» Continental Europe Synchronous Area Separation on 24 July 2021

ICS Investigation Expert Panel » Final Report » 25 March 2022

Executive Summary

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EXECUTIVE SUMMARY

On Saturday, 24 July 2021 at 16:36 CET, the Continental Europe (CE) Synchronous Area was separated into two areas due to cascaded trips of several transmission power system elements. Specifically, the Iberian 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 Transmission System Operators (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.

The event was classified as a scale 2 extensive incident according to the ENTSOE-E Incident Classification Scale (ICS)[1] methodology. Therefore, according to article 15(5) of the System Operation Guidelines (SO GL)[2], in the immediate aftermath of the system separation, European TSOs, in close collaboration with ENTSO-E, began a joint process to collect all relevant facts regarding the incident. An investigation Expert Panel composed of representatives from TSOs affected by the incident, the relevant Regional Security Coordinators (RSCs), a representative of subgroup ICS, regulatory authorities and ACER was set up. The objective was 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 manner. A detailed technical analysis of the incident was completed.

1 ENTSOE-E Incident Classification Scale (ICS) methodology of 4 December 2019

2 Commission Regulation (EU) 2017/1485 of 2 August 2017 establishing a Guideline On electricity transmission System Operation (SO GL)

This Final Report presents the final collection of the gathered facts and provides recommendations to mitigate the risk of future system separation events and their consequences. The final report is structured into several parts, which are briefly summarised below.

Figure 1 gives a broad overview of the five main phases that occurred during the overall system split:

1. Situation before the event
2. Sequence of events that led to the system split
3. Behaviour after system separation and activation of automatic countermeasures
4. Activation of manual countermeasures and system stabilisation
5. Resynchronisation

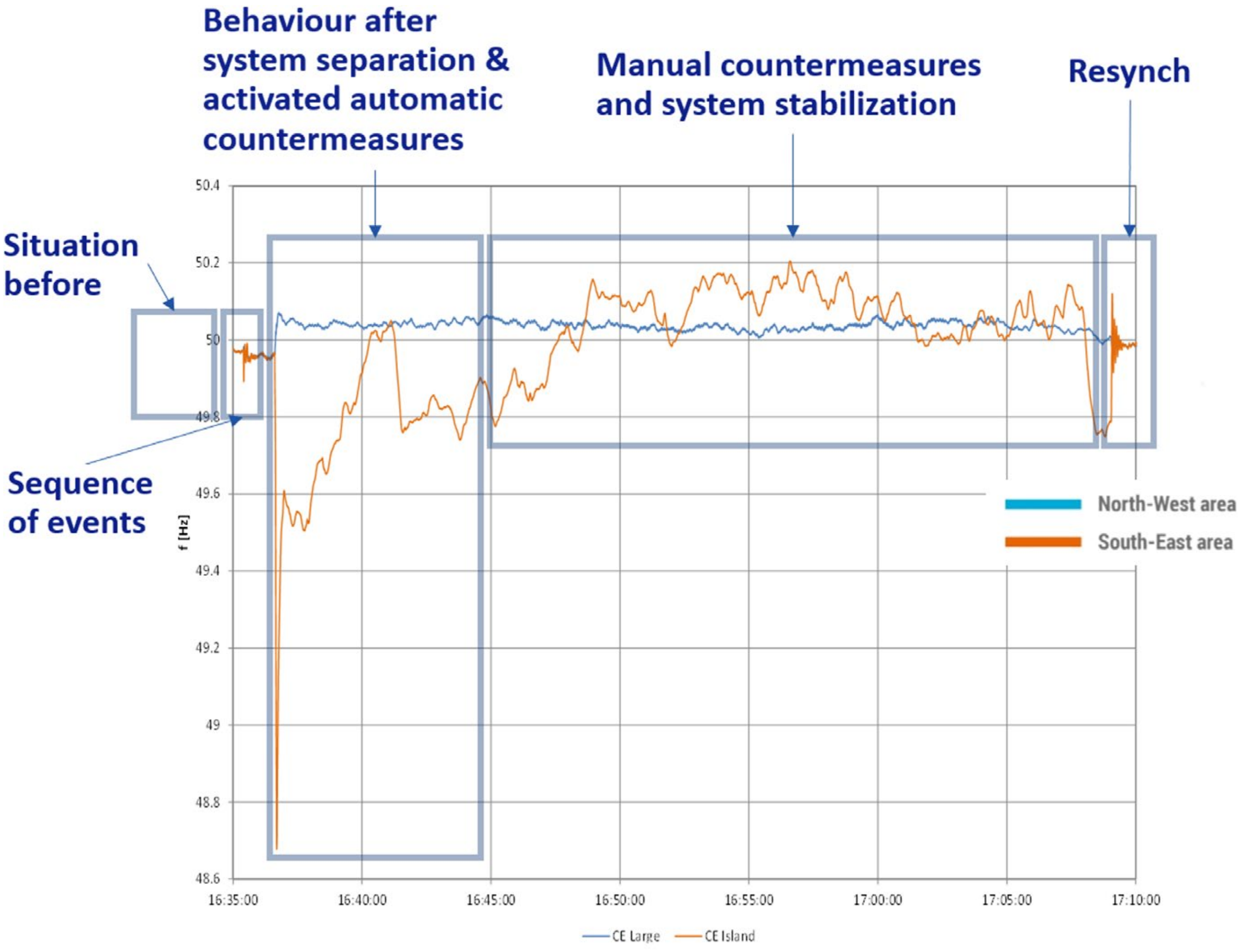

Figure 1: Phases of the system split.

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 its 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)–Vic (ES) tie-line and from the Baixas (FR)–Santa LLogaia (ES) HVDC interconnection link. Section 2 further provides historical data about wildfires in the affected region in order to give an estimate of the risk of such environmental conditions occurring.

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 well as the coordination activities in the operational planning phase by Coreso, the RSC and the Coordinated Capacity Calculator of the South-West European Capacity Calculation Region. The section describes outage planning coordination and the short-term adequacy assessment. Prior to the incident, 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 corridor, located in the area where the wildfire occurred, accounted for 1,119 MW. The power plant 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 occurred 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 networks, 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 global Rate of Change of Frequency (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. It should be noted that the ROCOF was estimated over a sliding window, as detailed in Section 4.2. 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.

This Section further gives a general overview of the overall energy balance, considering automatic frequency restoration reserves (aFRR) that were correctly activated in Spain and Portugal, the manual frequency restoration in Spain, and the intentional and unintentional disconnections of generation units across the system. Specifically, in Spain and Portugal in total, 4,241 MW of loads were shed, 2,302 MW of pumps disconnected, and 3,690 MW of generators disconnected. This section also explains automatic disconnection and reconnection of coil reactors and capacitors in Spain and France. In Portugal, co-generation-type producers, in addition to generation, also tripped the associated consumption, causing a further 172 MW reduction of consumption from the system.

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 given by dedicated fault location devices. The analysis proves that all line protections acted according to their settings and demonstrated 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 (FCR; also known as primary control) that acted with sufficient speed and delivered the predefined power quantities. The frequency deviation in the Iberian Peninsula was much higher than the predefined 200 mHz for FCR controlled frequency range; therefore, Spain and Portugal activated the full amount of FCR within 30 seconds (380 MW and 50 MW, respectively). Subsequently, this Section analyses the activation of aFRR (also known as secondary control) and the activation of manual frequency restoration reserves (mFRR) that occurred in Spain only, for a total requested power of 1,602 MW upward and 3,162 MW downward between 16:29 and 17:30. Finally, the impact of coordination between affected TSOs during the incident is analysed.

Resynchronisation

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 50 MW maximum each. The reconnection was performed at 17:09 CET by energising the 400 kV Hernani (ES)–Argia (FR) line from Argia 400 kV and synchronising from Hernani 400 kV using its dedicated resynchronisation functionality. At the time of reconnection, the frequency difference was still large (218 mHz) and, therefore, an active power oscillation on the 400 kV Hernani–Argia tie-line 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 SO GL. The analysis shows that the contingency analysis complies with the applicable EU rules.

Communication of coordination centres/ SAM and between TSOs

Section 9 describes communication of coordination centres/Synchronous Area Monitor (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 SAM in CE were responsible for the procedures and coordinated countermeasures. In other words, they were in contact with the affected TSOs (RTE and REE) immediately after the separation and regularly throughout the entire event. They also kept all other TSOs informed throughout the event.

Market Impact

Section 10 describes the impact of this event on the market, starting from day ahead Capacity Calculation until last trade price. As a synthesis, figures in this section show that the event had no impact on the market. The section describes 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 emergency and restoration. Subsequently, 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. Due to the underfrequency condition, 1,995 MW of pumped storage were disconnected in Spain and 307 MW in Portugal. Moreover, in Portugal 394 MW of industrial loads were disconnected according to dedicated service agreements.

Classification of the incident based on the Incident Classification Scale methodology

Section 12 describes the classification of the incident based on the ICS methodology, carried out according to the valid legal framework, i.e. the SO GL. According to the analysis, the most critical criterion is L2 (Incidents on Loads) and, therefore, the event is classified as an extensive incident of scale 2.

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 prior to the launch of the investigation. The expert investigation panel was established on 22 October 2021, published a factual report on 12 November 2021, and is publishing the present document (final report) on 25 March 2022.

Technical Analysis of the incident

Section 13 presents the results of the technical analysis of the incident carried out by the Task Force based on the collected facts.

The dynamic behaviour of the system during the incident was replicated by means of dedicated dynamic simulations. First, a simplified dynamic analysis based on a single busbar approach was performed. Such a model is widely adopted by ENTSO-E for frequency stability studies and was used in this specific case to confirm the registered ROCOF values as well as the overall system inertia at the moment of the incident. Subsequently, a detailed electromechanical analysis based on a full dynamic model of the system was carried out. This detailed set of simulations confirmed the identified sequence of events and the overall dynamic behaviour of the system in terms of frequency and voltage stability that matched the high-resolution Wide Area Monitoring System (WAMS) measurements.

The detailed dynamic model was further utilised to validate the behaviour of protection devices (of loss of synchronism and distance protection relays). According to the results of dedicated simulations, it was verified that all protections intervened according to their operational settings. Furthermore, it was numerically verified that in Portugal, the main cause of disconnection related to under-frequency, whereas in Spain most of the generators tripped due to voltage transients (over and under-voltage).

The Section further verifies the frequency support during the system separation, by providing an in-depth analysis that correlates the high-resolution measurements coming from the WAMS and the changes of power flows triggered by the disconnection of distributed generation, load, pumping storage systems and voltage compensation devices (coil reactors and capacitor banks). A handful of PMUs located in strategic positions across the system were selected. The analysis verified that the frequency was supported correctly by the automatic and manual connections and disconnections of grid elements.

Finally, the Section analyses thoroughly the activation of LFDD relays (Low Frequency Demand Disconnection) of pump-storage and domestic loads. In particular, the individual digital protection relays and transient recorder measurements from several locations in the Iberian Peninsula from REN and REE were studied. The analysis verified that all relays acted in accordance with the predefined frequency thresholds, and that the overall LFDD scheme worked properly and as expected.

Conclusions and recommendations

Based on the collected facts, the further technical analysis and the subsequent analysis of main causes and critical factors, the Expert Panel proposed several recommendations, which are detailed in Section 14 concluding the final report. The report also reviews and comments on the recommendations from the report by the Expert Panel for the 8 January 2021 system split event.

RECOMMENDATIONS DERIVED FROM THE EVENT OF 24 JULY

1. Reduce the volume of generation tripping

The Network Code on Requirements for Generators (NC RfG) establishes that generating units should not automatically trip in the frequency range between 47.5 Hz and 51.5 Hz and in different voltage ranges independently of the voltage of the point of connection. The NC RfG is only mandatory for generators installed after its requirements of general application have been defined at the national level.

As detailed in Section 4.6, during the event, in total 3,764 MW of generation was disconnected. Most of the generation units which were disconnected in Spain operated at the medium voltage level and were disconnected due to under- or overvoltage relays on the DSO level. In Portugal, most of the generator disconnections occurred due to underfrequency relays on the DSO level. As precise and reliable voltage measurements are only available at the high voltage transmission level, it is difficult to assess the exact amount of non-conform disconnections.

This recommendation is focused on avoiding as much as possible the generation tripping that is acting against the system stability and has a consequence of imposing more load shedding than the minimum necessary. The recommendation also addresses the need to improve the data collection in the case of generation trips. Specifically, the Expert Panel recommends the following:

a) Improve TSO–DSO coordination for the definition of settings of under frequency protection settings that trip the generation connected to the distribution grids.

b) Improve the monitoring of distributed generation by means of digital relays or dedicated transient recorders in the connection points of the generation.

c) Develop clear specifications in terms of standardised protocols and interfaces on the way to collect and exchange data in case of generation trips.

d) Improve the consistency between the specifications on conform automatic tripping affecting generating units connected on all voltage levels in the NC RfG and the Demand Connection Code (DCC).

e) Investigate and quantify the risk posed by the fact that the NC RfG does not apply to existing generators and quantify, through a cost-benefit analysis, the advantage of making existing generators comply to the NC RfG.

f) Analyse at the ENTSO-E level which TSOs (if any) have difficulties in getting real-time data from generators directly or indirectly as per SO GL Articles 44, 47 and 50 and, where this is the case, identify and implement corrective actions at the national level, in coordination with and to be approved by the national competent authority.

2. Improving the assessment and handling of weather-related risks

Incorporating climate-related risks into transmission network outage planning is addressed by Article 8 of ACER's decision on a methodology for coordinating operational security analysis and in SO GL Article 33(2) on Contingency lists. This implies that TSOs are able to monitor weather and environmental conditions with a potential impact on system operation.

Several communication channels are in place which allow TSOs to be informed in the event that external conditions have to be considered in the security analysis. For example, TSOs monitor weather conditions and the related environmental impact by means of service agreements with the local weather service provider. Furthermore, firefighting organizations and civil protection authorities contact grid operators as soon as environmental hazards occur in the vicinity of electrical components. Conversely, Fire Departments are informed by TSOs in the event of electrical risks. The communication means are dictated by local agreements that are established on a national basis for each TSO.

The problem of wildfire risk is tackled from different standpoints by the power and energy community. For instance, the CIGRE Working Group C2.24 is working on a technical brochure aimed at finding an efficient way to mitigate the risk of fire starts caused by electricity assets and the consequences of fires near overhead lines for system operations. The scope of the Working Group is to describe methods for successful operational decision-making in the event of fire and methods for risk assessment. Furthermore, coordination with external parties such as fire agencies when creating safety conditions and mitigating impact shall be considered.

As detailed in Section 2, in the current event, it appears that a lack of information about ongoing wildfire did not allow its potential impact to be anticipated; furthermore, the risk of the environmental hazard was hedged appropriately but there is room for improvement. Therefore, the following recommendations are proposed by the Expert Panel:

a) Assess weather conditions that are currently considered in the security analyses by TSOs under normal and other conditions (storm, snow, wind, fire…), as per SO GL Article 33.

b) Re-evaluate the existing processes set up by TSOs to monitor environmental hazards, to assess the associated risk for system operation and to mitigate the risks assessed with corresponding operational procedures.

c) Identity best practices and best available technologies for early warnings and online monitoring tools to detect exceptional environmental conditions that significantly increase the probability of an exceptional contingency (icing, wildfires, extreme wind, cold spells, etc.) in the vicinity of transmission corridors.

d) When necessary, identify how to develop complementary processes to ensure the awareness of environmental conditions changes. Regarding wildfires, it is recommended to:

- Exchange information with public authorities (Fire Department, Civil Protection) and Weather Forecast Service Provider to access the necessary information
- Consider using the existing platforms "ERCC – Emergency Response Coordination Centre" and "COPERNICUS" portals to gather information about different events related to Citizens Security.
- Investigate if new technologies could be used (e.g. thermal camera, satellite monitoring, specific sensors, IoT…) to ease the detection of wildfires in the vicinity of transmission corridors. Specific attention should be paid to areas where the risk of wildfire is relevant, and has an significant impact on the power system (due to grid configuration for instance, such as corridors between electric areas). A cost–benefit analysis has to be performed to assess the type and number of devices to be deployed, as well as the location to install them. This study should be based on the current statistics of wildfires, but also integrate possible evolutions of these events as a consequence of on-going climate change. TSOs should contribute to international collaborations (e.g. CIGRE Working Group C2.24) that could lead to implement additional measures if deemed necessary and relevant.
- Investigate if prioritised contacts between TSOs and public authorities should be established, e.g. a dedicated phone number or other communication means for contacting authorities in emergency cases.

e) When necessary, identify how to develop complementary processes to evaluate the risk of environmental hazards occurring.

3. Investigate the opportunity to supplement important transit corridors with Special Protection Scheme (SPS) functionality in combination with automatic overload protection.

SPSs used as a supplement for important transit corridors operation should be designed in such a manner that they immediately stop the cascading effect in a very short time after the trip of one or several elements leading other parallel elements to become overloaded. To achieve this objective, one example is to implement a rapid centralised automatic load shedding system.

In this event, corridor lines automatically tripped due to the activation of their overload protection relays, as detailed in Section 5. To limit this fact in the future, the Expert Panel recommends the following:

a) Investigate the opportunity to complement overload protection with 1 – 5 min threshold with SPS functionality, e.g. based on a centralised industrial load shedding scheme.

b) TSOs operating SPSs such as the DRS (*'Débouclage sur Rupture de Synchronisme'* – Protection against Loss of Synchronism) or similar should coordinate the settings with the protection schemes operated by neighbouring TSOs.

4. Enhance the monitoring and setting of LFDD operation (Low Frequency Demand Disconnection)

As detailed in Section 11, the information derived from LFDD relays was of paramount importance to investigate the causes of this event. To enhance the availability of LFDD recordings in the future, the Expert Panel recommends the following:

a) Improve data recording and collection from LFDD relays

b) Improve TSO–DSO coordination of monitoring and of relay settings and activation

5. Review the dedicated resynchronisation devices settings for tie-lines

As discussed in Section 7, the resynchronisation occurred when the frequency difference between the two areas was still large, therefore resulting in an active power oscillation over the re-connected tie-line. To enhance the resynchronisation in future events, the Expert Panel recommends the following:

a) Avoid synchronisation with inappropriate frequency settings

Recommendations derived from the event of 24 July

Recommendation		Justification	Responsible
R1	Reduce the volume of generation tripping	Generation disconnection may act against system stability	TSOs, DSOs, NRAs, ACER
R2	Improving the assessment and handling of weather related risks	Environmental hazards not correctly included in security calculations may result in system instability	TSOs, ENTSO-E
R3	Investigate the opportunity to supplement important transit corridors with Special Protection Scheme (SPS) functionality in combination with automatic overload protection	Automatic tripping of tie-lines due to line overloading may act against system stability	TSOs
R4	Enhance monitoring and setting of LFDD operation (Low Frequency Demand Disconnection)	LFDD relay recordings provide indispensable information to investigate power system incidents	TSOs, DSOs
R5	Review the dedicated resynchronisation devices settings for tie-lines	Resynchronisation performed with wrong settings may result in active power oscillations over the resynchronisation tie-line	TSOs

Publisher

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