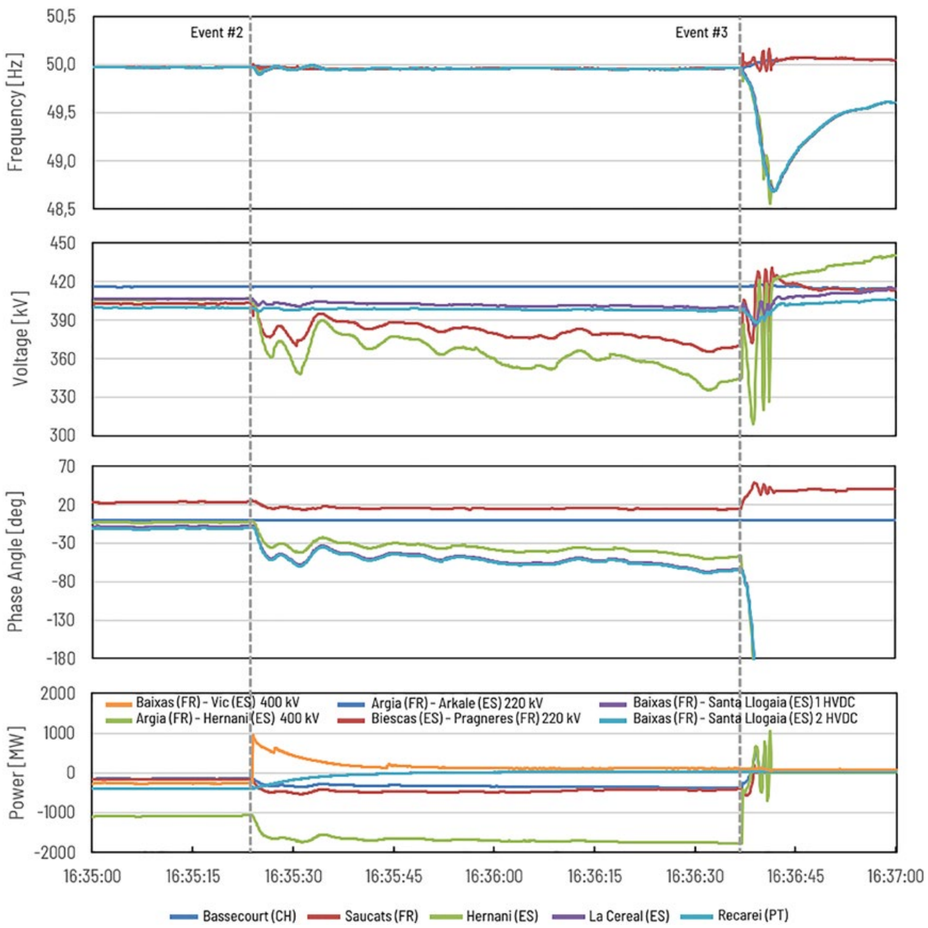


Figure 12: Frequencies, voltages, voltage phase angle difference and active power of France-Spain tie lines as measured by PMUs (reference for voltage phase angle difference is Bassecourt (CH) substations).

In Figure 13 the voltage magnitude as recorded by a PMU in Hernani with respect to the angle difference of Spain against the centre of Europe is displayed. It can be assumed that the angle difference is proportional to the active power flow P between Spain and France, with the approximated relationship $P = (V^2 \div X) \times \sin(\delta)$ where V is the voltage phasor magnitude and X is the impedance of the corridor. Between event #2 and #3 we clearly recognise in the dotted red line (interpolant) the classical 'nose curve' indicating a voltage collapse phenomenon caused by the high power flow increase on the physical section.

Due to the loss of synchronism, which occurred after the trip of the 400 kV Argia–Cantegrit line (event #3), the frequency in the Iberian Peninsula started to drop, even before the three remaining interconnection lines between Spain and France had tripped. The frequency in the rest of the Continental European power system increased slightly. The frequency values measured by PMUs in the middle of the Iberian Peninsula (La Cereal) and in the west of France (Saucats) are shown in Figure 14. This frequency difference between the Iberian Peninsula and the rest of the Continental European power system caused a voltage angle difference shift that increased in speed as the frequency

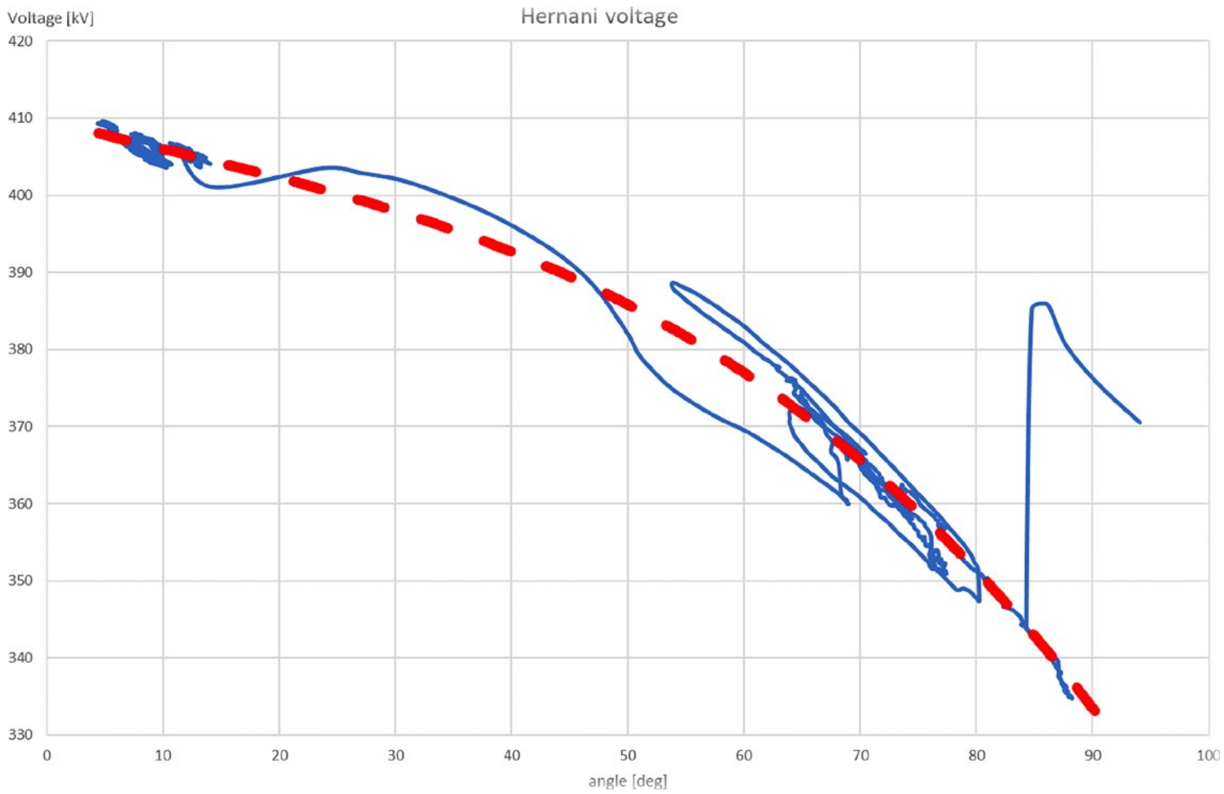


Figure 13: Voltage magnitude versus phase angle difference in Hernani substation – PMU recording (phase angle referred to Bassecourt (CH)).

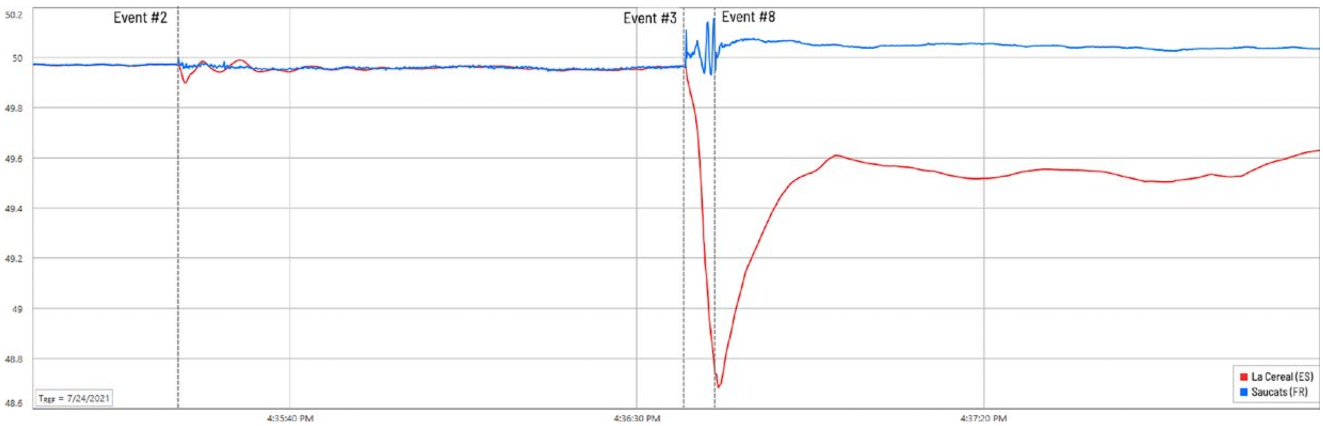


Figure 14: Frequency in Spain (La Cereal) and France (Saucats) as measured by PMUs.

difference increased. The voltage angle difference shift induced an active and reactive power and voltage oscillation between the two zones until the system split at 16:36:41.3 (event #8). The active power oscillations are shown in Figure 15. The nadir frequency measured in the middle of the Iberian Peninsula was 48.681 Hz, being nadir the lowest value of the frequency after a disturbance.

Figure 16 shows the rate of change of frequency (ROCOF) measured in several substations on the Iberian Peninsula. The ROCOF estimation was based on: f(t)– f(t–500ms)/0,5. This calculation was performed every 100 ms. As per SPD recommendations (System Protection and Dynamics subgroup), the ROCOF was calculated in several locations sufficiently far from the affected lines in order to avoid phase jump distortions. Furthermore, ROCOF was also calculated in Hernani that is close to the tripped lines. The higher ROCOF was measured close to the France–Spain border due to the oscillations created locally by transients. In the Hernani substation the maximum ROCOF measured was –1.03 Hz/s. In the southwestern part of the Iberian Peninsula (Carmona (ES), Sines (PT) and Alqueva (PT)) the ROCOF was around –0.7 Hz/s and in the middle (La Cereal), which is the approximate centre of inertia, the ROCOF was around –0.5 and –0.6 Hz/s.

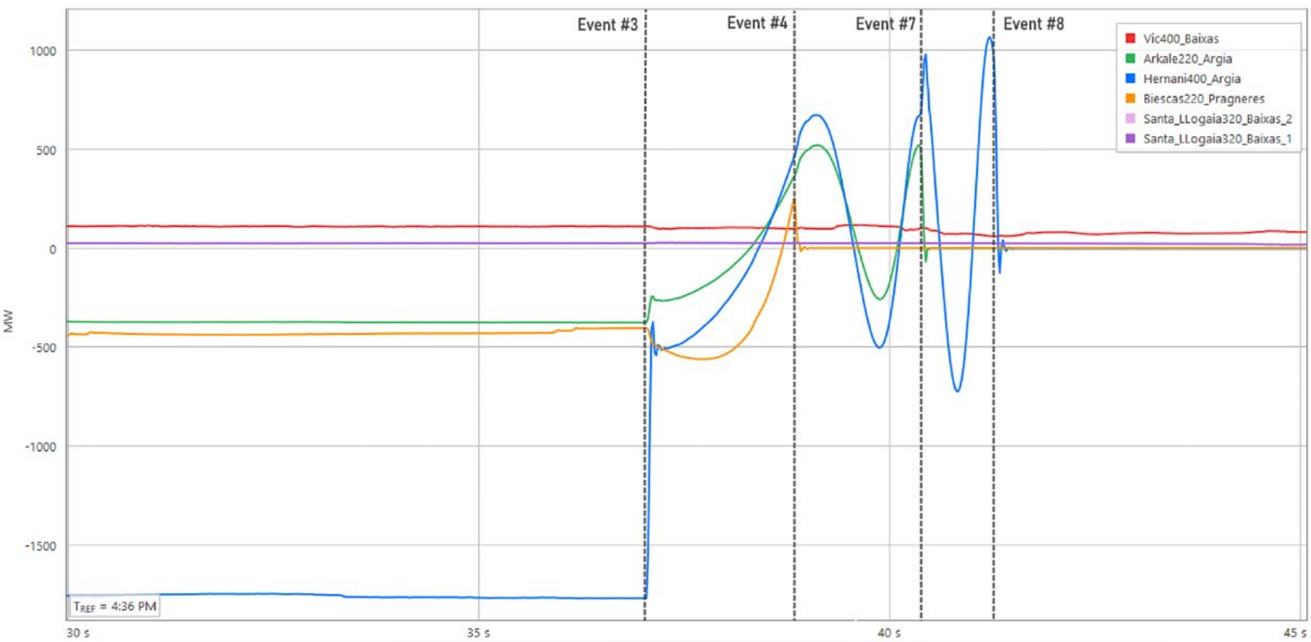


Figure 15: Active power of France-Spain tie lines as measured by PMUs (positive indicates power transfer from Spain to France).

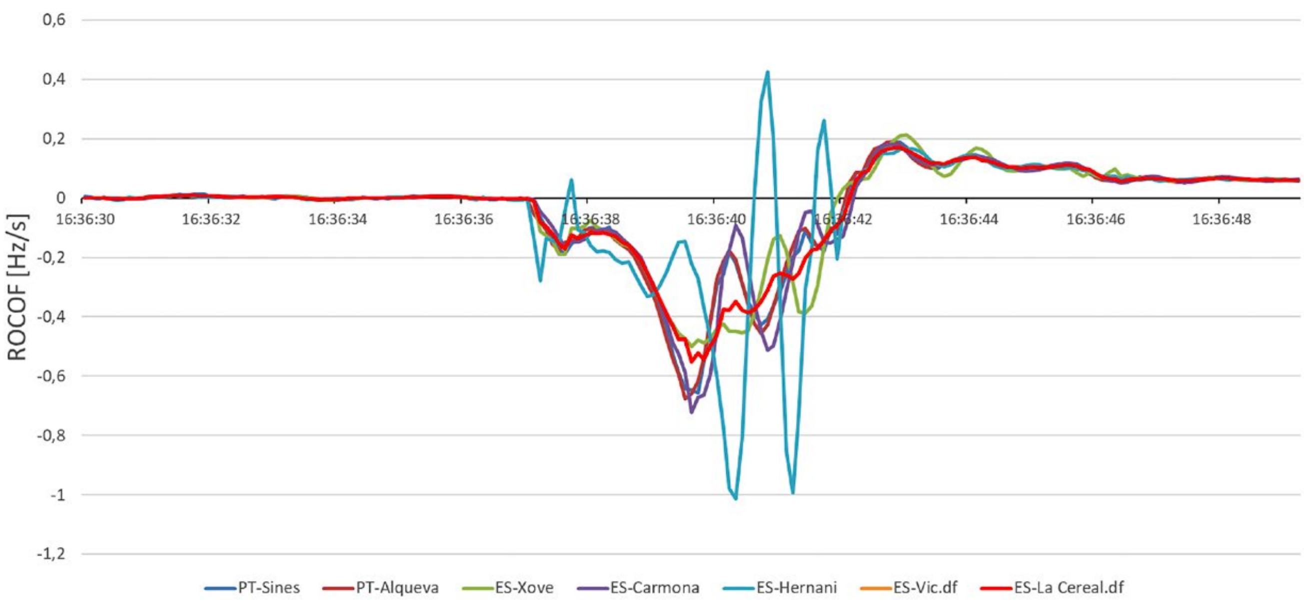


Figure 16: ROCOF measured in several substations on the Iberian Peninsula.

Figure 17 shows in the phase plan (phasor angle difference versus frequency) the overpassing of the so-called 'no return border' (disconnection of the Argia–Cantegrit line) that precedes the complete separation between the Iberian and French grids. Here the phase angle difference was chosen between two substations from each area corresponding to their centre of inertia and consequently the illustrated voltage phase angle difference is representative for the transients before, during and after the system split.

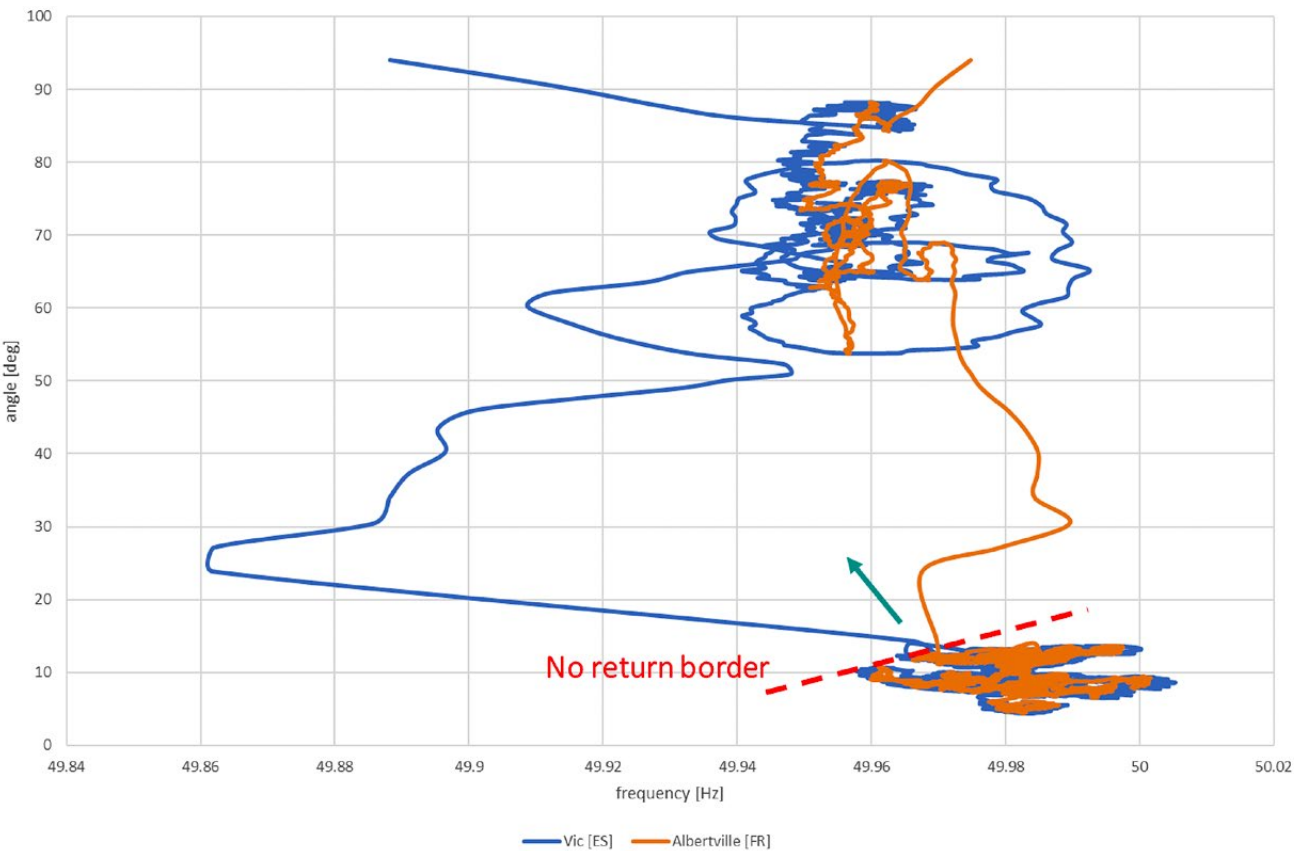


Figure 17: Phase plan (angle difference, frequencies) measured in France and Spain.

4.3 Voltage stability

After the split, high voltages emerged in the Iberian system especially in the north of Spain. These over-voltages were caused by load shedding, the loss of the interconnection lines and the disconnection of coil reactors, which had been disconnected when the voltages were low (before the system separation). Figure 18 shows the voltages measured by the PMUs installed in the 400 kV transmission network at two different times. Figure (a) represents the voltages five seconds before the trip of 400 kV Argia–Cantegrit line (event #3) and Figure (b) represents the voltages approximately one minute after the split, which is when the highest voltages were recorded at the Hernani substation (451.2 kV), close to the Spain–France border.

Figure 19 shows the voltages measured with PMUs in some 400 kV and 220 kV substations in the centre and (mainly) in the north of Spain.

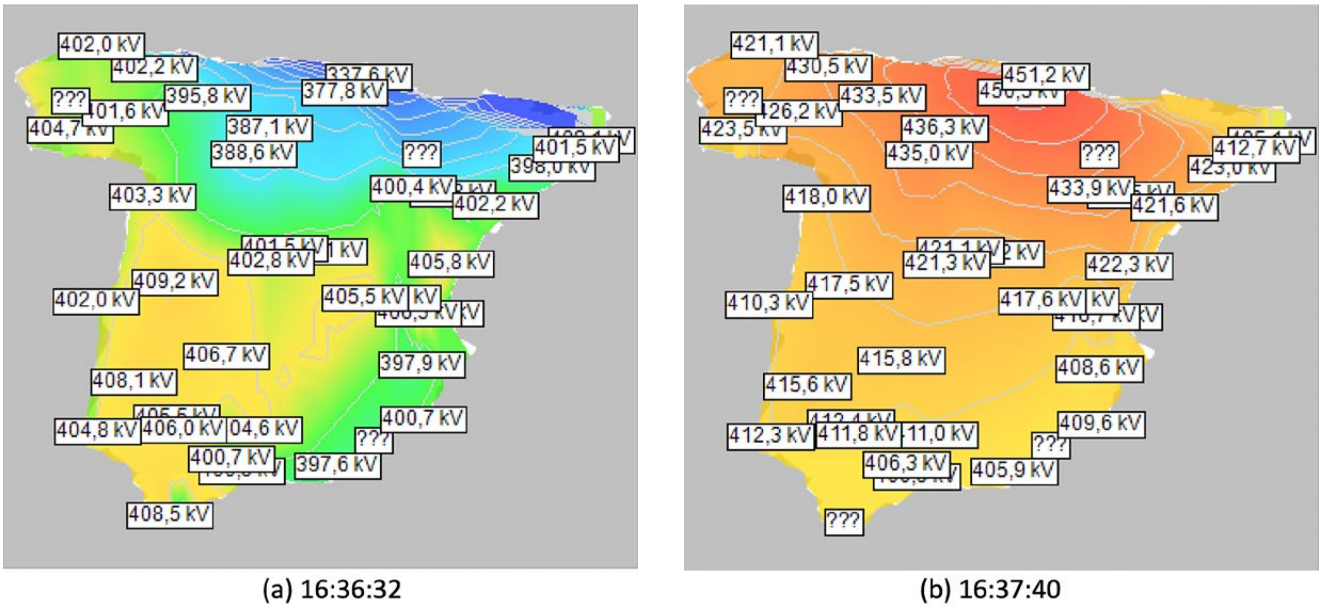


Figure 18: Voltages in Spanish 400 kV network.

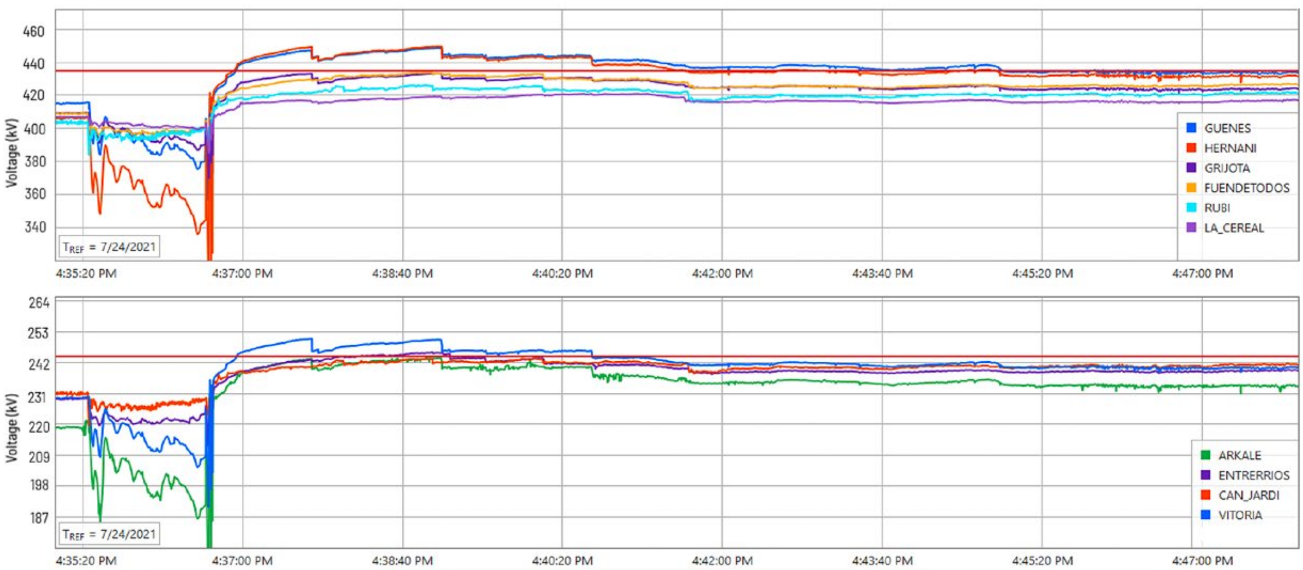


Figure 19: Voltages measured by PMUs at 400 kV and 220 kV transmission networks.

4.4 Behaviour of the Spain-France HVDC

One of the interconnectors between Spain and France consists of a VSC HVDC of 2 × 1,000 MW of nominal power (INELFE HVDC), seen in Figure 20 and Figure 21. This HVDC connects the substations of Sta Llogaia 400 kV (in Spain) and Baixas 380 kV (in France). It runs almost in parallel with the AC interconnection line Vic–Baixas 400 kV forming an AC–DC corridor.

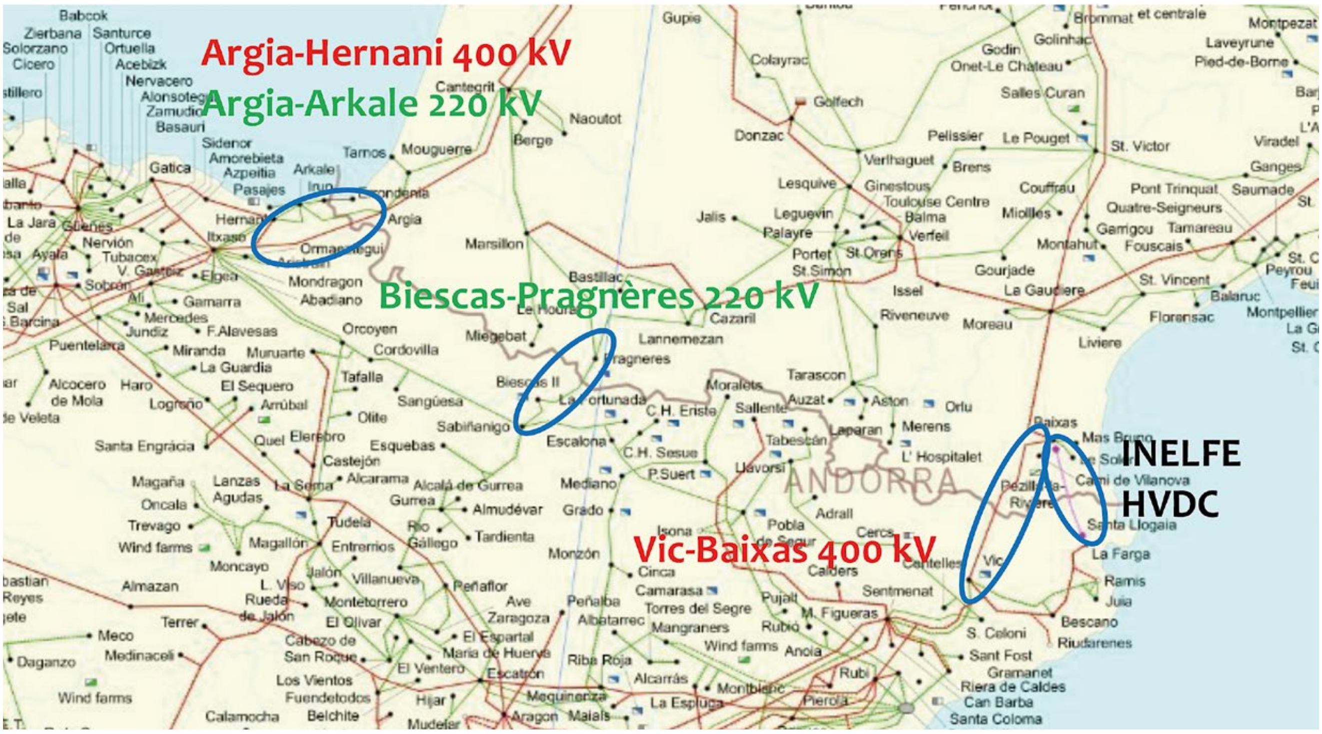


Figure 20: Transmission network in the French-Spanish border.

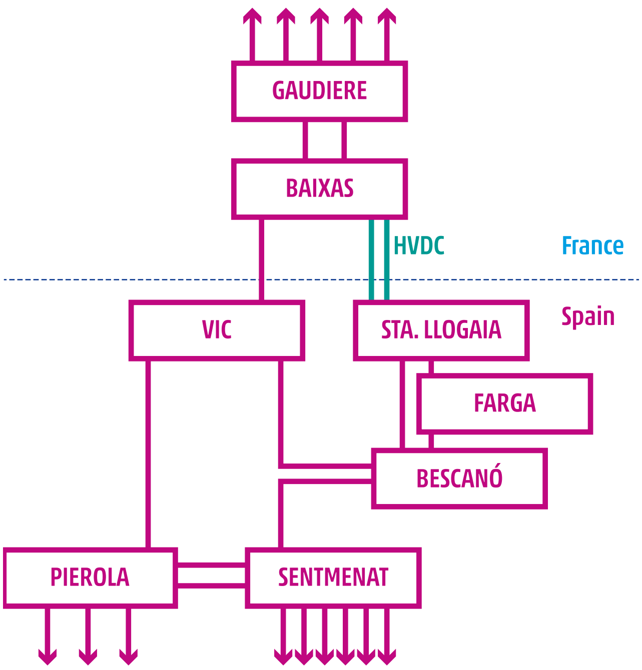


Figure 21: AC-DC corridor formed by the HVDC link and the Vic-Baixas line

During the event, the HVDC and the AC line Vic–Baixas remained connected, supplying energy to the Eastern Pyrenees of France. In Figure 22, the power flow during the system separation event at the AC–DC eastern corridor between Spain and France can be observed.

The HVDC active power control mode is an angle difference control, which emulates the behaviour of the active power transfer of an AC line and adapts smoothly to the new topology and system conditions, as can be seen in Figure 22. In addition, each converter station kept performing a correct voltage control in its terminal substations, assuring voltage stability in the French area that remained fed through the AC-DC eastern corridor and also in the Spanish side of the HVDC.

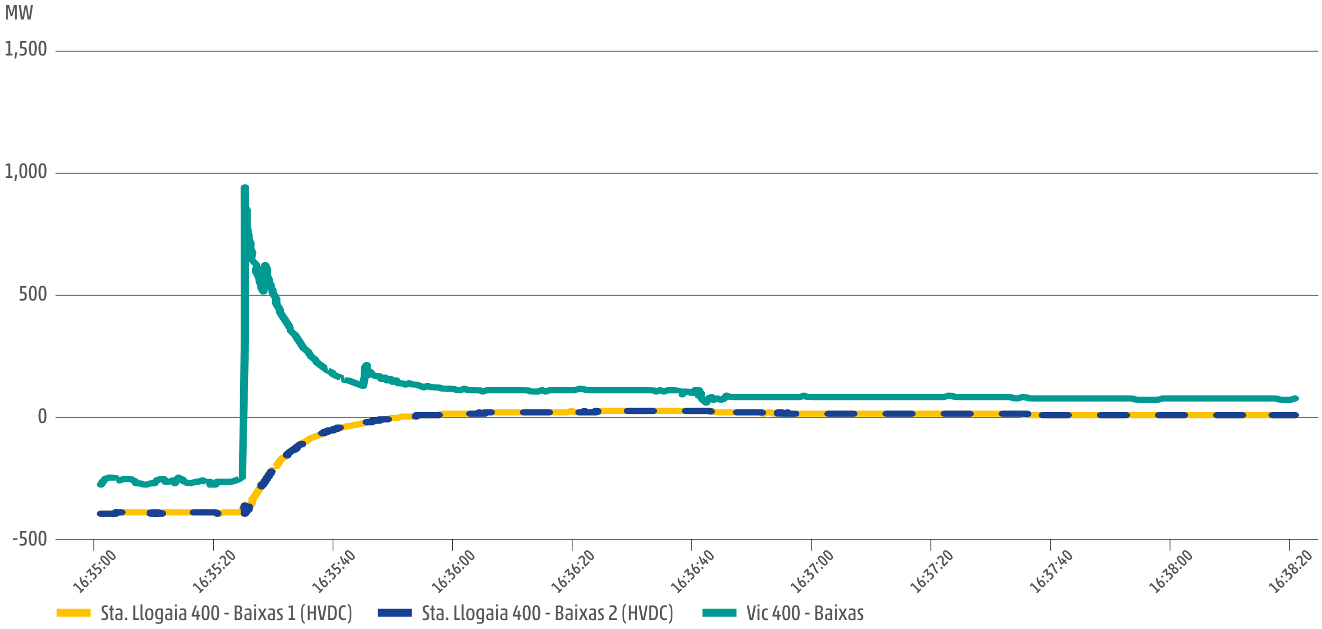


Figure 22: Active power of eastern France-Spain tie lines (positive means power transfer from Spain to France).

4.5 Preliminary Dynamic Analysis Results

This section describes the results of a preliminary dynamic analysis, which serves as an important basis to confirm the registered ROCOF values and evaluate the overall inertia of the system at the moment of the incident. More exhaustive simulation results are still under analysis and will be provided in the next technical report.

A first approach for the dynamic analyses has been made by means of the single busbar model used in ENTSO-E for all kinds of frequency stability studies (defence plans, load frequency disconnection schemes, ROCOF and inertia, etc.). This is a balanced model that, tuned appropriately with information taken from the ENTSO-E Transparency Platform, is able to reproduce the main frequency dynamic of the system and, therefore, confirm major hypothesis and facts of the event such as system inertia, activation of primary regulation, generation and pumping disconnection pattern and load shedding performance.

The model takes as an input the imbalance trend between the Iberian Peninsula and the rest of the Continental European system and the disconnection series for generation, pumps and loads in Spain and Portugal. Then, the results of the simulations are compared to the real measurements and, if needed, the input values are readjusted by means of an iterative process. As these simulations try to reproduce the effect over the frequency of the evolution of the system balance during a fast transient, the resulting adjusted value for the balance refers to the total variation of generation, and not only the reported disconnected generation appearing in this document (Section 4.7 and Section 11).

In the following graphs, the model output for frequency (Figure 23) and ROCOF (Figure 24) in the Iberian Peninsula during the event (starting at event #3) is compared to the real PMU measured value.

The accurate match obtained between model and real behaviour sets the basis for further analyses to be performed with the full dynamic model. The main parameters for the single busbar model are shown in Table 18.

Parameter	Value
System load	35.4 GW
Active power deficit	1,000 MW (at 16:36:37.1)
	1,500 MW (at 16:36:38.7)
System inertia constant (H)	4 s
Self-regulating effect of loads	2%/Hz

Table 18: Main parameters for the single busbar model.

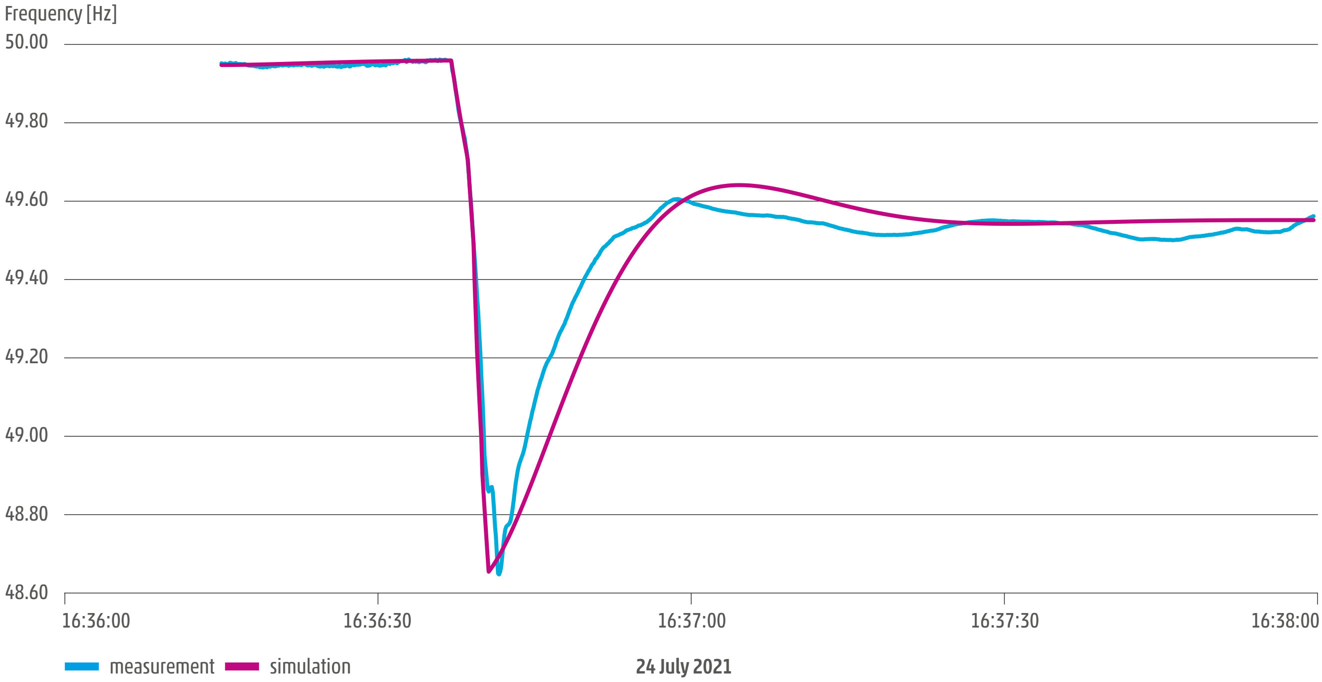


Figure 23: Simulation results (frequency) of the single busbar model and comparison with real PMU measured value (La Cereal).

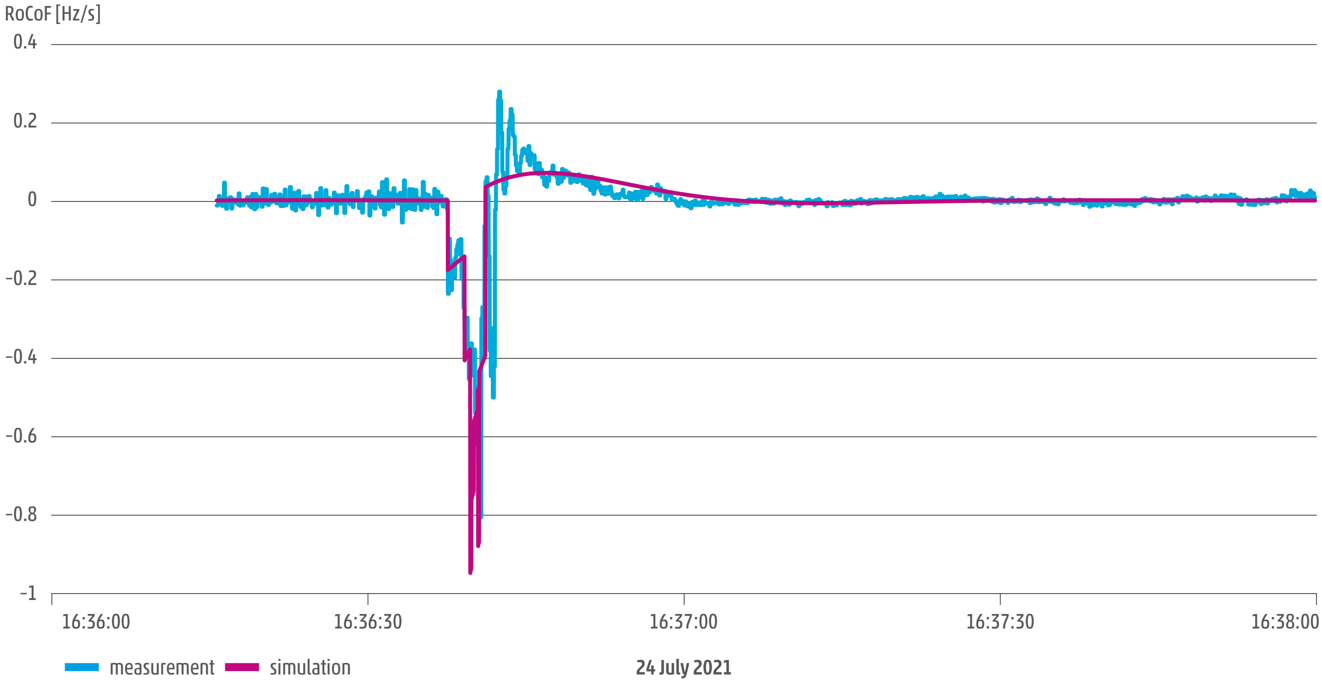


Figure 24: Simulation results (ROCOF) of the single busbar model and comparison with real PMU measured value (La Cereal).

4.6 Automatic defence actions activated

Frequency Support Overview

The frequency deviation in the Iberic Peninsula was higher than 200 mHz, and therefore the frequency containment reserve (FCR) was fully activated. In Spain, the total amount of FCR estimated in the 30 second period after the incident was 376 MW, in line with the total amount of FCR for the Spanish Control Block (380 MW). In Portugal, the peak FCR reached 58.5 MW, which is above the requested value (50 MW). Further details about the frequency support are provided in Section 6.

Low-Frequency Demand Disconnection Overview

The frequency deviation in the Iberic Peninsula also activated automatic low-frequency demand disconnections. In particular, the total amount of load shedding was 4,872 MW (3,561 MW in Spain, 1,246 MW in Portugal and 65 MW in France). The total amount of pumped storage shedding was 2,302 MW (1,995 MW in Spain and 307 MW in Portugal). Further details about the frequency plan and the load shedding are provided in Section 11.

4.7 Loss of generation units

In Spain the type of generation which tripped, except the CCGT of Sabon, was distributed generation, as shown in Table 19. In order to determine the distributed generation disconnected due to the incident, those facilities with a nominal capacity above 1 MW that were producing at 16:33 and which production was zero or close to zero, below 5% of the nominal capacity, at 16:40 have been considered. From the information received from generation control centres, the disconnection criteria for almost 60% of the installations have been derived. It is estimated that the cases reported as over-frequency happened due to the loss of means to evacuate the generation, because of the tripping of its own facilities or because of the tripping of other agent facilities as no over-frequency was recorded during the incident.

Cause	Wind [MW]	Solar FV [MW]	Hydroelectric [MW]	Cogeneration, Thermal RE and waste [MW]	Solar Thermal [MW]	Combined Cycle [MW]	Total [MW]
Loss of other agent facilities	43	105.5	6.9	44.1			199.5
Voltage Out of Step (78)			10.4	24			34.4
Over-Frequency	39.2	3.6	8.3	23.8			74.9
Over-Voltage	254.4	358.5	14.9	218.4		227.7	1,073.9
Ground Over-Voltage	2.8						2.8
Under-Frequency	95	13.9	15.7	55.1			179.7
Under-Voltage	50.7	33.9		25.5	22.3		132.4
Without information	226.9	172.1	19.9	463.1	94.2		976.2
SUM	**712**	**687.5**	**76**	**854.1**	**116.4**		**2,673.8**

Table 19: Disconnection of generation units in Spain.

In Portugal, records indicate that on 24 July at 16:36, a high loss of generation occurred at high voltage and medium voltage levels. This generation loss resulted from the operation of several frequency relays, reaching a total power of **1,015 MW**. From this amount, about 780 MW were due to the distributor's protections, 110 MW were due to the producers' own protections and another 110 MW were due to the branches that were disconnected as part of the load shedding.

Table 20 characterises this loss, by type of generator.

Type	P [MW]
Wind	404
Solar	235
NG Cogen	249
Biomass Cogen	23
Biomass Other	81
Small Hydro	23
SUM	**1,015**

Table 20: Loss of generation by type.

Table 21 describes in a simplified way the lost generation blocks and the corresponding frequency and time delay values.

F [Hz], time delay [s]	P [MW]
49.8	199
49.5	544
49.5 @ 1.5	89
49.5 @ 2.4	122
48.7	61
SUM	**1,015**

Table 21: Loss of generation by frequency threshold.

Finally, it should be noted that in some of the COGEN-type producers considered in the two previous tables, the operation of the frequency relays, in addition to generation, also tripped the associated consumption, causing the formation of islands (with generation and consumption). The reduction in consumption connected to the system, with this origin, reached **172 MW**. Table 22 characterises this reduction.

F [Hz]	Generation [MW]	Consumption [MW]
49.8	57	40
49.5	81	58
48.7	61	73
SUM	**199**	**172**

Table 22: Loss of load of COGEN with corresponding generation.

5 PERFORMANCE OF THE PROTECTION SYSTEM DURING THE INCIDENT

The protection system constitutes a key element in the operation of the electrical system, so that its design, coordination and performance in response to disturbances occurring in the grid determine the quality of supply and the stability of the electrical system. The ultimate objective of the protection system is to try to minimise the impact of disturbances. This section analyses the performance of the protection system during the incident.

5.1 400 kV Baixas–Gaudière 2 line protection

At 16:33:11, a phase-to-phase fault on the 400 kV Baixas–Gaudière 2 line was detected and correctly cleared by line differential protections, acting in 49.4 ms (circuit breaker opening time included). In BAIXAS substation, the fault had also been detected by differential protections, and eliminated in 53 ms (circuit breaker opening time included).

A phase-to-phase fault between phase 0 and phase 8 occurred on this transmission line, and the transient recording gives us the information reported in Table 23. Figure 29 provides a graphical interpretation of the phase naming.

Gaudière Bay					Baixas Bay			
Phase 0	Phase 4	Phase 8	Residual current	Residual voltage	Phase 0	Phase 4	Phase 8	Residual current
12,400 A	980 A	13,300 A	90-100 A	5,000 V	3,400 A	870 A	2,500 A	250 A
179° phase shift between 0 and 8					179° phase shift between 0 and 8			

Table 23: Transient recording analysis.

Table 23 confirms that currents and voltage phase shifts were close to 180° (see also Figure 25 and Figure 26); this behaviour is typical for an isolated phase-to-phase fault. In fact, an angle equal to 180° means that the two currents in Phase '0' and Phase '8' have reverse signs, which means that the fault current flows from one phase ('0') to the other phase ('8'). The fact that the current amplitudes differ and the residual current (the current that flows to ground due to the fault) is not equal to zero, might point towards a very resistive double phase-to-ground fault. It has to be a highly resistive fault, as the residual current to ground is relatively small. This high resistivity of the fault confirms the typical 'fire effect' behaviour that causes a high ionisation of air near the conductors and non-linear high resistance (15 … 20 Ohms).

A dedicated locator device estimates the fault location at 7.8 km from Gaudière substation. Offline calculations of the fault position locate the fault at 8.9 km from Gaudière substation, which confirms the value from the locator device.

Five seconds after this first trip, an automatic reclosing occurred from Gaudière substation. The reclosure attempt was unsuccessful. Consequently, no automatic reclosing occurred from Baixas substation.

The complete sequence of events is clearly evident in Figure 27. The protections on this line demonstrated correct behaviour during the event and worked according to their settings.

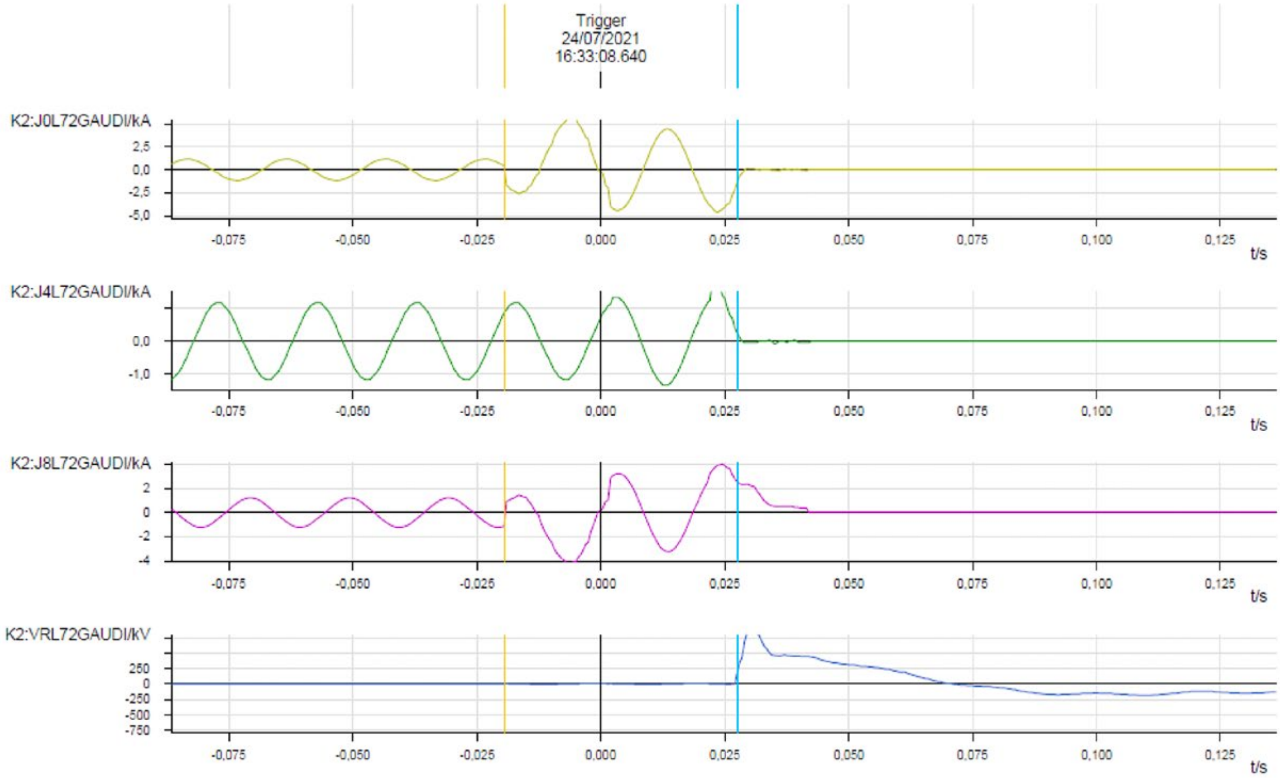


Figure 25: Oscillography recording of currents of Gaudiere bay.

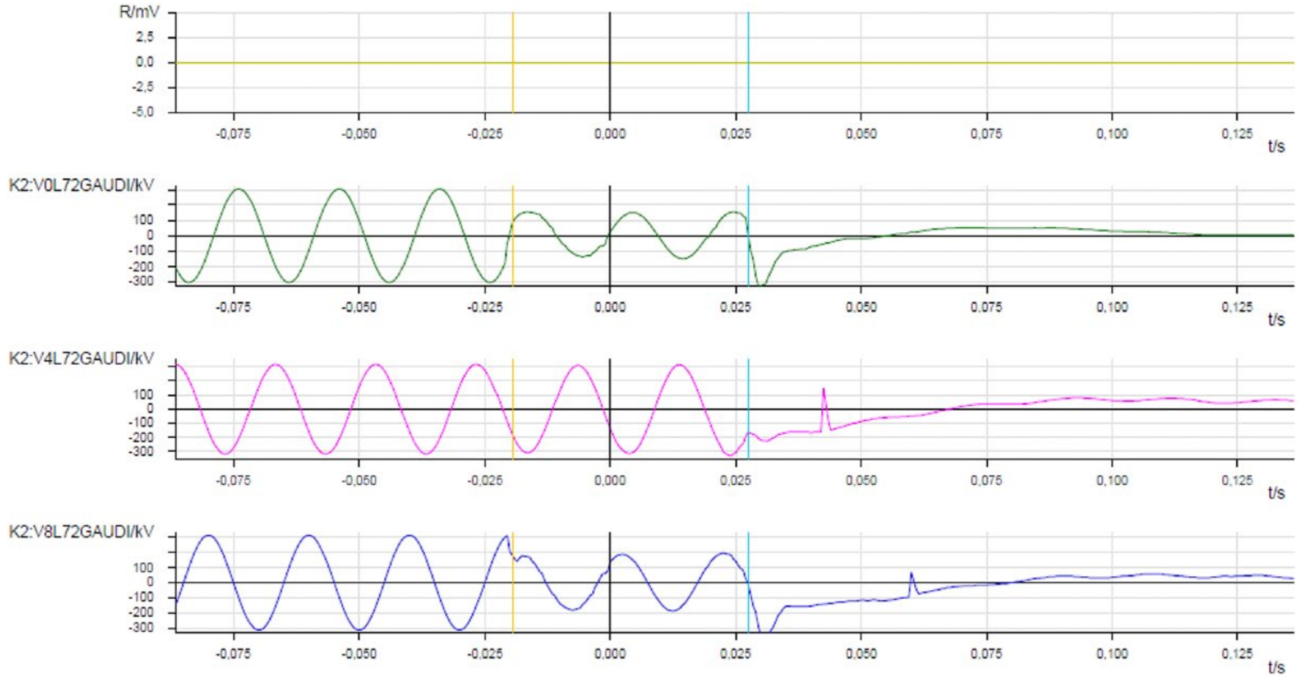


Figure 26: Oscillography recording of voltages of Gaudière bay.

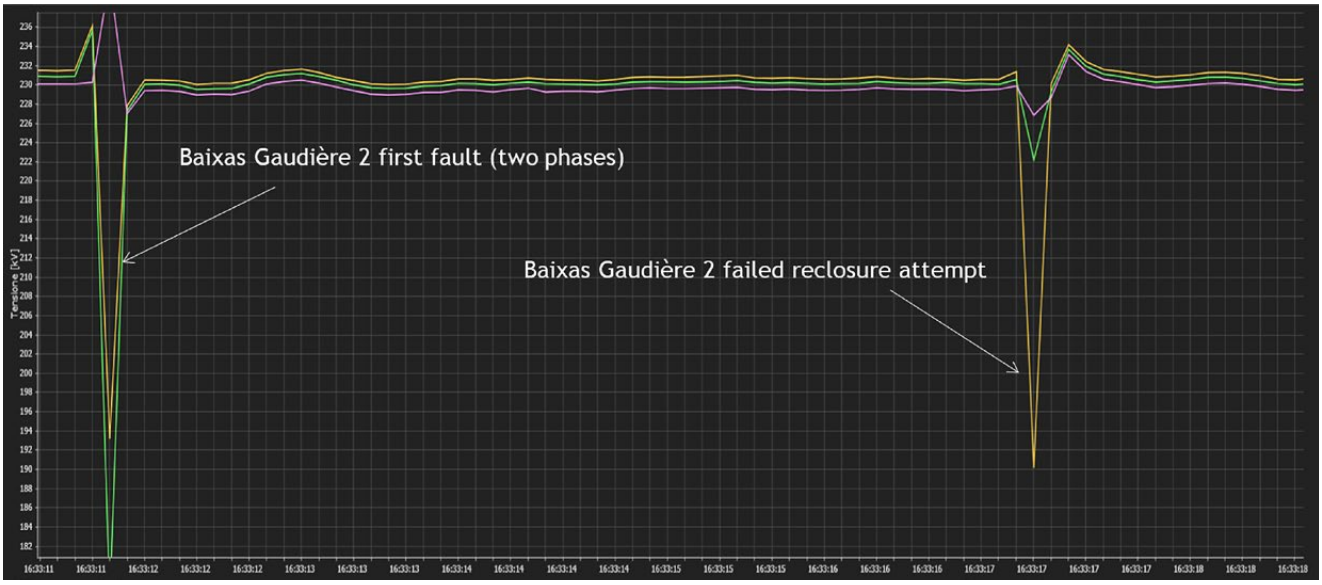


Figure 27: PMU recording of voltages in Baixas (20 ms sampling rate).

5.2 400 kV Baixas–Gaudière 1 line protection

At 16:35:23 the system was in N-1 condition; at the same time, a double circuit fault on the 400 kV Baixas-Gaudière one line had been detected and correctly cleared by line differential protections, acting in 50.6 ms (circuit breaker opening time included). At Baixas substation, the fault had been detected by differential protections, and eliminated in 62 ms (circuit breaker opening time included).

				Gaudière Bay	Baixas Bay
Phase 0	Phase 4	Phase 8	Residual current	Residual voltage	unavailable
10,800 A	1,800 A	12,400 A	140–160 A	5–8.5 kV	
177° phase shift between 0 and 8					

Table 24: Transient recording analysis.

Similar to the first fault, an analysis of the recordings in Table 24 indicates an isolated phase-to-phase fault or a very resistive double phase-to-ground fault. The calculated fault location estimated the fault at 7.2 km from Gaudière substation. SIGRA software locates the fault at 7.8 km from Gaudière substation.

Five seconds after this first tripping, an automatic reclosing occurred from Gaudière substation. No automatic reclosing occurred at Baixas substation, probably due to an exceeded transmission angle (66° was estimated, whereas 60° is the maximum allowed by the protection system). This was confirmed by the PMUs' phase recording as shown in Figure 28.

The protections on this line demonstrated correct behaviour during the event and worked according to their settings.

The fault locations of both 400 kV Baixas–Gaudière lines are consistent with the wildfire area in the Aude region on 24 July (see the map in Chapter 2). Regarding the typology of the line, the phases that tripped are located on the bottom part of the pylons (see Figure 29).

The fault location, temporality and fault types confirm the causal links between the wildfire and the tripping of both Gaudière–Baixas lines.

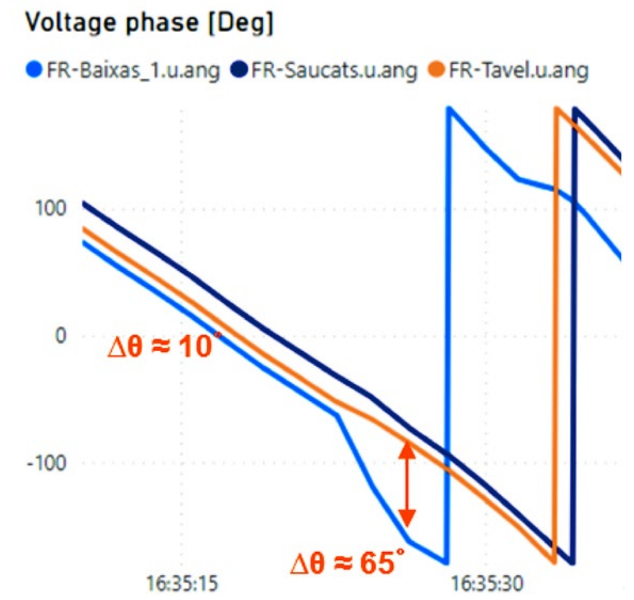


Figure 28: PMUs phase angles.

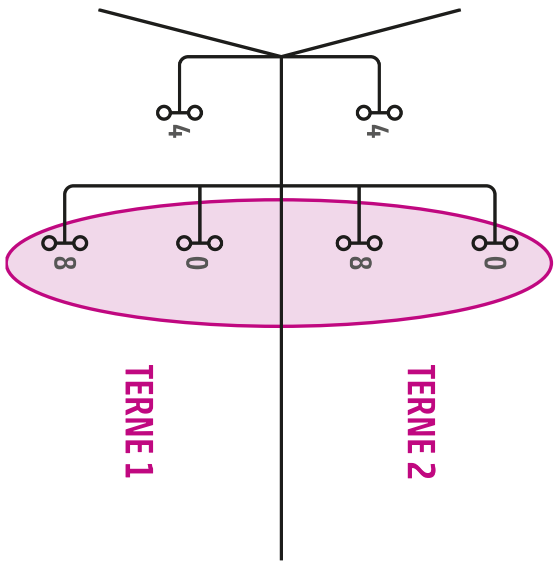


Figure 29: Phase identification on the wildfire area.

5.3 400 kV Argia–Cantegrit line protection

At 16:36:37.0, after the successive trips of Baixas-Gaudière lines, all transit was redirected to the other interconnection lines, mainly located on the Atlantic coast side.

The current intensity on interconnection lines increased between 16:35 and 16:36, as presented in Table 25.

It is worth pointing out that on this transmission line the following scheme applies, depending on I value (intensity of the current):

- If PATL < I < TALT 20′, the overload protection will switch off the line after 20 minutes
- If TALT 20′ < I < TALT 10′, the overload protection will switch off the line after ten minutes
- If TALT 10′ < I, the overload protection will switch off the line after one minute (to avoid tripping due to transient phenomena)

These limits are set respecting the physical operation limits of the transmission line and also to avoid endangering surrounding people, goods and installations close to the line.

The estimated current at 16:36 was higher than the PATL and even higher than the TATL 10′. As expected, overload protection started operating at Argia 400 kV substation, on the Cantegrit outgoing line. The line tripped due to the confirmed overload.

The protections on this line showed correct behaviour during the event and worked accordingly to their settings.

		Argia 400 kV substation, outgoing Cantegrit
16:35	Estimated current [A]	1,742
16:36	Estimated current [A]	3,028
PATL [A]		2,050
TATL 20′[A]		2,400
TATL 10′ [A]		2,800

Table 25: Argia 400 kV substation, outgoing Cantegrit.

5.4 220 kV Biescas–Pragneres line protection

At 16:36:38.40, after the trip of the 400 kV Argia-Cantegrit line, the impedance measured by the relay installed at Biescas substation (parameter shown in Table 26) entered zone 2,400 ms later the distance protection tripped, and the breaker opened at 16:36:38.873. Only the main 1 protection tripped.

		Main 1			Main 2
Prot. functions	Set value [Ω]	Time	Prot. functions	Set value [Ω]	Time
21 (Z1) – phase mho	17.4	0 ms	21 (Z1) – phase mho	17.55	0 ms
21 (Z2) – phase mho	38.5	400 ms	21 (Z2) – phase mho	38.55	400 ms
21 (Z3) – phase mho	63.0	800 ms	21 (Z3) – phase mho	62.80	800 ms

Table 26: Biescas 220 kV bay Pragneres protection settings.

Figure 30 shows the protection recording which confirms that zone 2 of the distance protection (M2P) caused the trip. The power oscillation block function was active, and the relay detected a power oscillation (OSB), but the inverse sequence current exceeded the threshold that enables zone 2 distance tripping (50Q2). In any case, the loss of the synchronism condition had been reached before this tripping, so the line disconnection was inevitable.

Figure 31 is an R / X graph representing the impedance, resistance and reactance, evolution in Pragneres bay at Biescas 220 kV substation during the incident. It has been calculated using PMU data because the protection recording is too short to represent the whole incident. The situation before and after the trip of Baixas–Gaudière circuit 2 (event #1) is represented, in blue the impedance after the trip of Baixas–Gaudière circuit 1 (event #2) in orange, and after Argia–Cantegrit 400 kV trip (event #3) in red.

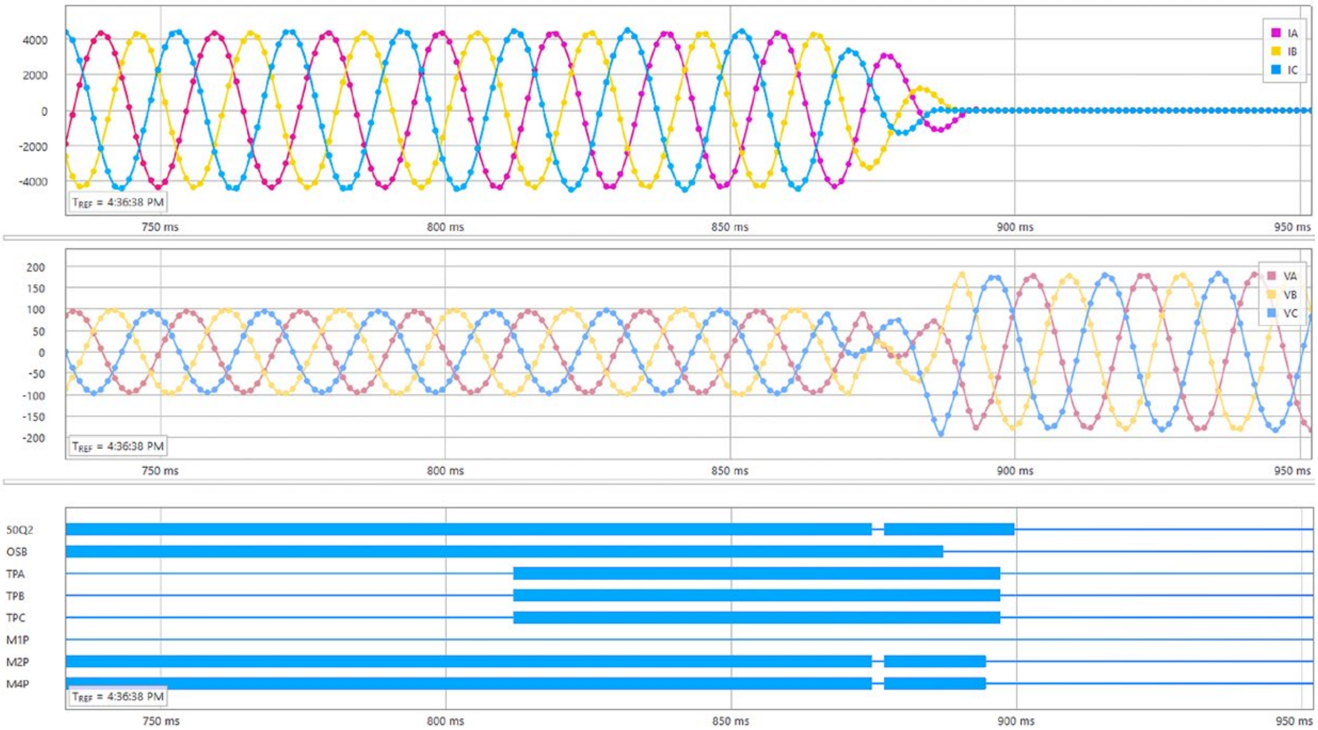


Figure 30: Pragneres bay at Biescas 220 kV substation relay recording.

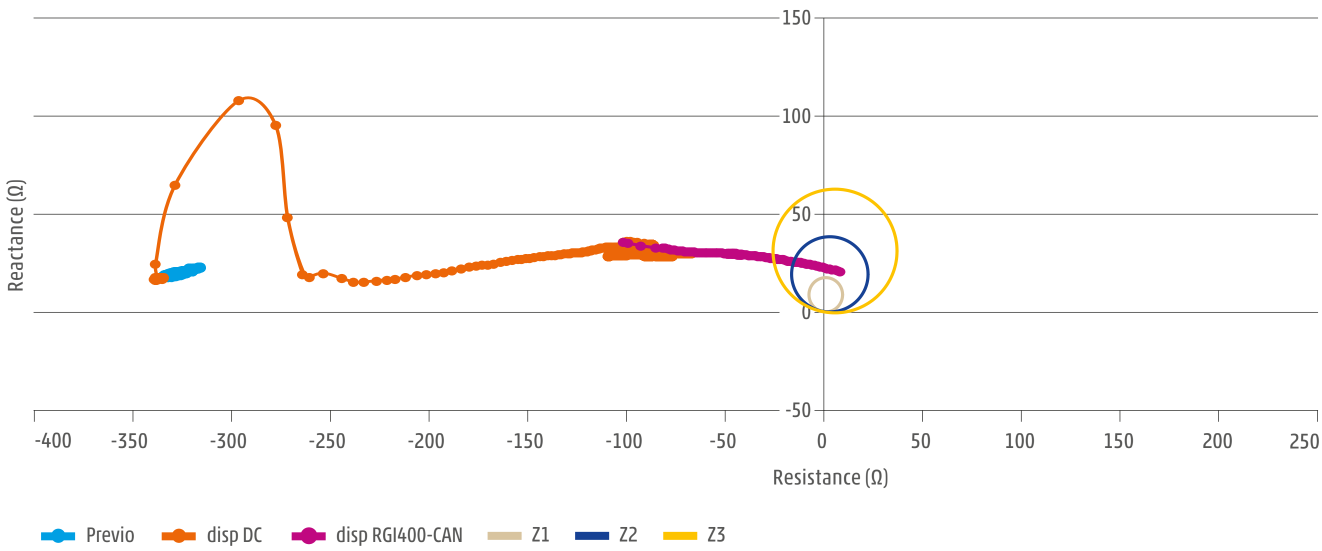


Figure 31: Pragneres bay at Biescas 220 kV substation: Impedance evolution using PMU data.

5.5 400 kV Puerto de la Cruz–Melloussa and Puerto de la Cruz–Beni Harchen

At 16:36:39.18, the 400 kV Puerto de la Cruz–Beni Harchen line opened in Beni Harchen due to an underfrequency protection and also sent a direct transfer trip to the Spanish side (Puerto de la Cruz) that opened a few milliseconds later.

Figure 32 shows the current, voltage, active and reactive power measured by the PMU installed in the line. After the line trip, there was still current and voltage due to the discharge of the submarine cable on the reactor.

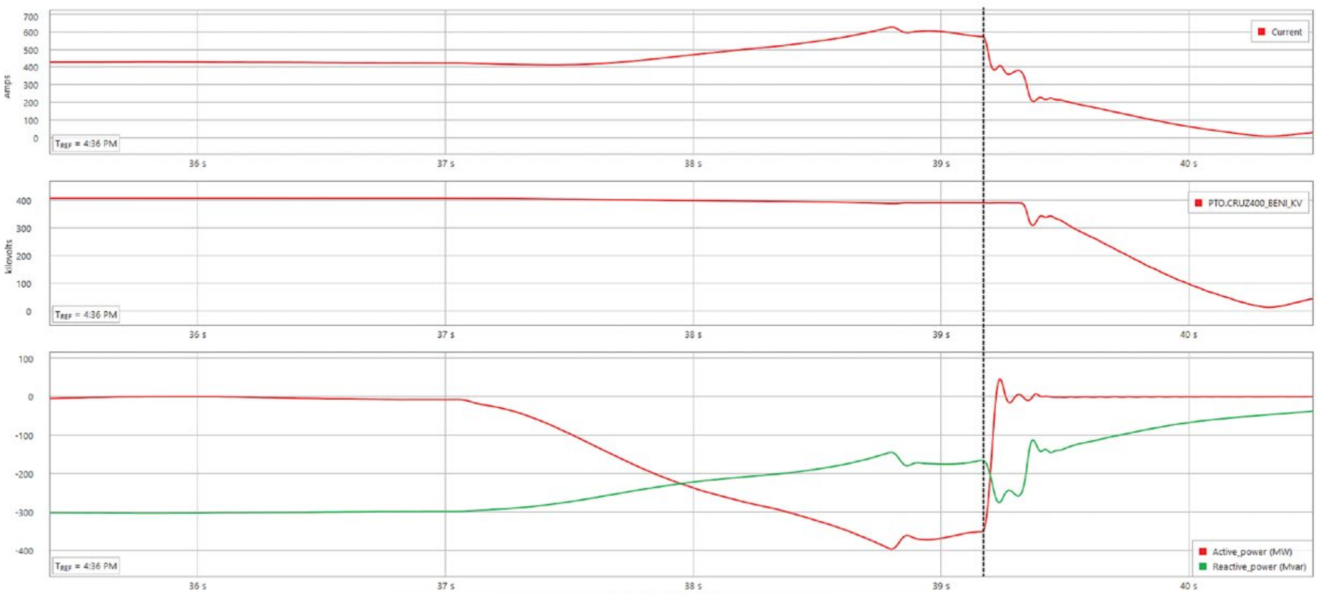


Figure 32: Beni Harchen bay at Puerto de la Cruz 400 kV substation PMU recordings.

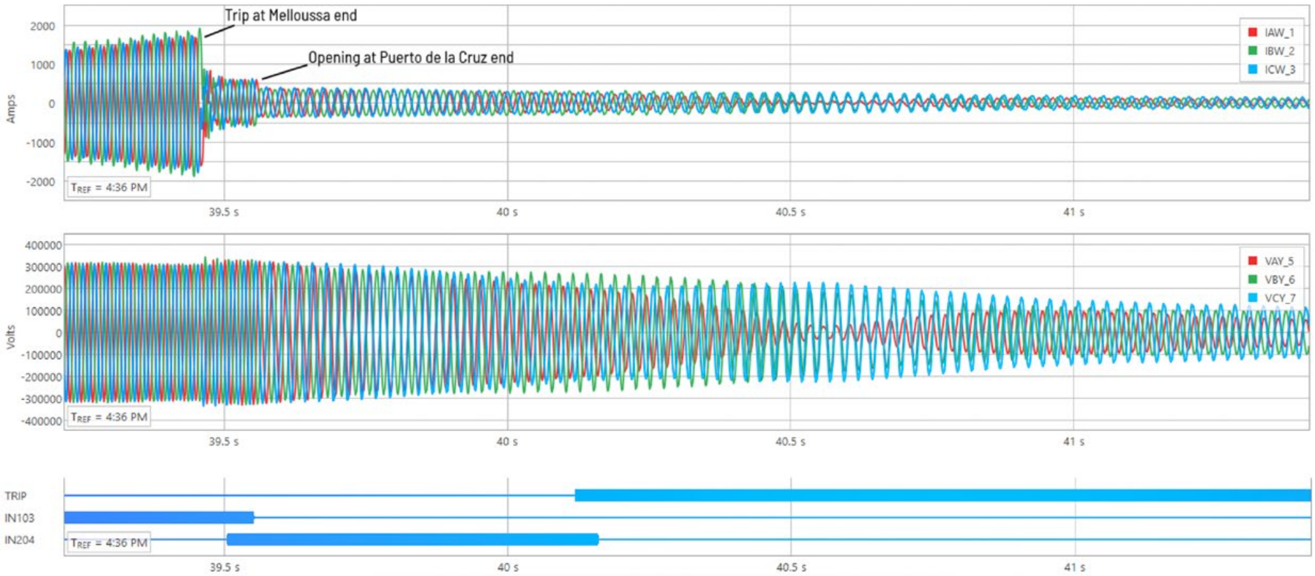


Figure 33: Melloussa bay at Puerto de la Cruz 400 kV substation relay recording (IN103: breaker position, IN204: direct transfer trip reception).

At 16:36:39.458, the 400 kV Puerto de la Cruz–Beni Harchen line opened in Melloussa due to an underfrequency protection and also sent a direct transfer trip to the Spanish side (Puerto de la Cruz), which opened 103 milliseconds later.

Figure 33 shows the recording of the protection installed in the Melloussa bay at the Puerto de la Cruz 400 kV substation. The recording shows how the Moroccan end of the line tripped and indicates that it sent a direct transfer trip to the Spanish end. Additionally, Figure 33 shows a trip signal, but this operation happened when the breaker was already opened. This relay operation was caused by the discharge of the submarine cable on the reactor as there was current with a low voltage. The protections of both interconnectors displayed the correct behaviour during the event and worked according to their settings.

5.6 220 kV Arkale–Argia line protection

At 16:36:40.451, the 220 kV Argia–Arkale line opened in Arkale due to the tripping of the out of step DRS protection.

The DRS protection ('Détection Rupture de Synchronisme') permanently measures the voltage peak values. When the relay measures at least ten consecutive decreasing peaks followed by four consecutive increasing peaks, it detects one beat if the minimum voltage reached is below a configured voltage threshold. After detecting the configured number of peaks, the relay is ready to trip, and it will trip after a time delay that starts when the average RMS voltage during the oscillation is exceeded, as seen in Figure 34. The DRS settings at the 220 kV substation Arkale are shown in Table 27.

DRS protection

Setting	Set value
Beat numbers	2
Voltage	65%
Switch time	30 ms

Table 27: DRS settings at Arkale 220 kV substation.

Figure 35 shows the digital fault recorder (DFR) oscillography that confirms the operation of the out-of-step protection. Figure 36 shows the voltage PMU recordings in Arkale 220 kV. In this record it can be seen how the relay tripped after the second beat.

The protections worked according to their settings during this event. The current assessment is based only on the Spanish side protection system operation.

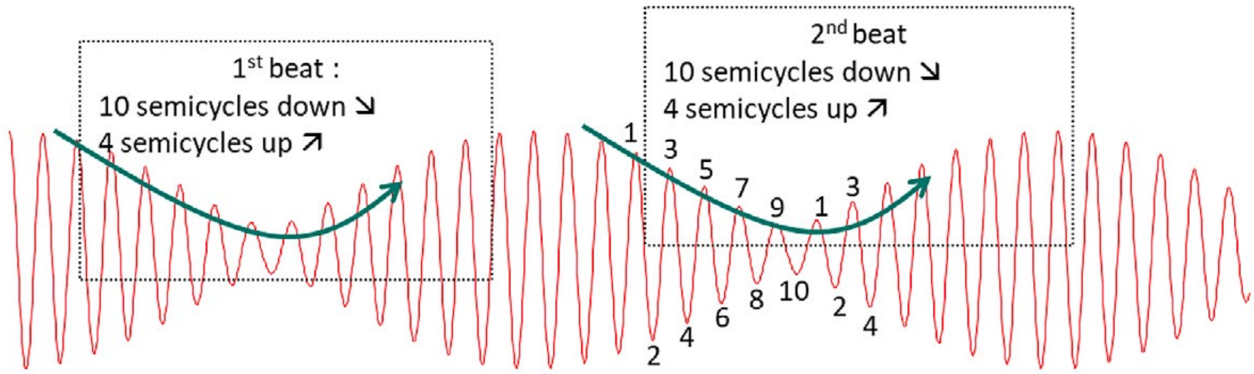


Figure 34: DRS operating principle.

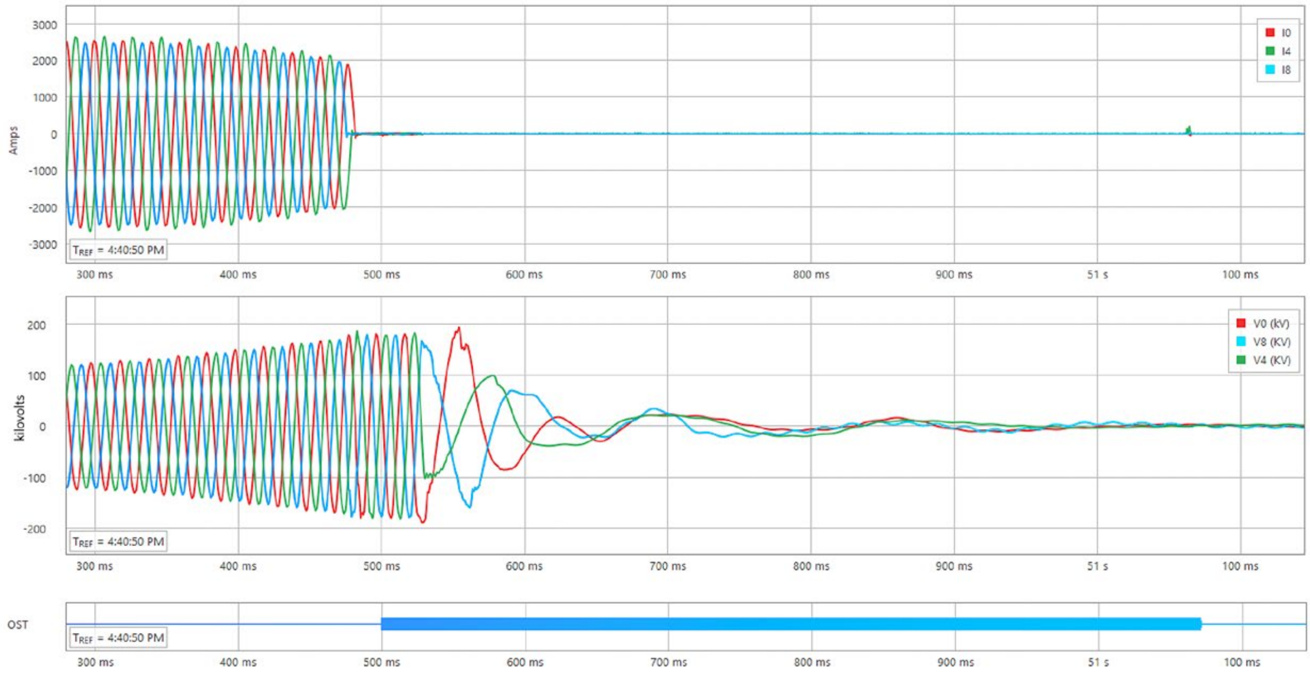


Figure 35: Arkale 220 kV bay Argia DFR recording (device not time synchronised).

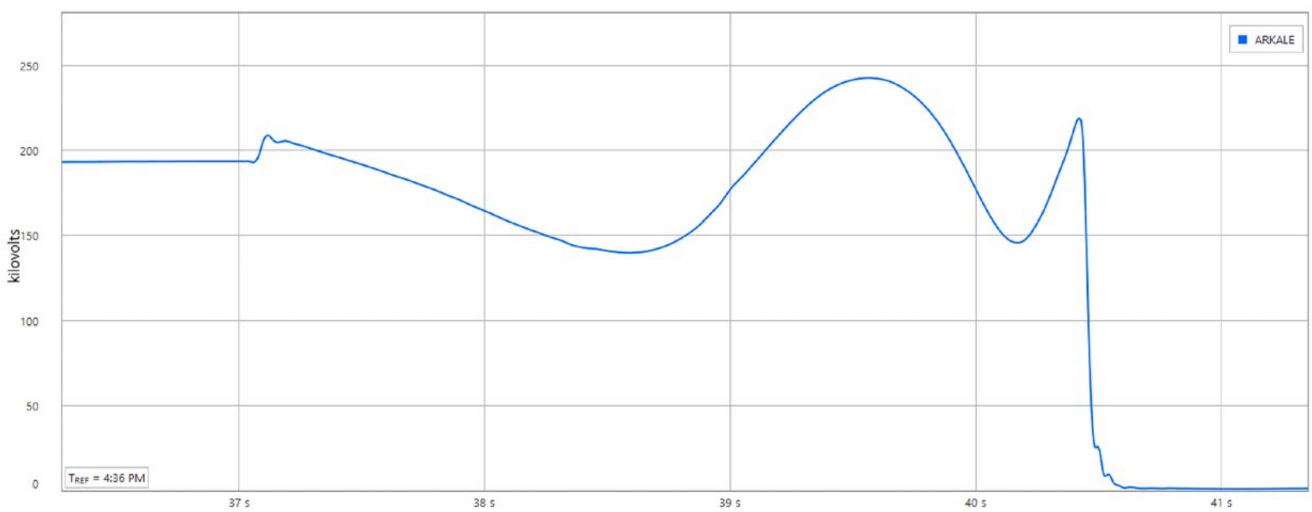


Figure 36: Arkale 220 kV voltage.

5.7 400 kV Argia–Hernani line protection

At 16:36:41.3, the 400 kV Argia–Hernani line opened in Argia due to the tripping of the out-of-step protection DRS.

Focus on Protections against Loss of Synchronism ('DRS')

After the Argia–Cantegrit 400 kV tripping, the only synchronising links between France and Spain remaining were Biescas–Pragneres 220 kV, Argia–Arkale 225 kV and Argia–Hernani 400 kV. These three lines were connected to the French network via three links:

- Cantegrit–Mouguerre 225 kV (only UHV link remaining on the Atlantic coast) ensuring the Cantegrit > Mouguerre > Argia > Spain link.
- Marsillon–Pragneres 225 kV, Cazaril–Lannemezan 225 kV and Lannemezan-Pragneres 225 kV.
- 63 kV axis between Marsillon and Mouguerre.

Those links were not strong enough (the impedance was to high) to maintain frequency synchronisation between France and Spain leading to a loss of synchronism.

Protection against loss of synchronism is part of the defence protection scheme implemented by RTE. It monitors voltage on the line where protections are installed in order to detect voltage beats. It triggers the opening of the line according to defined settings (voltage thresholds and number of voltage beats).

The overall scheme for the protection against loss of synchronism in France is designed with 19 consistent zones (oscillations of rotating machines, similar frequency beats). In the case of a loss of synchronism leading to voltage beats, loss of synchronism protections will support the preservation of 'healthy' zones. At the 400 kV and 225 kV levels, loss of synchronism protections are located at both ends of a line. At lower voltage levels, loss of synchronism protections are only located at one end of a line.

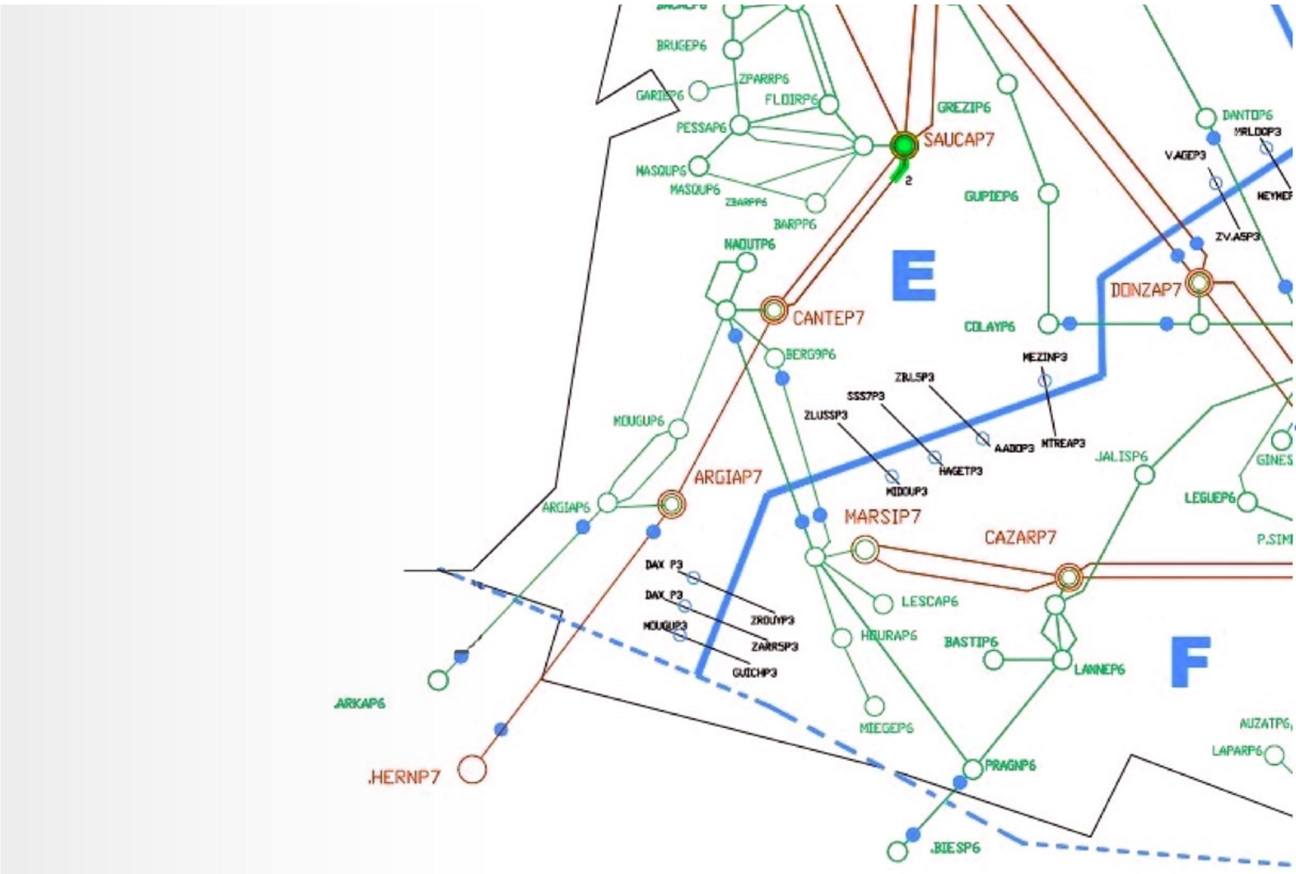


Figure 37: "E" DRS area, with connection lines with "F" area. Red lines: 400 kV, Green lines: 225 kV, Black lines: 63 kV

Transmission line	Nr. Voltage beats	Voltage thresholds [%]
63 kV lines	1	80
225 kV lines	2	65
Argia-Hernani 400 kV	2	65

Table 28: DRS settings for the 'E' area.

Voltage beats	Voltage thresholds [%]
First voltage beat	71
Second voltage beat	64
Third voltage beat	60

Table 29: Voltage beats at the Argia 400 kV substation.

The Basque Country region is located in the 'E' DRS area (see Figure 37), defined by:

» South: Argia–Arkale 225 kV and Argia–Hernani 400 kV interconnection lines.

» South-East: Link to the 'F' DRS area is ensured by the following lines: 225 kV Cantegrit–Marsillon and Berge-Marsillon; 63 kV Guiche–Mouguerre, Dax–Arriosse–Orthez, Dax–Rouye–Lacq–Marsillon, Midour–Naoutot–Lussagnet, Hagetmau–St Sever, Aire s/ Adour–Naoutot–Borderes et Lamensan and Mezin-Montreal. On the 24 July, these 63 kV tripped around 16:36:40.

Each of the protections against loss of synchronism mentioned above is expected to have the same behaviour, see Table 28. NB: It is expected to be considered by the protection, actual voltage thresholds must be lower than the value given in Table 28.

During this event, three voltage beats occurred in about four seconds.

» The first voltage beat caused the 63 kV transmission lines to trip;

» The third voltage beat caused the 400 kV Argia-Hernani transmission line to trip.

Figure 38 shows the voltage beats measured at Argia 400 kV substation, on Hernani outgoing. This figure gives the depth[1] of each one of these beats (see Table 29).

The first voltage beat was not deep enough to be taken into account by the protection, which explains why the line tripped only after the 'third' voltage beat. Thus, the protection operated as expected.

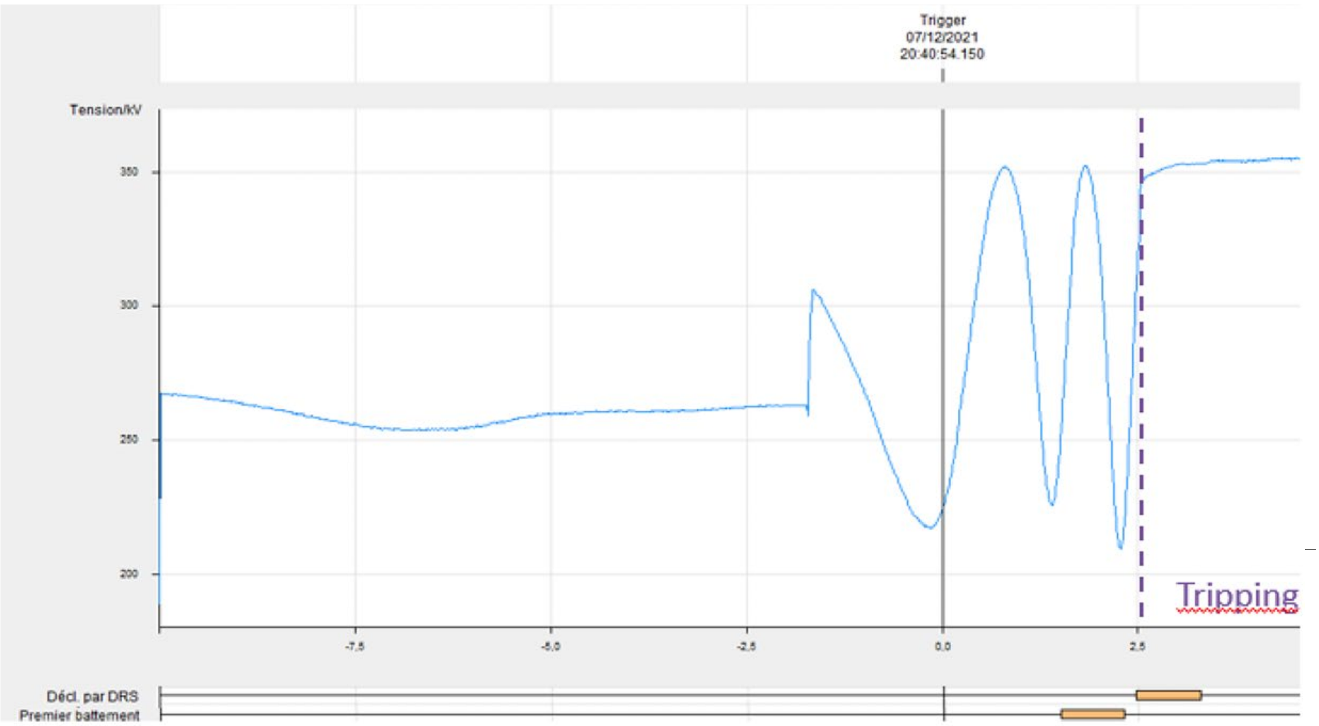


Figure 38: Voltage beats at Argia 400 kV substation (device not time synchronised).

1 Beating depth corresponds to the ratio between the lowest value of voltage of the beat and the 'peak' value of voltage just before the beat

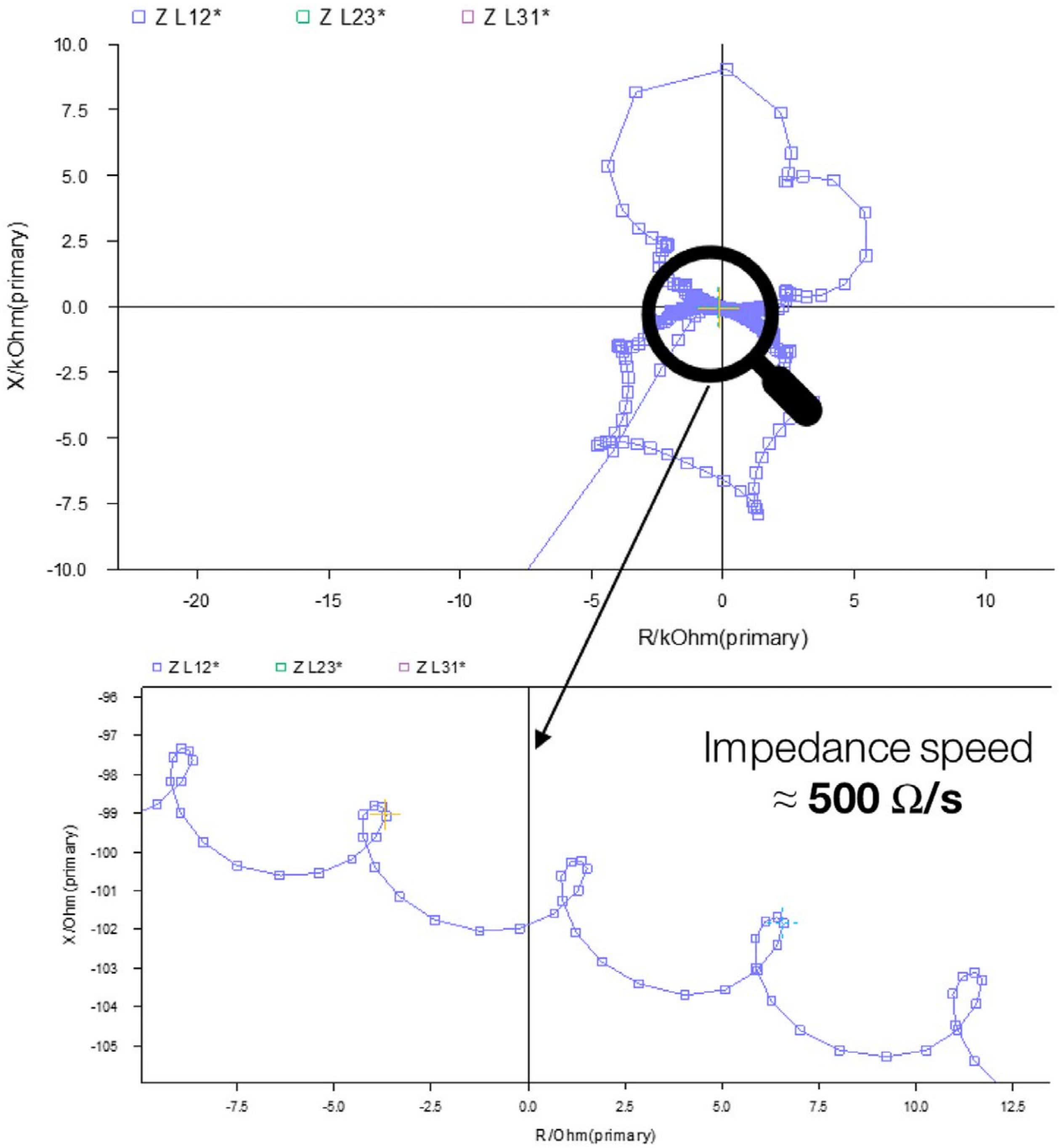


Figure 39: impedance trajectory seen by protection.

6 FREQUENCY SUPPORT AND ANALYSIS

6.1 Activation of Frequency Containment Reserves (Primary Control)

The frequency deviation on the Iberian Peninsula was very high in the first minutes after the separation, requesting the activation of the full amount of frequency containment reserve (FCR) in Spain and Portugal. According to ENTSO-E requirements for 2021, the frequency containment reserve in Spain has to be 380 MW and 50 MW in Portugal.

Since the frequency deviation was much higher than the predefined 200 mHz, REE and REN were required to activate the full amount of FCR within 30 seconds. According to the real-time unit's active power SCADA measurements, REE practically fulfilled the requirements with the delivery of 376 MW. In Portugal, the frequency containment reserve response was satisfactory as well. In the peak it reached 58.5 MW, which is above the requested value. To conclude, on the Iberian Peninsula the frequency containment reserve responses were fast enough and the requested quantity was delivered. The frequency change in the main part of the CE synchronous area network was not sufficient and did not allow TSOs to check the response of the units participating in the FCR.

The FCR from units (or aggregations of units) which provided FCR after the incident was measured by considering the variation of the power output of the units from 16:36:36. The total amount of FCR estimated in the 30 second period after the incident is similar to the total amount of FCR for the Spanish Control Block (380 MW).

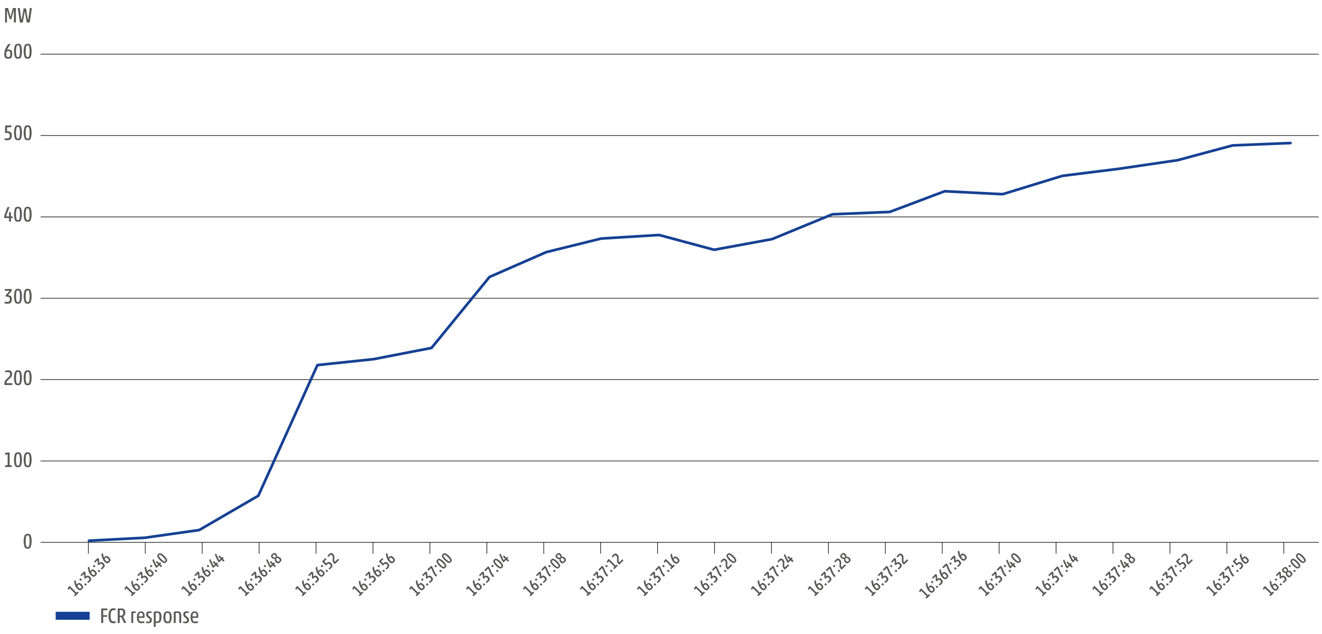


Figure 40: FCR activation in CB Spain.

6.2 Activation of automatic Frequency Restoration Reserves (aFRR) (Secondary Control)

Figure 41 presents the evolution of aFRR activation. Right after the incident, aFRR sharply increased, as the frequency mode was automatically activated in the Spanish Control Block at 16:36:44, after the Iberian Peninsula disconnected from Continental Europe and the frequency drop went below 49.7 Hz, as seen in Figure 42.

At 16:39:09, the absolute value of frequency deviation dipped lower than 250 mHz, and the frequency mode was automatically switched off because the LFC did not detect that the Iberian Peninsula was still disconnected from Continental Europe. The reason for this was that the tie line Vic–Baixas remained connected, feeding the load in the Baixas node. Due to this fact, the Spanish LFC output gave a downward signal from 16:39:09 until 16:42:08, when the exchange schedule was manually set to 0. The subsequent variations of aFRR activation happened due to the frequency deviation evolution. Additionally, starting at 16:55, a downward signal was generated in the system due to the ramping of the exchange scheduled for 17:00, which was later manually corrected and set to 0. REE was the frequency leader and the resynchronization leader, according to the predicted scenario in the REE–REN agreement.

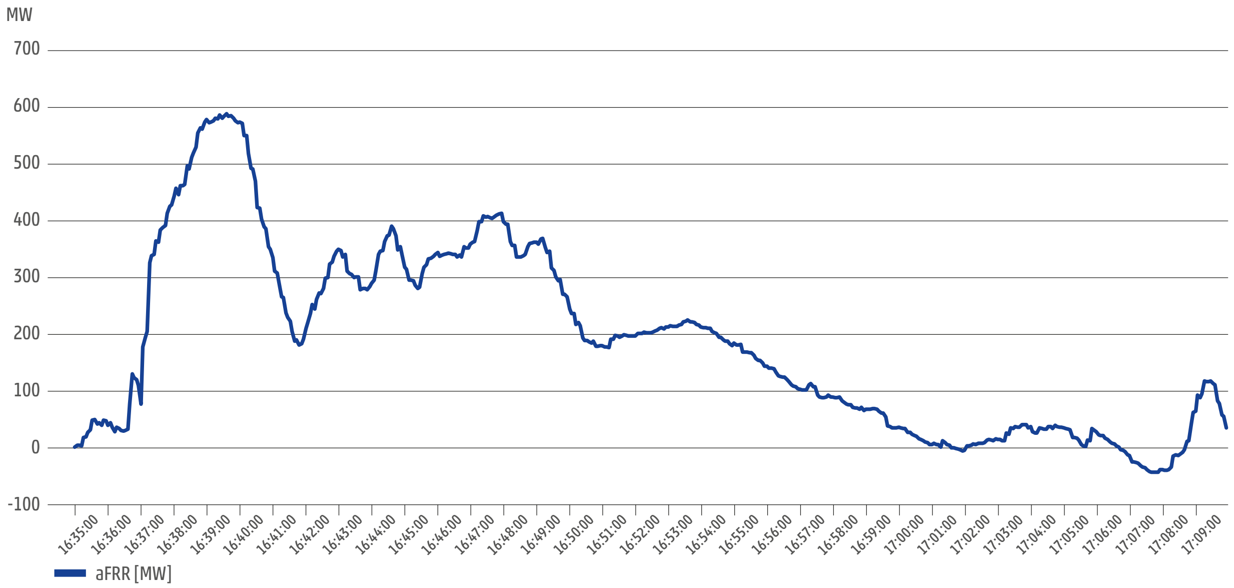


Figure 41: aFRR activation in CB Spain.

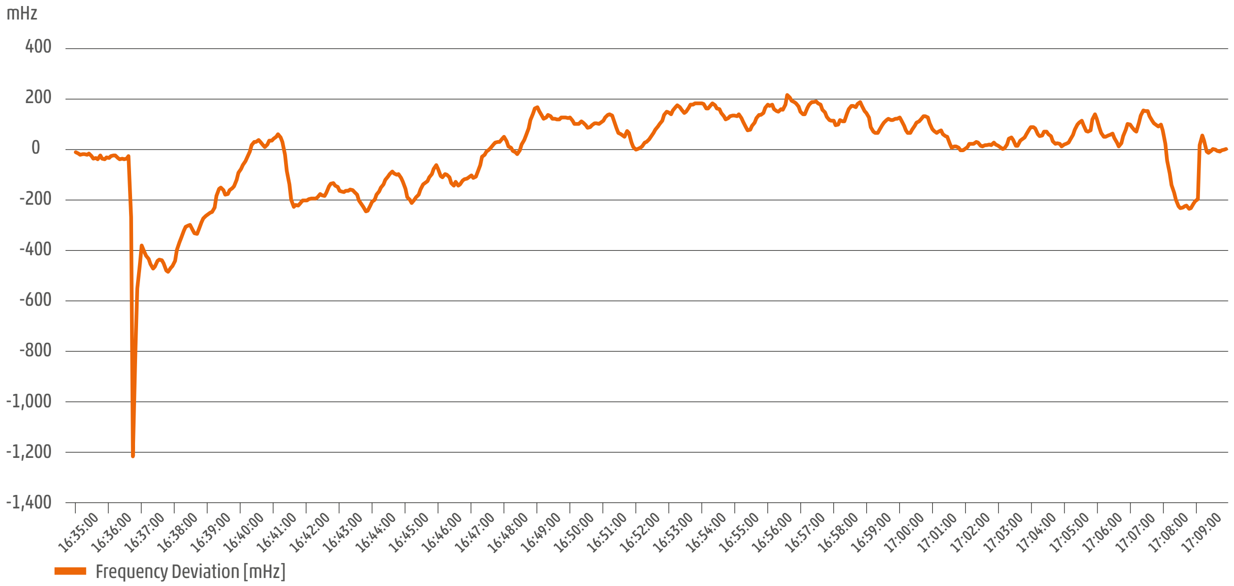


Figure 42: Frequency deviation in Iberian Peninsula.

6.3 Manual countermeasures and system stabilisation in individual areas

In Spain several manual frequency restoration reserve (mFRR) activations took place:

- At 16:29 (previously to the incident) downward mFRR of 477 MW were requested. The activation was effective at 16:40.
- At 16:38 upward 1,008 MW were requested. The activation was effective at 16:45.
- At 16:45 upward 567 MW were requested. The activation was effective at 16:50.
- At 16:58 downward 1,125 MW were requested. The activation was effective at 17:00.
- At 17:21 upward 680 MW were requested. The activation was effective at 17:30.
- At 17:30 upward 907 MW were requested. The activation was effective at 17:35.

In Portugal, after the incident, there were no manual actions in the period just after the separation.

France remained connected to the main part of the interconnection. The frequency changed just slightly, and there was no need for mFRR activation.

7 RESYNCHRONISATION PROCESS

7.1 Preconditions for system resynchronisation

Once the incident occurred, the highest priority was to stabilise the Iberian Peninsula System in terms of voltage and frequency and to prepare the resynchronisation with the European Continental System. During the first few minutes the resupply of load previously disconnected was not allowed due to the frequency relays activation. Once the frequency value reached 50 Hz, the progressive resupply of load was authorised stepwise (no higher than 200 MW) aimed at bringing the Iberian Peninsula frequency close to the European Continental System.

7.2 Preparatory actions

It was agreed to perform the reconnection by energising the L-400 kV Hernani-Argia line from Argia 400 kV and synchronising from Hernani 400 kV using its synchro-check once the frequency was stable and the frequency difference between areas was low.

7.3 Resynchronisation sequences

The lines which tripped during the incident were reconnected according to the following sequence:

- The resynchronisation with the Continental European System was performed at 17:09 by energising the 400 kV Hernani-Argia line from Argia 400 kV and synchronising at Hernani 400 kV.
- At 17:17 CET RTE reconnected the 400 kV Baixas–Gaudière 1 line.
- At 17:28 CET the 220 kV Biescas–Pragneres line was reconnected.
- At 17:33 CET the 220 kV Arkale–Argia line was reconnected.
- The 400 kV Baixas–Gaudière 2 line remained unavailable. RTE reconnected it on 25 July at 13:46 CET.

It is worth mentioning that due to an increase in the frequency difference between systems during the process of reconnecting, the frequency difference was 218 mHz. After the resynchronisation, a power oscillation was observed on the 400 kV Hernani–Argia line and on the frequency. The power oscillation had a frequency of 0.20 Hz and an amplitude of 1,840 MW peak–peak, which disappeared in approximately 30 s, leaving a load in a steady state of 500 MW through the 400 kV Hernani–Argia line.

8 N-1 SECURITY EVALUATION

8.1 Contingency analyses

The operational security of any power system relies on respecting the operational security limits and on the application of the N-1 Operational Standard, which states that any single contingency should not endanger the system.

Contingency analyses are performed by RTE pursuant to SOGL Article 34.

Article 34 of European Union's System Operation Guideline (Regulation 2017/1485 of the European Commission) stipulates in particular that:

> *1. Each TSO shall perform contingency analysis in its observability area in order to identify the contingencies which endanger or may endanger the operational security of its control area and to identify the remedial actions that may be necessary to address the contingencies, including mitigation of the impact of exceptional contingencies.*
>
> *2. Each TSO shall ensure that potential violations of the operational security limits in its control area which are identified by the contingency analysis do not endanger the operational security of its transmission system or of interconnected transmission systems.*
>
> *3. Each TSO shall perform contingency analysis based on the forecast of operational data and on real-time operational data from its observability area. The starting point for the contingency analysis in the N-Situation shall be the relevant topology of the transmission system which shall include planned outages in the operational planning phases.*

RTE continuously checks the contingency analysis and applies – or plans to apply – available remedial actions if needed to mitigate the consequences. To do so, RTE is using an up-to-date real-time and forecasted network model of its control area merged with the ones provided by neighbouring TSOs. These models include planned and forced outages on the grid, topological options, local generation and demand forecast.

This set of data is merged and computed in operational planning (from monthly, weekly, day-ahead up to intra-day). Additionally, contingency analyses are updated by RTE every 15 minutes in real-time.

RTE's contingency list is established pursuant to SOGL Article 33.

Regarding the contingencies to be monitored by TSOs, Article 33 'Contingency lists' specifies that:

> *1. Each TSO shall establish a contingency list, including the internal and external contingencies of its observability area, by assessing whether any of those contingencies endangers the operational security of the TSO's control area. The contingency list shall include both ordinary contingencies and exceptional contingencies identified by application of the methodology developed pursuant to Article 75.*
>
> *2. To establish a contingency list, each TSO shall classify each contingency on the basis of whether it is ordinary, exceptional or out-of-range, taking into account the probability of occurrence and the following principles:*
>
> *[A] each TSO shall classify contingencies for its own control area;*
>
> *(b) when operational or weather conditions significantly increase the probability of an exceptional contingency, each TSO shall include that exceptional contingency in its contingency list; and*
>
> *(c) in order to account for exceptional contingencies with high impact on its own or neighbouring transmission systems, each TSO shall include such exceptional contingencies in its contingency list.*

RTE is considering ordinary and exceptional contingencies, depending on operational conditions, in its contingency list where 'exceptional contingency' refers to SOGL Article 3 Definitions which specifies:

> *(39) 'exceptional contingency' means the simultaneous occurrence of multiple contingencies with a common cause;*

Multiple contingencies could be relevant regarding the sequence of events on July 24: the initial trip of the 400 kV Baixas–Gaudière 2 line was followed, a few minutes later, by a trip on the 400 kV Baixas–Gaudière 1 line. These two lines are part of a double-circuit line and share the same towers. As such, the simultaneous occurrence of the contingency of both lines cannot be excluded.

RTE includes the double-circuit contingency in its contingency list under exceptional environmental conditions only.

Article 8 of ACER's decision on a methodology for coordinating operational security analysis provides that:

> *1. Each TSO shall determine for each exceptional contingency the relevance and criteria of application of the following occurrence increasing factors:[...]*
>
> *(b) temporary occurrence increasing factors: [...]*
>
> *(ii) weather or environmental conditions;*

The weather conditions mentioned in Article 33 §2. (b) are duly considered by RTE: strong wind, lightning storms and sticky snow episodes are factors deemed likely to increase the probability of occurrence of the loss of a double-circuit line. Regarding environmental conditions, RTE considers at least the following occurrence-increasing factors: river regulation impacting nuclear units or wildfires close to double-circuit lines. Dedicated alarm processes are therefore organized with the French Weather Agency Meteo-France for exceptional weather conditions (see Figure 43, an example of lightning monitoring, and Figure 44, an example of other special conditions), nuclear generators for exceptional river conditions and regional fire departments for wildfires.

In the specific case of wildfires, there is one national agreement between RTE, the Public Authority, and the National Service of Fire and Human Protection, incorporated into agreements between each of the 95 French 'département' and the RTE's Regional Control Centre covering their area. These agreements are mainly focused on the safety of firefighters when they have to act near the HV grid.

Moreover, RTE considers the probability of occurrence mentioned in Article 33 §2 to establish its contingency list. Long-term statistics in France reveal that double-circuit contingencies have mostly occurred under exceptional environmental conditions. As an example, the previous proximate tripping of the 400 kV Baixas–Gaudière lines were recorded on 28 January 2017 at 01:15 and 04:12. These happened under lightning storm conditions. Considering that there were several hours between the two lines tripping, this event cannot be considered an exceptional contingency, and it occurred under

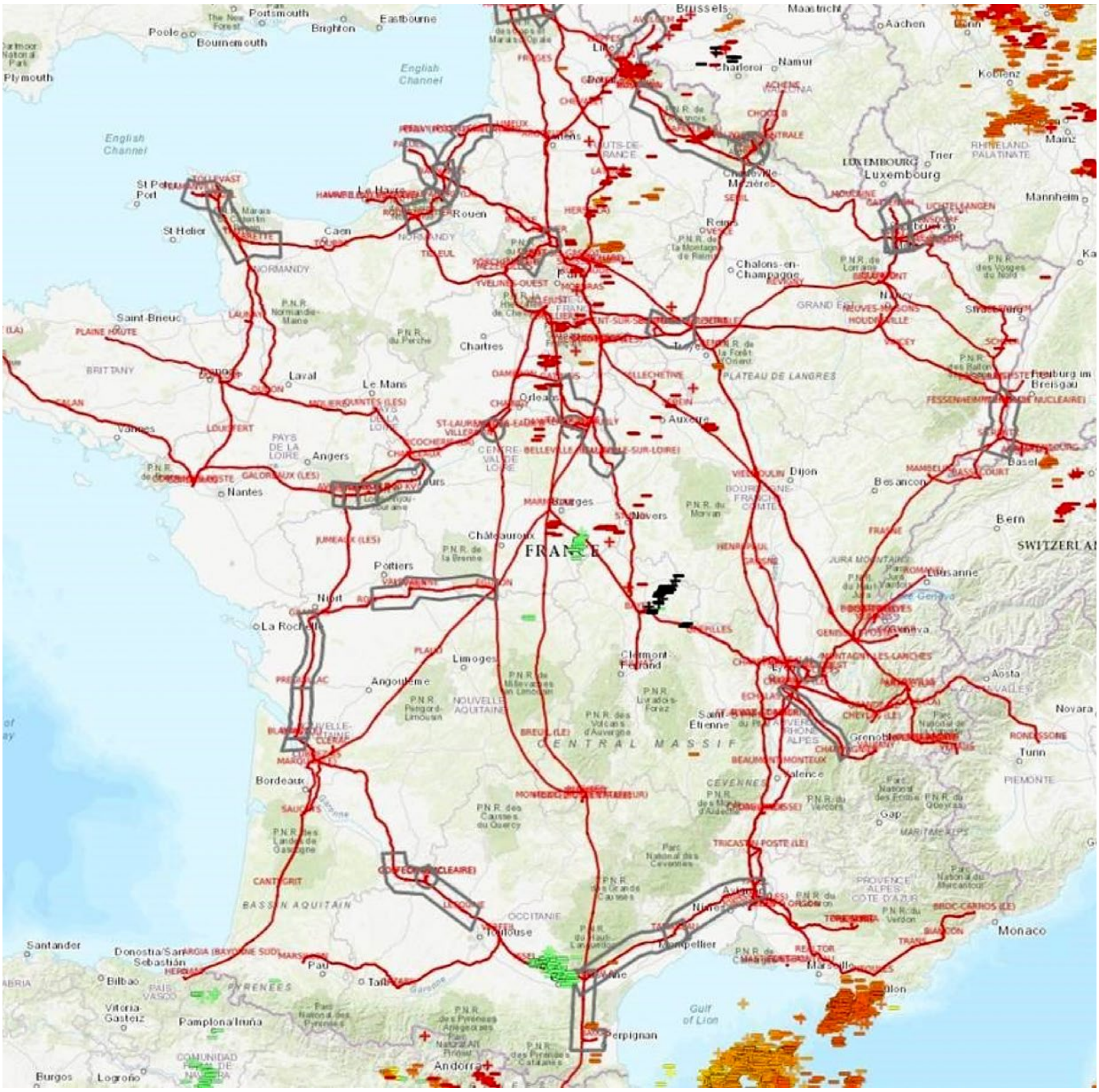


Figure 43: Real-time monitoring of lightning events close to the 400 kV French Grid.

exceptional environmental conditions. In fact, from 1 January 2015 to 24 July 2021, no double-contingency of Baixas–Gaudière ever happened (no information is recorded before this date).

To establish its contingency list, RTE considers the potential impact of remedial action compared to the very low probability mentioned in Article 33 §2(c). In particular, if the remedial action is very costly compared to a very low probability, these contingencies are only covered during exceptional conditions. As RTE determines, the Baixas–Gaudière double-circuit contingency requires limiting the exchanges between France and Spain by more than 1,000 MW, depending mostly on the market coupling and on the network outages to a much lower level. It can be stressed that a 1,000 MW reduction represents between 25 % and 30 % of the exchange capacity between the Iberian Peninsula and Continental Europe. Compared to a very low probability event, such permanent and massive reductions would have a huge impact on social welfare, energy exchanges, and system adequacy.

On 24 July, in the case that RTE would have been informed about the risk that a wildfire could be approaching close to the 400 kV Baixas–Gaudière double-circuit line, RTE would have assessed the related double contingency. The outcome of the contingency analysis would have been the preventive activation of the 1,500 MW counter trading that was identified as necessary after the initial trip of the 400 kV Baixas–Gaudière 2 line on 24 July.

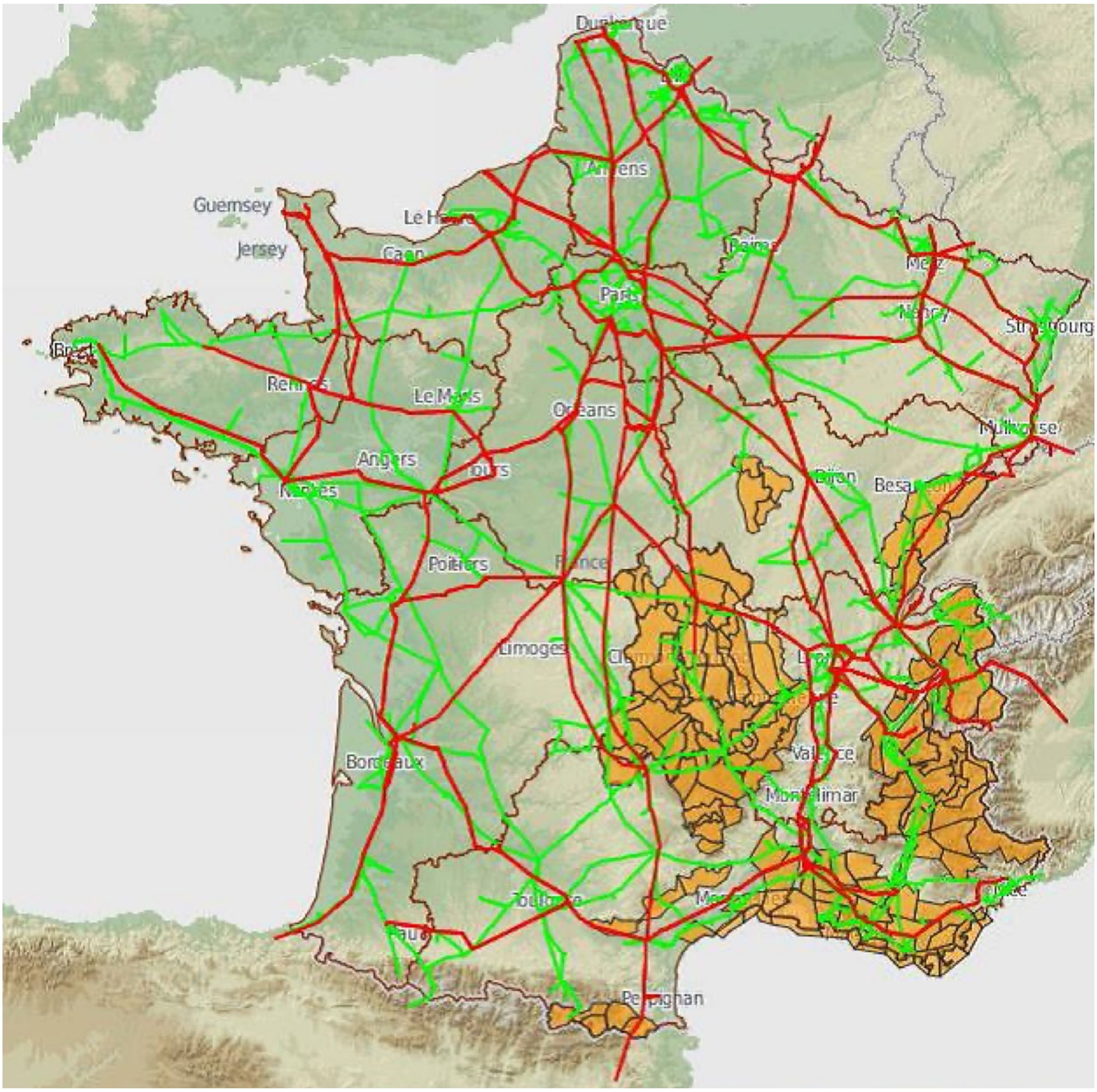


Figure 44: Day-ahead monitoring of special weather conditions (orange area: risk of high winds, thunderstorms, sticky snow …).

8.2 Robustness to sequences of N-1s

The robustness to consecutive N-1 is described in SOGL article 35 Contingency handling:

> *4. A TSO shall not be required to comply with the (N-1) criterion in the following situations:*
>
> *[A] during switching sequences;*
>
> *(b) during the time period required to prepare and activate remedial actions.*

Thus, TSOs don't have to cover all sequences of successive contingencies, while their main objective is to anticipate remedial actions, in order to react rapidly in case of contingency.

Having received no alert on exceptional environmental conditions on 24 July, RTE was operating the grid without the exceptional contingency N-2 Baixas–Gaudière 1 and 2 in its contingency list. Hence, operators in RTE's national control room had to ensure that an N-1 situation on Baixas-Gaudière would not endanger the system and that all operational limits were respected. Therefore, within a few minutes after the tripping of one of the Baixas–Gaudière lines, and using pre-defined remedial actions, RTE's operators coordinated with their colleagues in REE's national control room on how to restore the ability of the interconnected system to avoid facing another N-1. A reduction of the physical exchanges on the border was agreed to. Downward orders were sent to reduce the French net position. Upward orders were sent to increase the Spanish one. The fastest offers were selected on both sides, but the orders could not be met instantaneously due to ramping constraints on generation units as well as AGC parameters (for stability purposes). For a while, the French system was not robust to another N-1 close to the border and the tripping of the second Baixas–Gaudière 1 in particular. The modification of flows is usually achieved in about 10 minutes.

8.3 Conclusion

The events on 24 July do not question the rationality of the contingency analyses performed by RTE based on the statistics that all double-circuit contingencies have a very low probability of occurrence and only under exceptional environmental conditions. This is the case of the consecutive N-1 400 kV Baixas–Gaudière line 2 and then line 1 contingencies on 24 July.

Yet, 24 July does underline the reliance of the approach on the ability for RTE to anticipate such exceptional environmental conditions.

The contracted alarm process usually works reliably (see wildfires on 11 August 2021 close to the 400 kV double-circuit Gaudière–Issel 1 and 2) but the consequences of a failure as on 24 July indicate the need for substantial actions from RTE to secure the process to ensure such an event will not happen again. Process review has already started with concerned services (fire departments) and other provisions being investigated (such as using real-time satellite pictures, acquiring new informing systems, etc.) to ensure awareness of exceptional conditions close to the transmission lines.

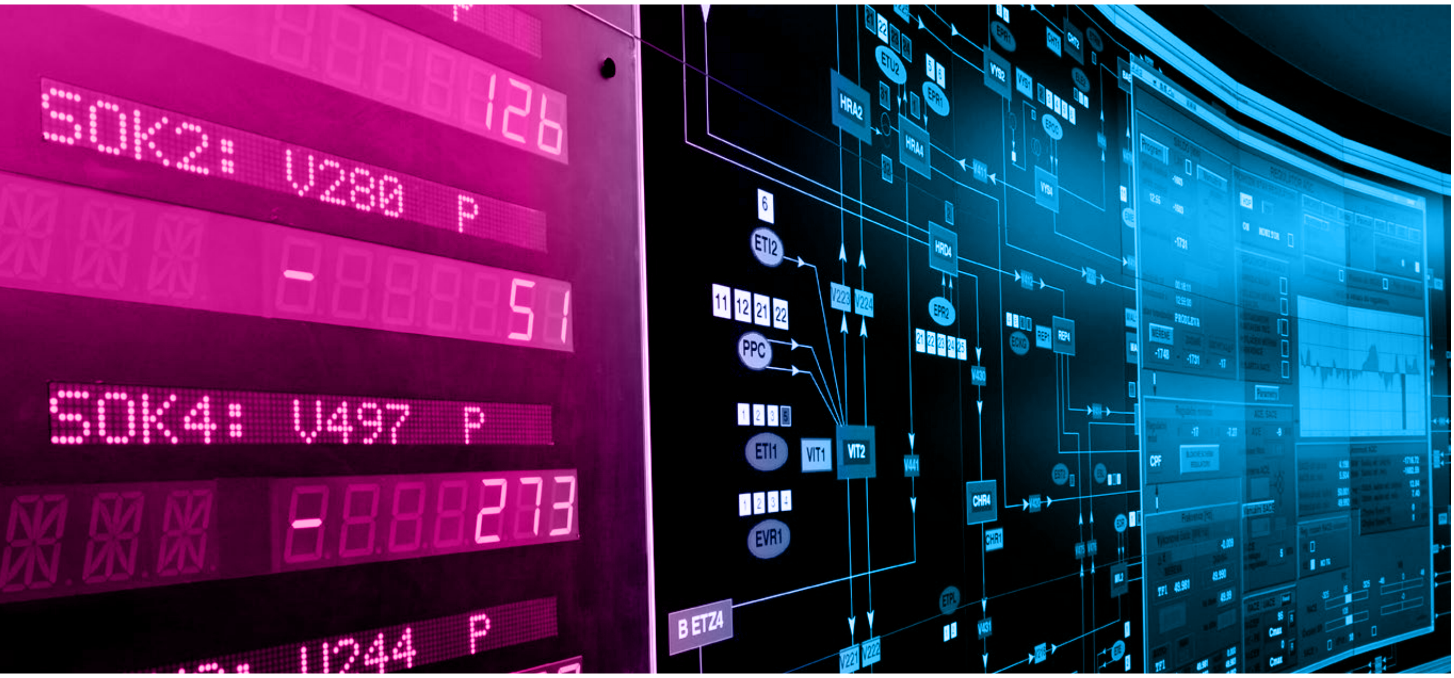
9 COMMUNICATION OF COORDINATION CENTRES/SAM AND BETWEEN TSOs

Communication among TSOs as well as with Synchronous Area Monitors is the basis for the operation of a wide, interconnected system. It ensures a common view of the situation, shared analyses, and coordinated actions on the grid. This communication is essential for day-to-day business, and of utmost importance in case of an incident. TSOs' operators usually communicate by phone, and when necessary, by e-mail to confirm the information previously exchanged. They also share a common tool: EAS (ENTSO-E Awareness System), which allows for the sharing of the system states in all countries among all European TSOs.

On 24 July, this communication took place, and is further detailed in the present chapter. This communication is of course performed on top of usual TSO business in each national control room.

In particular, just before the separation up until the reconnection of the grid, close coordination took place between RTE and REE.

Amprion (Germany) and Swissgrid (Switzerland) in their role as Coordination Centres (CC) North and South, respectively, and in their role as Synchronous Area Monitor (SAM) in Continental Europe, were responsible for the procedures and coordinated countermeasures. In other words, they were in contact with the affected TSOs (RTE and REE) right after the separation and regularly throughout the whole event. Then, the Coordination Centres informed all TSOs about the situation. In particular, they contacted all RG CE TSOs via phone (Amprion for CC North, Swissgrid for CC South), via the EAS system and via email. Amprion further coordinated measures concerning IGCC. After resynchronization, Amprion as SAM informed all TSOs about the end of the situation via EAS platform and via e-mail.



9.1 Timeline of communication among SAM and TSOs

Details of all communications between TSO, Synchronous Area Monitors and Regional Coordination Centres are shown below:

- **16:34** Immediately after the first tripping of the 400 kV Baixas-Gaudière 2 line, phone discussions started between the national control centres of RTE and REE, to analyse the situation, and jointly decide to decrease cross-border exchanges from 2.5 to 1.2 GW (reduction of 1.3 GW).
- **16:38** Two minutes after the tripping of the 400 kV Baixas-Gaudière 1 line and the disconnection of the Iberian Peninsula, RTE set 'Emergency State due to critical event' on the EAS Platform (see Table 30).
- **16:38** Additional contact was made between RTE and REE, resulting in the following joint decision exchanges to be reduced to 0 MW.
- **16:40** First coordination call occurred between Swissgrid and Amprion (decision Swissgrid as CC in lead will call RTE and REE).
- **16:44** Call between TNG as IGCC Host and Amprion (CC) (involving information about the separation of REE from IGCC and the decision that REN should be separated by TNG as well).
- **16:45** Discussions between CORESO and RTE to inform CORESO about the two trips.
- **16:48** Additional communication between REE and RTE to exchange information about the reconnection strategy and frequency stabilisation on the Iberian side.
- **16:50** Second coordination call between Swissgrid and Amprion (update of information; decision that AMPRION will take the lead as CC for this system split).
- **16:52** AMPRION (Synchronous Area Monitor) called RTE to ask for information about the event and reconnection strategy.
- **16:52** REN's control room operator contacted REE's control room operator and confirmed that the existing protocol was applicable in this specific situation. It was also determined that the scheduled exchange program should be maintained.
- **16:53** AMPRION starts to inform all TSOs (North) via phone.
- **16:55** Another call between RTE and REE. Discussions focused on frequency reconnection and the decision of which substation to be used for re-closing device the reconnection should be done at Hernani Station.
- **16:57** Third coordination call between Swissgrid and Amprion (decision Swissgrid will inform TSOs (South) as well.
- **16:57** EAS Freetext Message was sent by Amprion (see Figure 45).
- **16:57** Information about the system split was sent to all TSOs via mail by Amprion.
- **17:05** Call between REE and Amprion to discuss further steps.
- **17:09** Reconnection between areas. RTE and REE coordinated by phone during this reconnection.
- **17:12** Call between RTE and Amprion (information that both islands are reconnected again).
- **17:14** Fourth coordination call between Swissgrid and Amprion (information that islands are reconnected again).
- **17:19** EAS free-text-message that islands are reconnected again by Amprion (see Figure 45).
- **17:27** Mail was sent by Amprion to RGCE TSOs with the information that the islands are reconnected again.
- **17:31** End of RTE Emergency State on EAS Platform (see Table 30).
- **17:41** Discussions between RTE and AMPRION to explain the reconnection conditions and update the state of grids. RTE announced that the presumed cause of the trips is a fire.
- **17:43** Call between RTE and Amprion (status update).
- **17:53** RTE and REE calculated new NTC values (1,000 MW).
- **18:49** Email from RGCE Convenor to RGCE members.
- **20:52** Publication on REMIT Platform: Outage of 400 kV Baixas–Gaudière 2 line.

Time	TSO	System State	Main Message
24.07 - 16:38:44	RTE	Emergency state	Critical event
24.07 - 17:31:19	RTE	Normal state	
24.07 - 18:09:52	REE	Emergency state	Loss of tools and facilities
24.07 - 18:33:08	REE	Normal state	

Table 30: EAS states and main messages reported by the EAS system.

In addition to this operational information, the management of the TSOs had several exchanges, to provide updates about the situation, its evolution, and actions undertaken.

As detailed in this call-log, the communication among TSOs and SAM was very intensive and efficient during this event, allowing a fast resolution of the incident. Use of the EAS, as the awareness tool for all EU TSOs, also facilitated this communication, avoiding multiple phone calls to share information about the situation.

In the Portuguese control area, REN followed the bilateral agreement established between REN and REE in 2012, where this scenario was foreseen. In that agreement, it was determiend that in case of a separation of the Portuguese and Spanish system from the rest of RGCE, REE is the frequency and resynchronisation leader.

Table 30 reports the main messages that were generated by the EAS system. Nevertheless, CC Nord and CC South did not change the CCN and CCS system state, because there was no main message for system split available. The EAS Core-Team put this request in their requirements. Therefore, this main message will be available in the future.

The EAS platform was also used for several text messages in order to inform all TSOs and improve the overall situational awareness, as shown in Figure 45, which reports the EAS free text messages.

A	Date/Time	B1	B2	B3	Elem	Status
******* Saturday 24.07.2021 *******						
	24.07 16:57:27	Message from:	DE_AMPRN	to ALL		
	FTM	System Split in RGCE Split under investigation Amprion is in lead as CC				
	24.07 17:19:25	Message from:	DE_AMPRN	to ALL		
	FTM	The two islands are back together Further information will follow via email				
	24.07 18:32:53	Message from:	FR_RTE to	ALL		
	FTM	Separation SpainPortugal from Europe after trips in RTE reconnection at 17h09				
******* Monday 26.07.2021 *******						

Figure 45: EAS free text messages manually sent by operators.

9.2 Communication to the Market

At 16:34 and 16:37, the reduction of exchanges between France and Spain had been performed using counter trading, an agreement allowing to reduce the physical flows without modifying the commercial flows, thus providing transparency for the market.

At 16:46, due to the situation, XBID market on the Spanish side was closed. It was re-opened at 18:22.

10 Coordination activities by the Regional Security Coordinator

The system split concerns a border of the South-West European (SWE) Capacity Calculation Region, where Coreso/Brussels acts in the roles of the appointed Coordinated Capacity Calculator and Regional Security Coordinator. Both roles are executed based on the assumption that a system security threat can be predicted at an earlier stage based on internal grid models (IGMs) provided by the TSOs. Independent of the RSC activity, TSOs are executing their own forecasts, which might slightly deviate from the forecast of the RSC due to the amount of information available and the refresh periods.

The following activities were executed by Coreso in view of the 24 July 2021 incident with increasing timeliness of data (ascending order)

- 1. Outage planning coordination
- 2. Short-term adequacy assessment
- 3. Day-ahead capacity calculation
- 4. Day-ahead congestion forecast and intra-day congestion forecast
- 5. Real-time snapshot calculations

Here it should be noted that the concepts of these services do not consider specific effects resulting from the dynamic behaviour of the electricity transmission system.

10.1 Outage Planning Coordination OPC

For OPC all continental TSOs send their outage planning information to a Pan-European tool. Weekly reference grid models are established by Coreso with the exchange levels of the representative day of the previous week. The grid situation based on the reference grid model is superimposed with the outages of the merged outage planning information.

Specifically, with a focus on the SWE region a security analysis has been performed by Coreso building on the following assumptions

- export scenario FR → ES of 2,700 MW and PT → ES of 1,300 MW,
- contingency lists as provided TSOs.

If costly remedial actions are required to solve constraints, a coordination would be triggered between Coreso and TSOs to determine if the cancellation of an outage is necessary.

The OPC calculation for 24 July 2021 did not reveal any evidence of an outage planning security constraint resulting from an outage planning incompatibility that cannot be relieved with adjusted tap positions of phase shifter transformers.

10.2 Short-term Adequacy Assessment STA

The STA is executed on a daily cycle based on the generation of availability data and transfer capacities available on continental European level. The calculation for the 24 July 2021 has been executed on 23 July 2021.

Results of the adequacy calculations were obtained for 24 July 2021 via the industrialised STA tool and methodologies used for the STA process:

- Deterministic STA calculation
- Probabilistic STA calculation:
  Percentage of cases where adequacy is satisfied with variation of load, wind and solar based on statistical parameters sent by the TSOs. The calculation is based on 500 different scenarios. All scenarios are correlated following the PEMM database for renewables and the ENTSO-E database for load.

No adequacy issue has been detected in either approach.

10.3 Day-Ahead Capacity Calculation

The day-ahead capacity calculation is based on the Capacity Allocation and Congestion Management (CACM) Guideline EU 1222/2015. Due to its specific geographical situation, the Iberian Peninsula has naturally emerged as the SWE capacity calculation region.

The capacity calculation is executed by Coreso based on the coordinated capacity calculation methodology developed by REN, REE and RTE and approved by ACER and the NRAs.

The calculation of TTCs for six timestamps is completed by Coreso and a proposal is sent to TSOs. A validation process is then completed by TSOs and then a spanning to allocate the 24 hours based on the six calculated timestamps is done by the TSOs. Their answers are sent and processed by Coreso to set the final TTC of each border in each direction. In order then to calculate the NTC, the following parameters are used:

- NTC = TTC – TRM
- The TRM is 7.5% of TTC for the ES–FR border with a minimum of 200 MW.
- The TRM is 10% of TTC for the PT–ES border with a minimum of 100 MW.

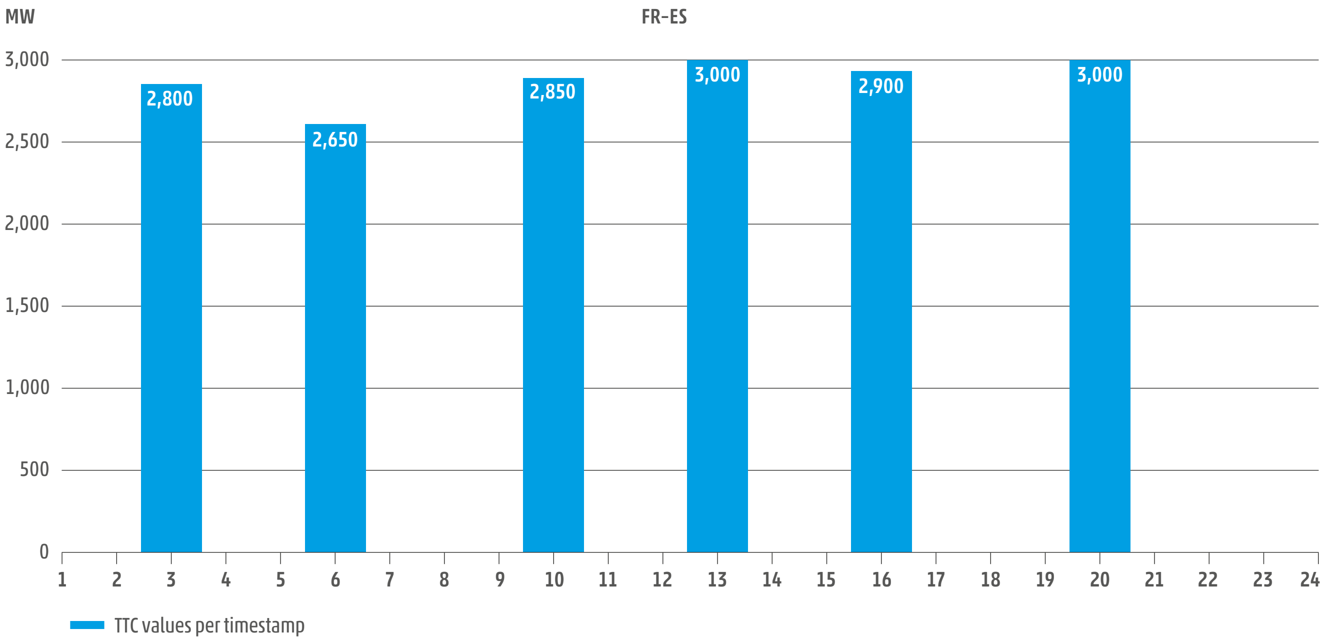


Figure 46: TTC calculation results for the FR/ES border. (1/2) →

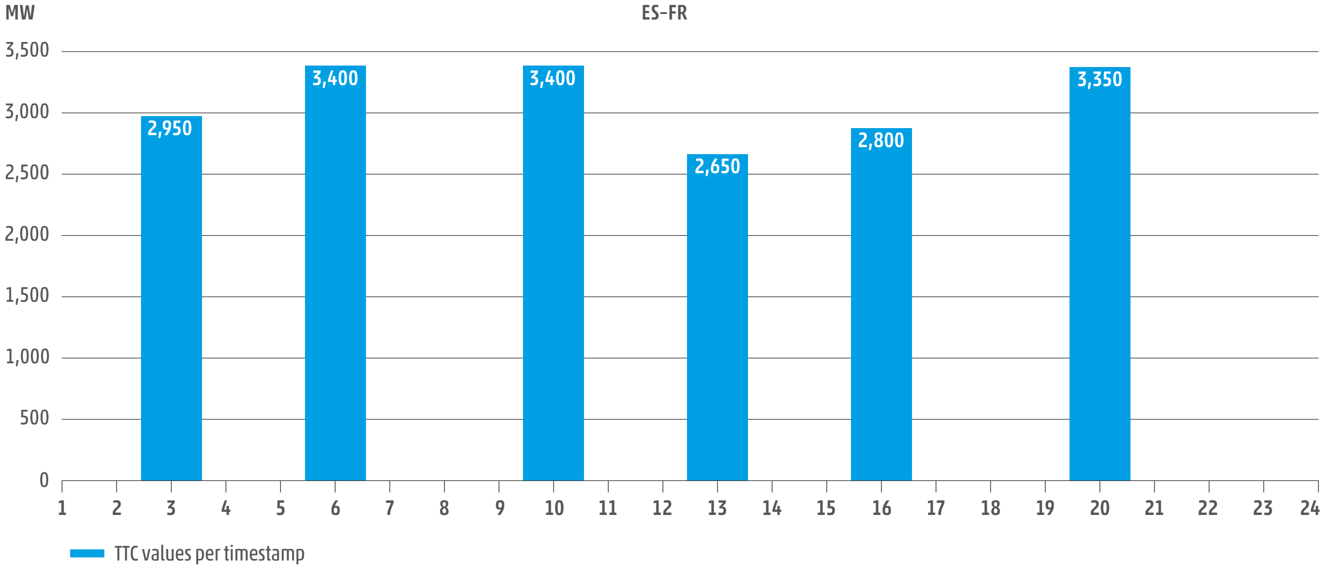


Figure 46: TTC calculation results for the FR/ES border. (2/2)

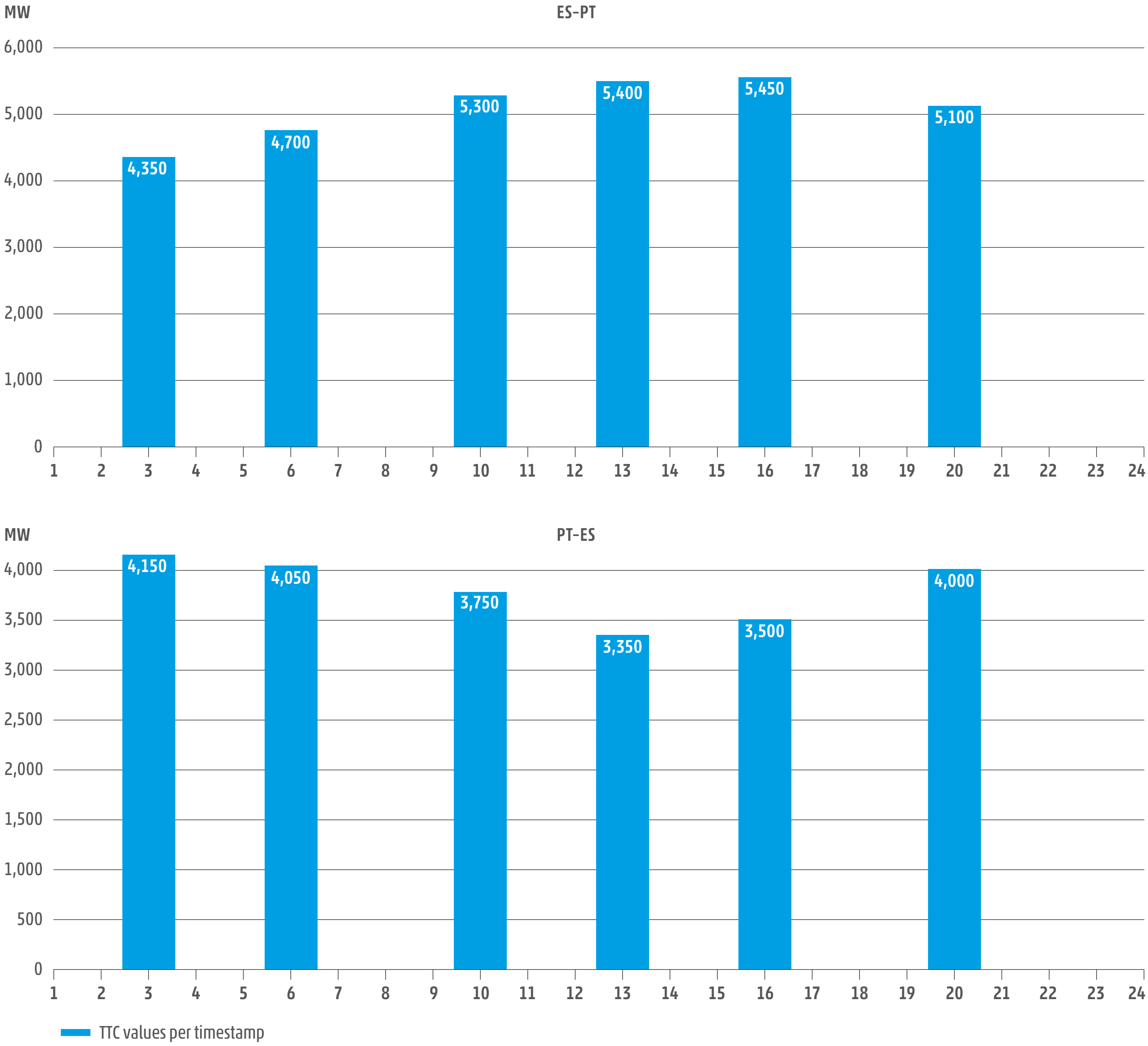


Figure 47: TTC calculation results for the PT/ES border.

10.4 Day-Ahead, Intra-Day Congestion forecast and Real-Time snapshot calculations

The security analysis for SWE is performed by Coreso on day ahead (DACF) and intraday (IDCF).

On request of TSOs in addition to the regular intraday cycle additional Intraday Coordinated Regional Operational Security Assessments can be executed.

The Intraday CGM for the TS 24 July 2021 – 16:30 was based on the last grid model created before the incident around 16:00.

As there were no extraordinary intraday requests no further intraday calculations were performed around the time of the system split.

For some TSOs and regions, other than for SWE CCR, Coreso regularly performs a security calculation based on merged real-time snapshots provided by the TSOs. This activity runs offline and cannot be used as a basis for real-time system operation evaluations.

TSO	Lines	Flows in MW		
		DACF	IDCF	Snapshot
REE	Azpeitia - Gatica 400 kV	298	249	317
	Bescano - Sentmenat 400 kV	290	196	260
	Azpeitia - Hernani 400 kV	–379	–342	–379
	Hernani - Ichaso 400 kV	417	333	400
	Bescano - Vic 400 kV	112	117	100
	Pierola - Vic 400 kV	–112	–102	–100
REE → REN	Aldeadavila - Lagoaca 400 kV	–442	–365	–199
	Aldeadavila - Pocinho 1 220 kV	–72	–58	–27
	Aldeadavila - Pocinho 2 220 kV	–71	–58	–27
	Brovale - Alqueva 400 kV	–303	–302	–362
	Cartelle - Alto Lindoso 1 400 kV	–131	–75	–110
	Cartelle - Alto Lindoso 2 400 kV	–131	–75	–110
	Cedillo - Falagueira 400 kV	–247	–234	–302
	Pueguzma - Tavira 400 kV	–252	–260	–268
	Sub TOTAL	**–1,649**	**–1,427**	**–1,405**
RTE	Argia - Cantegrit 400 kV	–1,192	–1,139	–1,131
	Cantegrit - Mouguere 225 kV	337	301	276
RTE ← REE	Arkale - Argia 220 kV	–165	–190	–130
	Hernani - Argia 400 kV	–988	–900	–1,029
	Santa Llogaia - Baixas 1 400 kV	–525	–496	–444
	Santa Llogaia - Baixas 2 400 kV	–525	–496	–444
	Biescas - Pragneres 220 kV	–179	–179	–150
	Vic - Baixas 400 kV	–300	–277	–255
	Sub TOTAL	**–2,682**	**–2,538**	**–2,452**

Table 27: Summary of RSC calculation results for 24 July 2021, 16:30

10.5 Communication between RSCs and TSOs

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. However, the following communication took place between Coreso, TSOs and RSCs:

- **Approximately 16:40** Elia calls Coreso for information regarding an observed frequency deviation and detected exchange imbalance. Coreso observed unusual flow deviations on the FR/ES border using the Coreso data acquisition system.
- **16:45** Discussion between Coreso and RTE takes place, confirming a decoupling between FR and ES due to lines tripping. The information is provided to Elia.
- **After the event**, restoration updates are provided to Coreso by RTE. Coreso provides an update to TSCNET, who request Coreso to share this information at the Daily Operation Planning Teleconference (DOPT conference).
- **21:00** Coreso provides an update on the situation to TSCNET and TSOs during the DOPT conference call.

11 TSO-DSO COORDINATION – FREQUENCY PLAN AND LOAD SHEDDING

TSO and DSO coordination is of utmost importance regarding system operation. This coordination takes place in real-time, but is also performed in advance, prepare for possible events. This is particularly the case for frequency events, where time to exchange and coordinate is not appropriate. This is the reason why, following EU legislation, a strong coordination between TSOs and DSOs has been set up, to design and implement the Low Frequency Demand Disconnection scheme.

11.1 Low-frequency demand disconnection scheme preparation

Articles 11, 12 and 15 of the regulation EU 2017/2196 establishing a *network code on electricity emergency and restoration* state that:

Article 11 – Design of the system defence plan

1. By 18 December 2018, each TSO shall design a system defence plan in consultation with relevant DSOs, SGUs, national regulatory authorities, or entities referred to in Article 4(3), neighbouring TSOs and the other TSOs in its synchronous area.

Article 12 – Implementation of the system defence plan

1. By 18 December 2019 each TSO shall implement those measures of its system defence plan that are to be implemented on the transmission system. It shall maintain the implemented measures henceforth.

2. By 18 December 2018 each TSO shall notify the transmission connected DSOs of the measures, including the deadlines for implementation, which are to be implemented

SECTION 2 – Measures of the System Defence Plan

Article 15 – Automatic under-frequency control scheme

1. The scheme for the automatic control of under-frequency of the system defence plan shall include a scheme for the automatic low frequency demand disconnection and the settings of the limited frequency sensitive mode-underfrequency in the TSO load frequency control (LFC) area.

According to these requirements, a strong coordination among TSOs and DSOs is established to design, prepare, implement, and regularly update an under-frequency load shedding plan. (LFDD = Low Frequency Demand Disconnection). This coordination includes the definition of frequency thresholds to be implemented in the relays, as well as the amount of load to be disconnected for each threshold.

The coordination in the design phase is needed and performed in advance, to allow a fast and adapted reaction when the frequency deviation occurs.

The behaviour of the System Defence Plan during the event is detailed in Chapter 4.2 System status and automatic defence actions in individual areas.

11.2 TSO-DSO coordination after low-frequency demand disconnection scheme activation

After the activation of the system defence plan, and especially in the case of the activation of the low-frequency demand disconnection scheme, a strong coordination is set up between TSO and DSO. The aim is to make sure that the reconnection of the shed load is scheduled according to system behaviour. For instance, in France, Toulouse Regional Centre have coordinated with the 'ACR Aquitaine Sud' (regional control room of ENEDIS, the French DSO), to agree on load reconnection by 17:06, and with 'ACR Nimes' (DSO control room for area of Baixas) to reconnect the load between 17:30 and 17:36.

In the case of Spain, communication between the TSO and the DSO was continuous during the whole period, and the reconnection of the shed load was allowed and coordinated, once both frequency and voltage were stabilized, starting at 16:55.

11.3 Overview on pumped storage shedding

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 during the frequency drop to support the restoration of the generation-demand balance.

Table 31 shows the frequency thresholds and the load assigned for every step. It should be noted that the load shedding relays of some units have a delay for its proper operation.

TSO	Frequency threshold [Hz]	Disconnected load [MW]
REE	49.5	1,004
REE	49.3	991
REN	49.3	122
REN	49.8	185

Table 31: Pumped storage shedding.

11.4 Overview on load shedding

The underfrequency condition on the Iberian Peninsula caused the activation of the first two load shedding steps in Spain and Portugal and first load shedding step in the southeast of France (see Table 32) to restore the generation-demand balance. In Spain 3,561 MW were disconnected, 680 MW in Portugal, and 65 MW in France, to restore the generation-demand balance.

Additionally, in the Portuguese system a group of industrial consumers were shedd at 49.2 Hz. The effective power reduction of these consumers reached a total value of 394 MW.

TSO	Frequency threshold [Hz]	Disconnected load [MW]
REE	49.0	1,574
REE	48.7	1,987
RTE	49.0	65
REN	49.0	424
REN	48.8	256

Table 32: Load shedding.

11.5 Portuguese System Defence Plan

The Portuguese defence plan for a situation of a sudden drop in system frequency, originating from an imbalance between production and consumption, includes the following components:

- A. Automatic disconnection of hydro-pumps
- B. Automatic power reduction in industrial interruptible consumers
- C. Low frequency demand disconnection plan

In the 24 July incident, where the frequency dropped to 48.65 Hz, these three components were activated, as described below.

A. Automatic disconnection of hydro-pumps

The hydro-pump disconnection plan, with a maximum power of 2,698 MW, has six frequency steps (49.8; 49.7; 49.6; 49.5; 49.4; 49.3 Hz), with zero timing and with similar power values.

In the 24 July incident, five hydro-pumps were connected, with a total power of 422.3 MW. One failed to trip and four tripped, resulting in a total amount of **307.5 MW**. Table 33 characterises the plan and the effective tripping.

			Plan		24 July – 16:36
Hydro pump	Code	P Max [MW]	Planned tripping value [Hz]	P actual realised [MW]	P tripped [MW]
Central do Alqueva – Grupo 2	ALQUEB2	120	49.6	114.8	[failed]
Central de Baixo Sabor Jusante – Grupo 1	BASBJB1	18	49.8	17.77	17.8
Central de Foz Tua – Grupo 2	FOZTB2	130.5	49.3	122.5	122.5
Central de Frades – Grupo 1	FRADEB1	95.5	49.8	85.0	85.0
Central de Frades – Grupo 2	FRADEB2	95.5	49.8	82.2	82.2
SUM		**2,698**		**422.2**	**307.4**

Table 33: Disconnection of hydro-pumps, planned and realised. Note that 2,698 MW represents the maximum power of all Portuguese hydro-pumps, while the table only includes those five connected at the time of the event.

B. Automatic power reduction in industrial interruptible consumers

In the Portuguese system there is a group of industrial consumers who provide a paid service, which includes the obligation to reduce their consumption to a certain power value, instantly, if the frequency value drops below 49.2 Hz.

On 24 July, the total consumption of this group of consumers was 655.5 MW, with a residual value of 28 MW, which corresponded to a maximum power reduction value of 627.5 MW. This power reduction value could be reached if all consumers were connected, with the average power considered in the contract and fulfilled the contractual obligation.

Current data reveal that on 24 July, at 15:36, the total power in these consumers was 628 MW, with a residual power of 23 MW.

The effective power reduction of these consumers, at 49.2 Hz, reached a total value of **394 MW**.

C. Low frequency demand disconnection plan

The Portuguese low frequency demand disconnection plan complies with the NCER and the provisions of Annex 5 of SAFA, with the following characteristics:

- » Provides a power reduction in the range of 45 +/– 7% of the total consumption if the frequency drops from 49.0 to 48.0 Hz.
- » It has 6 steps, with the following frequency values: 49.0; 48.8; 48.6; 48.4; 48.2; 48.0 Hz.
- » In the 49.0 Hz step, the reduction greater than or equal to 5% of the total consumption.
- » In each step, the reduction does not exceed 10% of the total consumption.
- » No intentional time delay was set in relays.
- » These characteristics were agreed upon between the TSO and the DSO.

On July 24, at 15:36, the total consumption was **5,145 MW**. At the time of the incident, the frequency dropped to 48.65 Hz, whereby the 49.0 and 48.8 Hz steps were activated. The tripped consumption at these steps, exclusively at the DSO level, were 424 MW and 256 MW, respectively, thus reaching a total value of **680 MW**. This value corresponds to 13.3% of the total 5,145 MW consumption, in line with the expected value of 13.2%. Table 34 characterises the plan and the effective tripping.

	Plan	24 July - 16:36	
Step [Hz]	P [%]	P [%]	P [MW]
49.0	6.7	8.2	424
48.8	6.6	5.0	256
48.6	6.9	0.0	0
48.4	6.6	0.0	0
48.2	6.4	0.0	0
48.0	9.7	0.0	0
SUM	**43.0**	**13.2**	**680**

Table 34: Disconnection of demand, planned and realised.

11.6 Spanish System Defence Plan

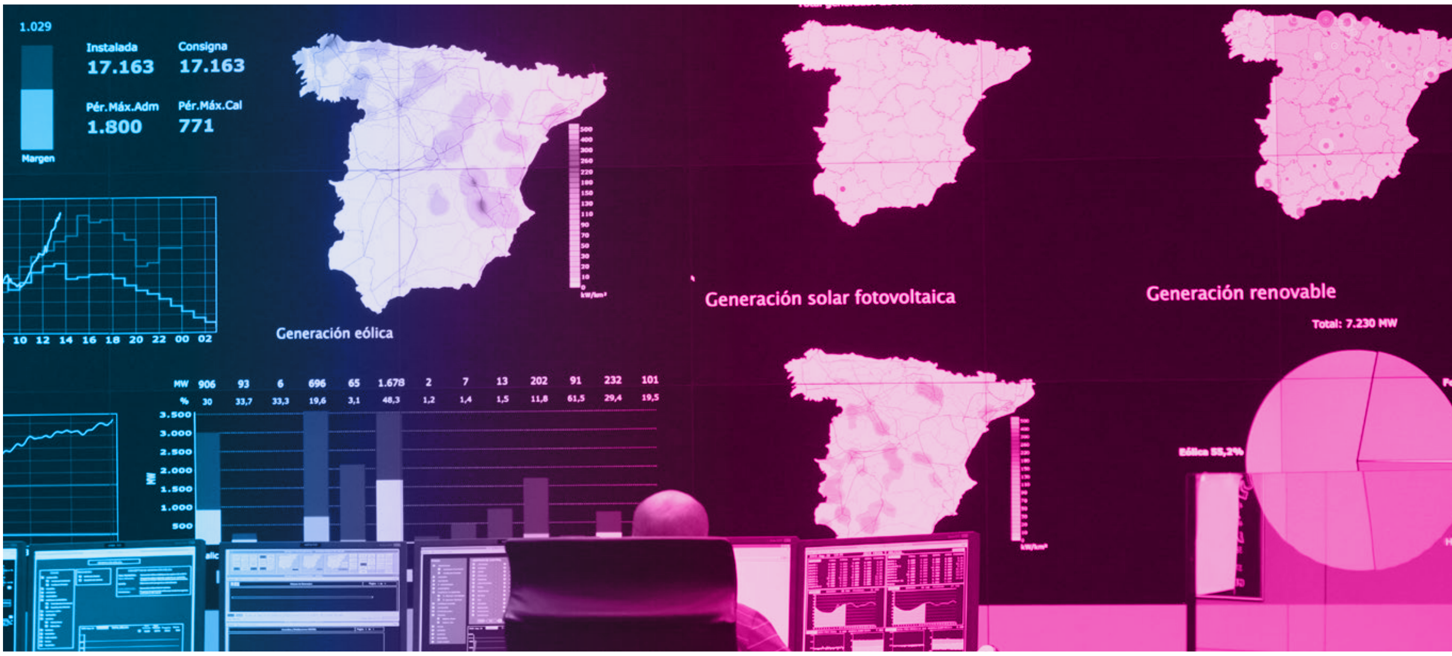
The Spanish defence plan for a situation of a sudden drop in system frequency, originating from an imbalance between production and consumption, includes the following measures:

A. Disconnection of low frequency automatic hydro-pumps

At 16:36:39.240, the frequency descended below 49.5 Hz, and at 16:39.600, the frequency dipped below 49.3 Hz, and hence both frequency disconnection steps were activated, and all connected hydro pumps were tripped, as shown in Table 35.

Name	Busbar	Step [Hz]	MW
La Muela G4	La Muela 400	49.5	210.0
Aguayo G2	Aguayo 220	49.5	89.0
Aguayo G3	Aguayo 220	49.5	89.0
Moralets G2	Moralets 220	49.5	74.0
Bolarque G1	Bolarque 220	49.5	52.0
Bolarque G2	Bolarque 220	49.5	51.0
Bolarque G3	Bolarque 220	49.5	52.0
La Muela G1	La Muela 400	49.5	194.0
La Muela G2	La Muela 400	49.5	193.0
Total at 49.5 Hz step			**1,004.0**
La Muela G5	La Muela 400	49.3	207.0
La Muela G6	La Muela 400	49.3	206.0
La Muela G7	La Muela 400	49.3	207.0
Aguayo G1	Aguayo 220	49.3	90.0
Aguayo G4	Aguayo 220	49.3	89.0
La Muela G3	La Muela 400	49.3	192.0
Total at 49.3 Hz step			**991.0**
Total (both steps)			**1,995.0**

Table 35: Hydro pumps disconnected in each frequency step.



B. Low frequency automatic demand disconnection

The Spanish automatic low frequency demand disconnection scheme, previous to the implementation of the requirements stablished in Regulation (EU) 2017/2196, establishing a network code on electricity emergency and restoration (NC ER), is shown in Table 36: Demand disconnection plan prior to implementation of NC ER.

REE, in coordination with DSOs, is currently in the process of adapting the scheme for the automatic low frequency demand disconnection to fulfil the requirements stablished in NC ER, evolving the previous scheme of 4 to 6 steps and therefore, reducing the size of the futures steps. The scheme is expected to be fully implemented within the deadline established in the Regulation, 18 December 2022.

In the 24 July incident, the lowest frequency recorded at La Cereal 400 kV Substation was 48.681 Hz, going below the first step and during 520 ms below the second step.

Step [Hz]	P [%]
49.0	10
48.7	10
48.4	15
48.0	15
SUM	**50**

Table 36: Demand disconnection plan prior to implementation of NC ER.

		24 July - 16:36
Step [Hz]	**P [%]**	**P [MW]**
49.0	5.2	1,573.5
48.7	6.6	1,987.0
SUM	**11.8**	**3,560.5**

Table 37: Demand disconnected in each frequency step.

11.7 French system defence plan

Low-Frequency Demand Disconnection on the French part of the island was comprising 65.35 MW of load, while the total French island had a total load of 363.83 MW. This load shedding was activated when hitting the 49.0 Hz threshold.

12 CLASSIFICATION OF THE INCIDENT BASED ON THE ICS METHODOLOGY

12.1 Analysis of the incident

The event started due to a fire in the area of Moux (south of France). The dispatching of RTE could not be informed about the fire close to the Baixas–Gaudière 400 kV axis and thus the risk of having an N-2 was not considered. The grid was N-1 compliant. The fire caused the subsequent tripping of the two lines Baixas–Gaudière 2 and Baixas–Gaudière 1, within a few minutes. This led to an overload on the remaining lines between France and the Iberian Peninsula. This is not an ON2 according to the ICS classification, because covering the N-2 Baixas–Gaudière 2 and Baixas–Gaudière 1 is not considered within the normal conditions on the contingency list.

The tripping of the Argia–Cantegrit line resulted in the cascading tripping of the remaining lines on that axis between RTE and REE. The result was a loss of interconnection between the Spanish and French systems. This is a T2 according to the ICS classification. This criterion was reached because there was at least one wide area deviation from operational security limits after the activation of curative remedial action(s) in N situation. There were also wide area consequences on the regional or synchronous area level, resulting in the need to activate at least one measure of the system defence plan.

The cascading of several line trips led to the system split. This is an RS2 according to the ICS classification. This criterion was reached because the separation of the grids involved more than one TSO and because at least one of the synchronised regions affected by the split had a load larger than 5 % of the total load before the incident.

The splitting of the grid led to a region with over frequency and a region with under frequency. In the region with over frequency, the deviation of more than 200 mHz lasted less than 30 seconds. In the under-frequency region, the deviation of more than 200 mHz lasted more than 30 seconds. This is an F2 according to the ICS classification. The criterion for an F2 was reached because there was an incident leading to frequency degradation (200 mHz for more than 30 seconds).

There was also a loss of load of 3,560 MW of a total load of 30,033 MW for more than three minutes for REE. Regarding REN, there was a loss of load of 1,494 MW of a total load of 5,145 MW. For both TSOs the L2 criteria according to the ICS classification was met. This criterion was reached because the loss of load was higher than 10 percent of the load in both TSOs.

12.2 Classification of the incident

The priority of each criterion is shown in Table 38 with a number from 1 to 27, where 1 marks the criterion with highest priority and 27 marks the criterion with lowest priority. When an incident meets several criteria, the incident is classified according to the criterion that has the highest priority; however, information regarding all sub criteria is also collected.

Scale 0 Noteworthy incident		Scale 1 Significant incident		Scale 2 Extensive incident		Scale 3 Major incident / 1TSO	
Priority / Short definition (Criterion short code)		Priority / Short definition (Criterion short code)		Priority / Short definition (Criterion short code)		Priority / Short definition (Criterion short code)	
#20	Incidents on load (L0)	#11	Incidents on load (L1)	#2	Incidents on load (L2)	#1	Blackout (OB3)
#21	Incidents leading to frequency degradation (F0)	#12	Incidents leading to frequency degradation (F1)	#3	Incidents leading to frequency degradation (F2)		
#22	Incidents on transmission network elements (T0)	#13	Incidents on transmission network elements (T1)	#4	Incidents on transmission network elements (T2)		
#23	Incidents on power generating facilities (G0)	#14	Incidents on power generating facilities (G1)	#5	Incidents on power generating facilities (G2)		
		#15	N-1 violation (ON1)	#6	N violation (ON2)		
#24	Separation from the grid (RS0)	#16	Separation from the grid (RS1)	#7	Separation from the grid (RS2)		
#25	Violation of standards on voltage (OV0)	#17	Violation of standards on voltage (OV1)	#8	Violation of standards on voltage (OV2)		
#26	Reduction of reserve capacity (RRC0)	#18	Reduction of reserve capacity (RRC1)	#9	Reduction of reserve capacity (RRC2)		
#27	Loss of tools and facilities (LT0)	#19	Loss of tools and facilities (LT1)	#10	Loss of tools and facilities (LT2)		

Table 38: Classification of incidents according to ICS methodology

The highest criterion from ICS for this incident is an L2, and thus an expert panel for a scale 2 investigation is required.

For incidents of scales 2 and 3, a detailed report must be prepared by an expert panel composed of representatives from TSOs affected by the incident, a leader of the expert panel from a TSO not affected by the incident, relevant RSC(s), a representative of SG ICS, the regulatory authorities and ACER upon request. The ICS annual report must contain the explanations of the reasons for incidents of scale 2 and scale 3 based on the investigation of the incidents according to article 15(5) of SO GL. TSOs affected by the scale 2 and scale 3 incidents must inform their national regulatory authorities before the investigation is launched according to article 15(5) of SO GL. ENTSO-E must also inform ACER about the upcoming investigation in due time, before it is launched and not later than one week in advance of the first meeting of the expert panel.

Each TSO must report the incidents on scale 2 and 3 classified in accordance with the criteria of ICS in the reporting tool by the end of the month following the month in which the incident began, at the latest. As the incident happened on 24 July 2021, the affected TSOs have to classify the events during this incident according to the ICS Methodology before 31 August. An expert investigation panel with TSOs, NRAs and ACER was established on 22 October 2021 and will publish its final report in first quarter of 2022.

13 ANNEXES

13.1 Annex 1 – List of TSOs (alphabetical order)

Company	Country (abbreviation)
50Hertz	Germany (DE)
Amprion	Germany (DE)
APG	Austria (AT)
ČEPS	Czech Republic (CZ)
CGES	Montenegro (ME)
Creos Luxembourg	Luxembourg (LU)
ELES	Slovenia (SI)
Elia	Belgium (BE)
EMS	Serbia (RS)
Energinet	Denmark (DK)
ESO EAD	Bulgaria (BG)
Fingrid	Finland (FI)
HOPS	Croatia (HR)
IPTO	Greece (GR)
MAVIR	Hungary (HU)
MEPSO	North Macedonia (MK)
National Grid ESO	Great Britain (GB)
NOS BiH	Bosnia and Herzegovina (BA)
OST	Albania (AL)
PSE	Poland (PL)
REE	Spain (ES)
REN	Portugal (PT)
RTE	France (FR)
SEPS	Slovakia (SK)
Statnett	Norway (NO)
Svenska Kraftnät	Sweden (SE)
Swissgrid	Switzerland (CH)
TenneT DE	Germany (DE)
TenneT TSO B.V.	The Netherlands (NL)
Terna	Italy (IT)
Transelectrica	Romania (RO)
TransnetBW	Germany (DE)
TEIAS	Turkey (TR)
VUEN	Austria (AT)

13.2 Annex 2 – List of abbreviations

A	Ampere(s)
ACE	Area Control Error
ACER	Agency for the Cooperation of Energy Regulators
aFRR	Automatic Frequency Restoration Reserves
AGC	Automatic Generation Control
CACM	Capacity Allocation and Congestion Management
CC	Coordination Centre
CE	Continental Europe
CET	Central European Time
DACF	Day-Ahead-Congestion-Forecast
DC	Direct Current
DRS	Protection against Loss of Synchronism – Détection Rupture de Synchronisme
EAS	ENTSO-E Awareness System
ENTSO-E	European Network of Transmission System Operators for Electricity
ER NC	Emergency and Restoration Network Code
FCR	Frequency Containment Reserves
GNSS	Global Navigation Satellites System
GPS	Global Positioning System
GW	Gigawatt
HPPs	Hydro power plants
HVDC	High Voltage Direct Current
ICS	Incident Classification Scale
IDCF	Intra-Day Congestion Forecast
IGCC	International Grid Control Cooperation
LFC	Load Frequency Controller
mHz	Millihertz
mFRR	Manual Frequency Restoration Reserve
MLA (Operation Handbook)	Multilateral Agreement (Operation Handbook)
MVA	Megavolt ampere
MW	Megawatt
NCER	Emergency and Restoration Regulation
NPPs	Nuclear Power Plants
NRA	National Regulatory Authority
NTC	Net Transfer Capacity

OHL	Overhead Line
PATL	Permanently Admissible Transmission Loading
PMU	Phasor Measurement Unit
PV PPs	Photovoltaic Power Plants
ROCOF	Rate of Change of Frequency
RSC	Regional Security Coordinator
SAFA	Synchronous Area Framework Agreement
SAM	Synchronous Area Monitor
SCADA	Supervisory control and data acquisition
SOGL	System Operation Guideline
SS	Substation
SVC	Voltage source converter
TATL	Temporarily Admissible Transmission Loading
TPPs	Thermal power plants
TSO	Transmission System Operator
TTC	Total Transfer Capacity
TRM	Transmission Reliability Margin
kV	Kilovolt(s)
VSC	Voltage Source Converter
WAM	Wide Area Monitoring
WPPs	Wind Power Plants

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