Non-confidential version of the report of the committee for the analysis of the circumstances that occurred in the electricity crisis of the

April 28, 2025

Introduction: Objective of the Analysis

On April 28, 2025, at 12:33:30 p.m., there was a zero voltage in the Iberian Peninsula and the disconnection of the electricity system of Spain and Portugal from the European interconnected system.

At the same time of the incident, an electricity crisis was declared in accordance with Regulation (EU) 2019/941 of the European Parliament and of the Council of 5 June 2019 on risk preparedness in the electricity sector and repealing Directive 2005/89/EC, and with the Plan for Preparedness against Risks in the Electricity Sector in Spain, as the thresholds for loss of load and non-supplied energy provided for in said plan have been exceeded.

The Government of Spain, through the Ministry for the Ecological Transition and the Demographic Challenge, communicated to the European Commission and the French and Portuguese authorities this declaration of an electricity crisis.

By mandate of the National Security Council, which may use support bodies for the exercise of the functions assigned to them when the management of a crisis requires it under Article 20.3 of Law 36/2015, of 28 September, on National Security, and by means of a communicated order, of 30 April 2025, of the Third Vice-President of the Government and Minister for the Ecological Transition and the Demographic Challenge, the "COMMITTEE FOR THE ANALYSIS OF THE CIRCUMSTANCES THAT OCCURRED IN THE ELECTRICITY CRISIS OF 28 APRIL 1995 IS CREATED".

2025" (hereinafter, "Committee 28-A").

The report and its conclusions must be submitted to the plenary of the National Security Council for approval.

The committee is chaired by the Third Vice-President of the Government and Minister for the Ecological Transition and the Demographic Challenge and is composed of: the Director General of the Department of National Security, Commander-in-Chief of the Joint Cyberspace Command (MCCE); the Commander of the MCCE Combat Group, the Deputy Director General of the National Cryptologic Center, belonging to the National Intelligence Center (CCN-CNI); the Director of the National Center for the Protection of Critical Infrastructures (CNPIC), the Head of the Cyber Coordination Office (OCC); the Secretary of State for Energy; the Director General of Energy Policy and Mines; the Director General of Energy Planning and Coordination; the Director General of Water; the Deputy Director General of Digital Security; the Director General of the Institute for Energy Diversification and Saving (IDAE) and the Director General of the National Institute of Cybersecurity of

Spain. The technical secretariat of the Committee is exercised by the Director of the Cabinet of the Secretary of State for Energy.

At its meeting on April 30, the committee agreed to set up two working groups: one on Cybersecurity and Digital Systems (GTCSD1) and another on Electricity System Operation (GTOSE2). The creation of these two specialized working groups responds to the need to analyze what happened in a specific but coordinated way from the two most relevant perspectives to determine its causes: the electricity system management perspective, on the one hand, and the digital one, on the other.

This report is structured into seven sections and twelve annexes that, in an orderly and progressive manner, allow us to understand the context, development and conclusions derived from the electricity crisis of 28 April 2025. Each section addresses specific aspects of the analysis carried out by the Committee, from the justification

1 The GTCSD is composed of the Commander-in-Chief of the Joint Cyberspace Command, the Commander of the Joint Cyberspace Command Combat Group, the Deputy Director General of the National Cryptologic Center, the Head of the Incident Response Area of the National Cryptologic Center, the Director of the National Center for Critical Infrastructure Protection; the Head of the Cybersecurity Coordination Office, the Deputy Director General for Digital Security and, as an assistant on behalf of GTOSE, the Director General for Energy Planning and Coordination.

2 The GTOSE is made up of the Secretary of State for Energy, the Director of Energy Policy and Mines, the Director General of Energy Planning and Coordination, the Deputy Director of Electric Energy and the Director of the Institute for Energy Diversification and Saving, with the Director of Energy and the Deputy Director of Electric Energy of the CNMC acting as guests.

from its creation, its operation and methodology, to the detailed description of the events, the technical analysis, the conclusions and the proposals for improvement. This organization seeks to offer a complete and structured vision of the work carried out, facilitating both the global understanding and the timely consultation of each of the phases of the analysis process.

After an introduction on the creation of the Committee, setting out the context that motivated its constitution and the foundations that support its work, the first section presents the origin, purpose and operation of the committee, created under Law 36/2015, of 28 September, on National Security and Law 40/2015, of 1 October. of the Legal Regime of the Public Sector. In particular, the composition, responsibilities and work dynamics are set out, detailing the voluntary nature of the provision of information by the agents of the sector and the confidential nature of the actions of the committee, without this having prevented the fulfillment of its purpose.

The second section sets out the methodology followed by the two working groups that have developed the Committee's actions. Likewise, the type of information requested from the different agents of the electricity sector is detailed, highlighting that most of the requirements were satisfactorily met. This collaboration has been decisive for the preparation of a rigorous analysis and a precise chronology of the events that occurred on April 28.

The third section presents a detailed description of the events that occurred on April 28. To this end, the Committee has structured the timeline of events in 5 phases, which coincide with those articulated in the content of this section. Phase 0 that addresses the days before and tomorrow of the event between 9:00 and 12:00 in the morning; phase 1, between 12:00 and 12:30, in which different oscillations are detected and dampened; phase 2, which covers the minutes between 12:32 and 12:33:18, in which the first generation losses due to overvoltage occur; phase 3 in which the collapse of the system to zero between 12:33:18 and 12:33:30 is described; Finally, phase 4 in which the supply is restored from 12:33:30 on April 28, until 14:36 on April 29.

The fourth section reflects the analysis carried out by both working groups. This analysis is organized into two subsections: the first, related to the operation of the system

electrical, prepared by GTOSE; and the second, focused on digital systems and cybersecurity, developed by the GTCSD. The first subsection addresses both the events that occurred on April 28 and the different factors of the system that allow them to be explained.

The fifth section contains the set of conclusions derived from the analysis developed in section four. These conclusions are differentiated according to their scope, on the one hand, those relating to digital systems and, on the other, those corresponding to the strictly electrical field.

The sixth section sets out a set of measures to address the factors that led to electricity zero and that would allow a reinforcement of the system as a whole. Again, this section separates those measures focused on the digital field and cybersecurity, proposed by the GTCSD, from those that affect the strictly electrical field, proposed by the GTOSE.

Finally, section seven includes a set of additional reflections at the European level.

The report also incorporates twelve annexes that provide detailed information or complementary context on the different aspects dealt with in the main body of the document. Such information, because of its length or ancillary nature, has been included in the annexes to facilitate the clarity and organization of the report.

Purpose and functions of the Committee

Context

The National Security Council, by virtue of article 21.1 a) of Law 36/2015, of 28 September, on National Security, which attributes to it the function of "issuing the necessary guidelines in terms of planning and coordination of National Security policy", adopted at its meeting of 30 April 2025 the directive to create within the scope of the General State Administration, a committee for the analysis of the circumstances that occurred in the electricity crisis and the preparation of conclusions, which will be submitted to the plenary of the National Security Council, as an adequate measure of protection of national security.

Within the scope of her own powers, the Third Vice-President and Minister for the Ecological Transition and the Democratic Challenge, and in exercise of those attributed to her by Article 16 of the aforementioned National Security Law, executed the aforementioned directive, approving the Order communicated to her of 30 April 2025, which creates and regulates the functioning of the Committee for the analysis of the circumstances that occurred in the electricity crisis of 28 April 2025 (hereinafter, the Order), with the nature of a working group, in accordance with article 22.3 of Law 40/2015, of 1 October, on the Legal Regime of the Public Sector.

"The Committee will analyse the circumstances of the electricity crisis that occurred on 28 April 2025 and will draw conclusions that will be submitted to the plenary session of the National Security Council by the Third Vice-President of the Government and Minister for the Ecological Transition and the Demographic Challenge".

The Committee "may agree to the incorporation of experts in the field, seek their opinion, request information and invite representatives of the Public Administrations and the public and private sector to participate in its activities".

Functions

The electricity crisis that occurred on April 28, unprecedented in our country, led the National Security Council to consider it essential to equip itself with an "agile and specialized instrument for the analysis of the factors that have contributed to the crisis, the identification of vulnerabilities and the proposal of measures to improve the procedures, resources and capabilities of the National Security System." All

this, in line with the principles of unity of action, inter-ministerial coordination and collaboration between Public Administrations that inspire national security policy, and in compliance with the legal and strategic mandates in force.

The complexity and scope of the events that occurred require a multidisciplinary approach and the collaboration of the different ministerial departments, public bodies involved and experts who can provide relevant information, in order to guarantee an exhaustive assessment of the situation and the formulation of effective proposals for its resolution and prevention of future incidents.

To fulfil its objective, the committee is empowered to gather information and expert opinion, and to invite representatives of the Public Administrations and the public and private sectors to participate in its activities.

Operationally, as has been pointed out, the committee has set up two working groups: the Cybersecurity and Digital Systems working group (GTCSD) and the Electricity System Operation working group (GTOSE).

Voluntary provision of information provided to the Committee by electricity system operators.

Without prejudice to the general principle of collaboration provided for in Article 7 of Law 36/2015, of 28 September and, in general, in Article 18 of Law 39/2015, of 1 October, on the Common Administrative Procedure of Public Administrations, the Committee has collected information from electricity system operators under the premises of cooperation and voluntariness.

The Committee's action has been carried out on the basis of voluntary collaboration, without prejudice to compliance with the rights and duties granted by the regulations to the different agents of the electricity system, and to the procedures of any kind that may be initiated by the competent bodies in the exercise of their functions in accordance with the applicable sectoral legislation. and in the areas that are specific to them, which are different from those that correspond to this Committee.

Confidentiality of the Committee's proceedings

The Committee's actions have been carried out under the premise of confidentiality.

The Committee has preserved the confidentiality of the data and reports provided by operators in cases where, when requested by third parties, operators have not given their express consent for its dissemination.

The same principle of confidentiality applies to the content of the Committee's sessions, whose members are subject either to the duty of confidentiality established in Article 26.2.b). 2 of Law 19/2013, of 9 December, on transparency, access to public information and good governance, or to the principle of confidentiality set out in art. 52 of the Revised Text of the Basic Statute of Public Employees Law, approved by Royal Legislative Decree 5/2015, of 30 October.

The above-mentioned confidential nature must be consistent with the raison d'être of the Committee, to which this report responds, which aims to analyse the circumstances of the electricity crisis of 28 April - which undoubtedly includes, as indicated in the explanatory part of the Order communicated of 30 April, "the analysis of the factors that have contributed to the crisis, the identification of vulnerabilities and the proposal of measures to improve the procedures, resources and capabilities of the National Security System" - and prepare the corresponding conclusions on this analysis and submit them to the Plenary of the National Security Council.

The report pronounces on all the aspects analysed in fulfilment of the mandate conferred on it, with the necessary degree of detail to make that analysis intelligible and useful for the purposes for which the Committee has been created.

The balance between the two factors – the principle of confidentiality and compliance with the Committee's mandate – is based on the fact that the report only specifies certain data on specific facilities or operators, strictly limiting itself to those that are essential to be able to specify the factors that have contributed to the crisis, identify vulnerabilities and propose measures for improvement.

In general, and with regard to the public communication of the principle of transparency of public activity, it is considered that it must comply with the provisions of the aforementioned Law 19/2013, of 9 December, both in relation to the so-called "active publicity" regulated in its article 5.1 and in the observance of the limits to the right of access to public information (articles 5.3, 14 and 15).

In the same spirit of collaboration, and with the aim of facilitating maximum transparency, the committee sent, on 4 June, a letter to the agents of the sector with whom it has collaborated in which it requested express authorisation for the dissemination of the specific aspects of the information sent, asking them for maximum transparency so that it can be communicated to the public with the highest level of detail. This report takes into account the responses received from the different actors consulted.

Of the total number of agents consulted, 67, six expressed their express desire for the information to be confidential; three, they exposed the need to previously authorize the content for dissemination; 57 did not send express authorization and one has allowed the dissemination of his proprietary data.

This report takes into account the responses received from the different actors consulted.

Communication of data to competent authorities

The Committee, which has the nature of a working group, by virtue of the provisions of Article 22.3 of Law 40/2015, of 1 October, is subject to the principle of legality of Article 103 of the Constitution.

For its part, Article 61 of Law 39/2015, of 1 October, regulates the initiation of the procedure at the reasoned request of other bodies.

By virtue of the provisions of this article, any administrative body that does not have the competence to initiate the procedure in question and that has occasional knowledge, or because it has been assigned functions of inspection, inquiry or investigation, of circumstances, conduct or facts that are the subject of another procedure, is empowered to make a proposal to the body competent to initiate it.

The fact that the Committee has accessed the data or information that may be transferred to other bodies through the reasoned request referred to in Article 61 of Law 39/2015, in a context of confidentiality, is not an obstacle to such action insofar as it is carried out in a manner that respects the guarantee of non-self-incrimination in accordance with the scope that constitutional jurisprudence (STC 21/2021) attributes to such guarantee, which also operates, duly modulated, in administrative sanctioning law.

Context conditions

The work of this committee is, therefore, subject to its objectives, to the framework of voluntary collaboration on the part of the agents consulted, to the obligatory respect for confidentiality in the terms determined by the regulations and the agents themselves, who have freely established additional conditions when they have considered it appropriate.

A second factor that has determined the work of the committee has been the weather. Among other objectives, it aims to provide a solid basis for analysis for the compliance, by the Kingdom of Spain, with the provisions of Regulation (EU) 2019/941 of the European Parliament and of the Council, of 5 June 2019, on risk preparedness in the electricity sector and repealing Directive 2005/89/EC. from which the Risk Preparedness Plan in the electricity sector in Spain emanates.

In its article 6.5, the plan - in reference to article 17 of the Regulation - sets a maximum period of three months for the Competent Authority, in this case the Directorate-General for Energy Policy and Mines, to present an ex-post evaluation report to the European Commission and the Electricity Coordination Group, urging it to try to shorten this period. The committee has worked on this temporary mandate, redoubling its efforts to obtain a conclusive analysis that, on the one hand, allows it to propose the measures that mark its functions, and, secondly, constitutes the basis for the subsequent compliance with this reporting obligation with the European authorities.

In general, the committee has had the cooperation of all the agents in the electricity sector, which it thanks for their collaboration. In such a complex system, with a wide variety of agents of all types of size and legal nature, the response capacity and the granularity of the information received has been uneven, which is why it has sometimes been necessary to carry out a greater number of checks and modelling in order to reach conclusive evidence, an operational effort that has made it possible to overcome this shortcoming. In the same vein, on occasions, also due to lack of resources, the information has not been sent prior to the on-site visits, an issue that would have facilitated a more agile analysis.

The technological variety, the complexity of certain systems and, in some cases, the fact of not having certain monitoring elements and the lack of centralization has also been a challenge, especially in the field of digital systems analysis, which has also been solved with operational efforts, which have taken more than 1,200 hours of work.

However, the committee has identified certain contour elements that have conditioned its work.

The confidentiality framework, in addition to being a limitation in its public dissemination, has sometimes made it difficult to access certain elements of contrast, which have had to be supplied with other sources.

The voluntary framework, together with the complexity and length of the documentation, has led to some delays in receiving information.

Despite the willingness of most of the agents, the information has not always had a sufficient level of precision. In this sense, the committee emphasizes the measurements that, for different reasons, did not have the correct setting, an issue that has been corrected.

Similarly, as pointed out, not all agents have had adequate means to offer the information with the precise granularity and detail, mainly because they do not have the necessary equipment. There have also been certain omissions, information that for various reasons has not been received as of the date of completion of this report.

Another complexity has been derived from the configuration of the "downstream" system, where it is common to find legal entities – companies, joint ventures – made up of the different users of a collector station or a substation. In addition to the difficulty of identifying its representative, there has been a natural debate among its partners about the relevance of collaborating with this committee, which has caused delays in receiving information, despite the fact that the company had it shortly after receiving the request from this committee.

The ownership structure of this type of facility, which is decisive for the characterization of one of the main levels of study of this committee, has led the partners to decide on occasions to resort to independent analyses to issue

his assessment of what happened. The committee appreciates this effort on the part of the members, although it has been a second factor in delaying the receipt of information.

The different rhythms when receiving data, fast at the beginning and significantly slower in the last stretch of the analysis, has made it difficult to structure the work, increasing the level of iterations with the agents in order to complete the analysis.

With these boundary conditions, both temporal and detailed documentation and data collection process, the committee has been able to structure a contrasted account of the facts.

The degree of certainty, however, makes it possible to build a solid basis for fulfilling the functions of the committee, especially with regard to the recommendations that, at this early stage, can contribute to strengthening the system in the short and medium term.

Methodology and Documentation Management

In the case of the Cybersecurity and Digital Systems Working Group: The work plan was defined at three levels:

Level 1: System Operator of the Spanish Electricity Network

Analysis of documentation, information and data

On-site system analysis/review.

Level 2: Control Centers of different Companies.

Analysis of documentation, information and data.

On-site system analysis/review.

Level 3: Generation Centers that depend on these control centers.

Analysis of documentation, information and data.

Request data from control centers.

At the same time, an action plan was designed to strengthen the prevention and detection of cybersecurity in the electricity sector, among others:

Exposure surface analysis.

Strengthen the surveillance of open sources in forums and internet sites, darkweb, etc., to see if there is any credible claim by any relevant actor, sale of information or data from possible exfiltrations, etc.

Analyze similar cases of cyberattacks against the electrical system to study modus operandi: Tactics, Techniques and Procedures (TTPs).

The purpose of the analyses in the aforementioned entities has focused on the evaluation of their control centers, the operations and security procedures that are carried out in them, as well as the evaluation of existing activity records.

The study has taken into account the following elements of the entity's cybersecurity subsystem, among others:

Components of validation and authentication of Users in the system, especially those related to remote access.

Perimeter protection and network segregation and control assets: mainly firewall devices and layer 2, 3, 4 and 5 protection devices.

Protection system against harmful code and advanced protection of EDR (Endpoint Detection and Response) systems.

Threat detection and traffic monitoring probes.

Activity logs.

Incident management systems and records.

Security reports and vulnerability audits.

Network schematics and configuration diagrams.

To carry out the planned actions, the committee set up six rapid reaction teams (RRTs), which worked in coordination with a technical coordination team.

Approximately 133GB of information has been collected, which has contributed to this analysis. Annex VIII includes a list of actions carried out by the GTCSD within the framework of this analysis.

The organizations under analysis have collaborated, providing access to the information requested, as well as to the visualization and comparison of information through the technical consoles that were available in the different Control Centers.

Prior to the visit to the entity, they were sent a procedure and form for the analysis of cybersecurity and digital systems, so that the RRT would have, in advance, as much information as possible to prepare the visit and the analysis properly.

In parallel, the group has launched various complementary actions. Specifically:

Strengthening cyber surveillance

Information has been requested from all Control Centers, receiving reports that include, in some cases, information about their generation centers.

With the data provided by the different control centres, a preliminary non-intrusive analysis has been carried out to identify possible cybersecurity risks and threats that could be related to the crisis of 28/04/2025.

More than 1,000 public IPs have been analyzed, which have been checked against databases of threats and vulnerabilities, in order to identify indications of vulnerable systems or possible entry vectors.

Reports have been made on documented cases of cyberattacks against the electricity grid that have occurred in other countries, in order to identify similar Tactics, Techniques and Procedures (TTPs), patterns and indicators of compromise, as well as actors involved. This information has been made available to the RRTs to focus the search for evidence and indications and these TTPs.

Surveillance has been reinforced in forums and sites that are frequently used by certain actors, for the claim of cyberattacks, sale of extracted data, extortion, etc., without any relevant action having been identified.

In the case of the Electricity System Operation Working Group, the information requested has covered, at least, the period between 9:00 a.m. and 12:35 p.m. on 4/28/2025, for the purposes of analyzing the causes and sequencing of the incident, and the period between 12:35 p.m. and the moment of full restoration of supply, to evaluate the restoration procedure. Likewise, the different agents have been asked for information about the week prior to the incident, as well as any other information that could be relevant to clarify what happened. In particular, and as a suggestion from the sector, previously observed patterns similar to those that occurred from 12:00 on 28 April and, specifically, the episode of overvoltages on 22 April and the undervoltage episode of 24 April have been analysed.

The quantitative information collected includes data on active, reactive, frequency and voltage power measurements, installation tripping and shutdown sequences, causes of such disconnections, oscillographic logs and a complete list of SCADA alerts in your control system.

Qualitative information includes an explanation and interpretation of the data, information on the participation of the generation units in the restoration of the service as well as the analysis, reflections on what happened and proposal for action or measures, regulatory, new equipment or systems, improvement of communications or of another nature, with the aim of avoiding the repetition of an incident of this nature and to improve, where appropriate, the joint response of the system until the complete restoration of the supply.

When it has been necessary to specify or contrast information received, new requests have been made for clarification and expansion of specific elements of the information to allow the working group to develop as exhaustive an explanation as possible of what happened.

Likewise, at the invitation of different companies and in order to facilitate the exchange and contribution of information, several of the meetings of the GTOSE have been held at the offices of these agents. Telematic meetings have also been held. Due to organisational criteria, it has not been possible to respond to all the invitations, although an attempt has been made to maintain a fluid relationship with all the actors and, particularly, with the most relevant in terms of volume and interest for the characterisation of the circumstances that occurred on 28 April.

For the purposes of information analysis, a secure repository has been created, with restricted access, in which all documentation received in response to requests for information has been stored, as well as any other matter that GTOSE considers relevant.

The GTOSE has also created an analysis team or task force, made up of technical staff from different units of the Secretary of State for Energy (Cabinet, Directorate-General for Energy Policy and Mines, hereinafter, DGPEYM, Directorate-General for Energy Planning and Coordination, hereinafter DGPLACE, and IDAE), which has been responsible for exhaustively analysing the information received. preparing executive summaries and completing a control and monitoring table.

In the process, a total of 111 letters have been issued by the technical secretariat of the Analysis Committee requesting cooperation from the different agents, with 770 requests, which have been answered for the most part.

The actions carried out by the GTOSE are also described in Annex VII.

The information received has made it possible to prepare the analysis and chronology of the events that occurred on April 28 and their causes, contrasting data provided by different agents when they have been relevant to clarify what happened in specific locations or times, thus fulfilling the purpose entrusted by the National Security Council to this committee.

Description of the events that occurred on April 28

For a better description and analysis of the succession of events on April 28, the Committee has structured the timeline in the following five phases:

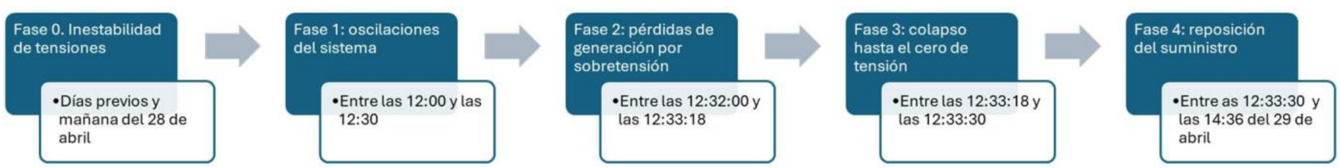
Phase 0 - voltage instability: week before and morning of the event between 9:00 and 12:00

Phase 1 - system oscillations: between 12:00 and 12:30:00

Phase 2 - Generation losses due to surge: between 12:32:00 and 12:33:18

Phase 3 - collapse to zero of peninsular voltage: between 12:33:18 and 12:33:30

Phase 4 - supply replenishment: from 12:33:30 on 28 April to 07:00 on 29 April for 99.95% of demand, although all technical work ends at 14:36h.



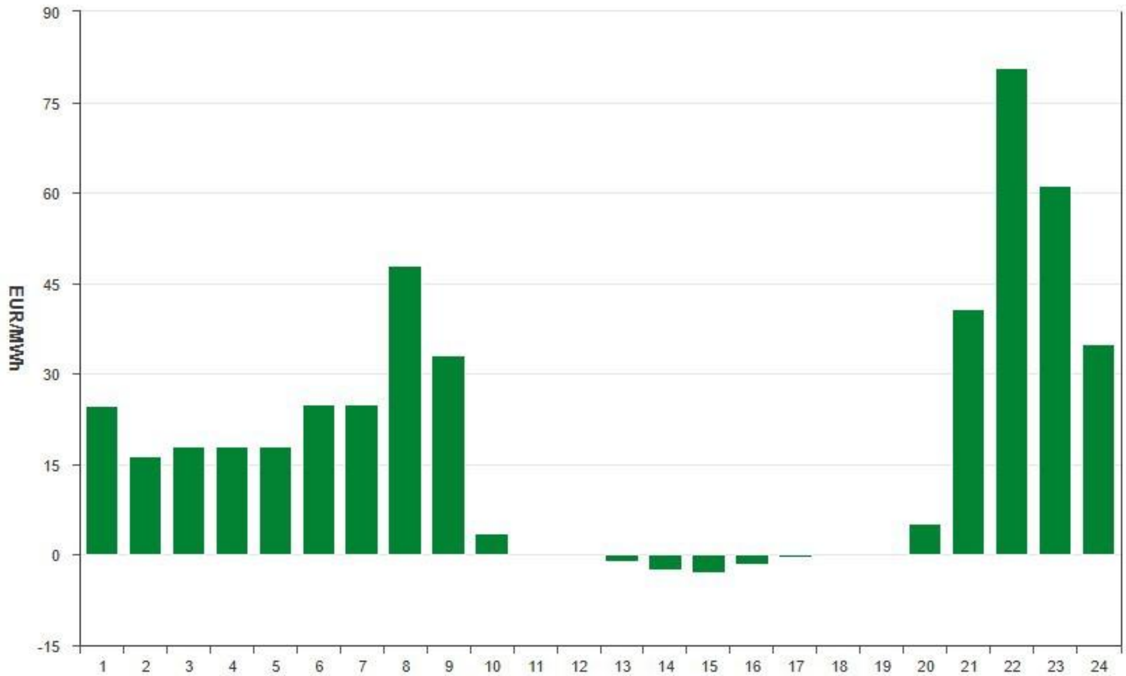
Phases of the April 28 incident

Context of the electricity system on April 28

Before describing the phases and chronology of the incident, a contextualization of the electricity system on April 28 is carried out, from different physical and market perspectives. Annex X and Annex XI detail the operation of the electricity system for better context of this section.

As usual in the electricity system, the mix conditions for April 28 were initially set by the procedures established the day before, on Sunday, April 27.

At noon on April 27, the daily wholesale market (OMIE) for each of the hours of April 28 matched, with an average daily price of €18.50/MWh3, with the central hours of the day showing zero or negative prices:



Graph 1 Hourly spot market prices (OMIE) on 28 April. Source: OMIE

In addition, as can be seen in Graph 2, the price of the intraday market, which results from successive auctions carried out subsequently, also shows variation between positive and negative prices, in this case with variations in quarter-hour periods.

3 As a reference, the arithmetic average price for 2024 was €58.6/MWh and that for 2025, up to and including May, is €60.4/MWh.

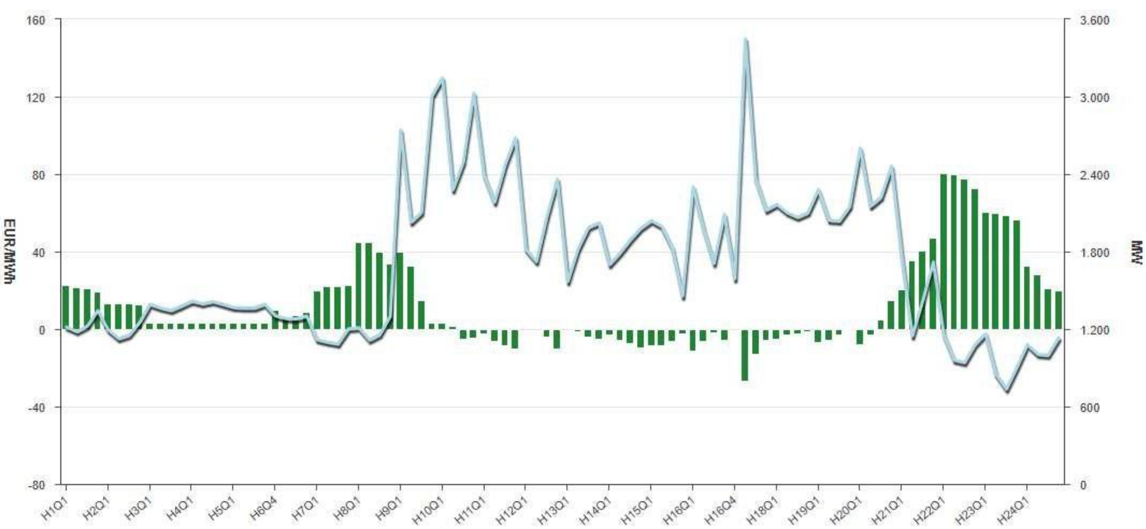


Chart 2 Prices and energy traded in the intraday market (session 1 28/04/2025). Source: OMIE

Likewise, and as every day, in accordance with Operation Procedure 3.2 "Technical Restrictions", the System Operator carried out the programming for the solution of the technical restrictions (RRTT) of the Daily Base Operating Program (hereinafter, PDBF) and, once the Provisional Viable Daily Program (hereinafter, PDVP) was published at 2:43 p.m. on April 27, carried out the programming of technical restrictions in real time, both on the afternoon of April 27 and already during the 28th itself.

For the programming of technical restrictions, the System Operator has those production facilities that have not been declared unavailable. For the programming corresponding to the 28th, based on aggregate information collected, there were a total of facilities with an installed capacity of 12,800MW whose owners had declared unavailable, including about 7,400MW of combined cycle and about 3,000 MW of nuclear.

Tabla 1 Indisponibilidades de unidades de producción. Fuente: REE

Tecnología	Potencia Indisponible* (MW)
Carbón	903,5
Ciclo combinado	7.426,3
Fuel-gas	0,0
Nuclear	3,078,6
Turbinación bombeo	1.392,1
Valores de potencia indisponible considerando periodos horarios completos para todas las indisponibilidades.	

Table 1 Unavailability of production units. Source: REE

As the Committee has been able to ascertain, it is clear from the reasons for unavailability declared by the operators of the generation plants that, in most cases, these are due to technical failures in repairs, inspection or maintenance work or refuelling. In cases of

, the declared reason for unavailability is

The peninsular electricity system had different production units available, as can be seen below by comparing the unavailability with the total power. All this, in a context of low demand as it should be due to seasonality.

Tecnología	Potencia Indisponible* (MW)	Potencia instalada total (MW)
Carbón	903,5	1.820
Ciclo combinado	7.426,3	24.562
Fuel-gas	0,0	8
Nuclear	3,078,6	7.117
Turbinación bombeo	1.392,1	3.331
Valores de potencia indisponible considerando periodos horarios completos para todas las indisponibilidades.		

Table 2 Unavailable power and installed power. Source: Authors' elaboration based on REE data

According to the information sent by the System Operator, the RRTT schedule, both the day before (at 2:43 p.m. on April 27, the PDVP for the 28th is published) and since that moment in real time, obeys different categories or dimensions of security of supply, with the following breakdown for April 28:

Dynamic voltage control: the system requires dynamic voltage control capabilities by setpoint that, according to Operating Procedure 7.4, conventional power plants are required to provide. For this reason, in the RRTT programming for the 28th, 10 thermal groups (3 nuclear groups and 7 combined gas cycles) are programmed for the dynamic voltage control function: central zone (1), southwest zone (2), southeast zone (1), northwest zone (1), northern zone (1), eastern zone (2), north east zone (1) and south east zone (1).

As can be seen, the groups have a certain distribution throughout the Spanish territory, given the more local nature of the tension and its control. However, one of the groups , relating to the south-west zone, recorded a breakdown due to and declared unavailability on the afternoon of the 27th (at 7:47 p.m., lasting until 00:00 on 4/30). As a consequence, in the programming of technical constraints in real time, at 8:36 p.m., the System Operator decides to keep a , which is scheduled from 0:00 a.m. to 2:00 a.m. on April 28 for voltage control in Andalusia (and between 8:00 a.m. and 9:00 a.m., by reservation).

Static voltage control: in order to maintain adequate voltage levels at night, with lower demand and reduced wind production, 14 thermal generation production units (nuclear, combined cycle gas and coal) are limited between 1:00 and 8:00. The limitation consists of the obligation to remain coupled (i.e., to remain connected to the system and operational) to guarantee a sufficient level of reactive absorption, given that, with the topological measures - coupling of ballasts and opening of lines - adopted by Red Eléctrica de España (REE, hereinafter), voltage levels within the regulatory operating ranges are not guaranteed without the adoption of these additional measures.

Security in permanent regime and in the event of contingencies: to avoid overloads in the grid, renewable production in Toledo and Ciudad Real in the PDVP is limited. In real time, on the same day 28/4, this limitation is extended (from 9:55 to 11:00 and from 11:51) and a limitation is added to renewable generation in Extremadura from 10:11, to avoid overloading the grid in the event of a contingency (N-1). Production is also limited for two hours in the morning to avoid overloads on the grid in Navarre.

Restrictions in the distribution network: at the request of the distributor in the area and to guarantee supply in a specific area due to local congestion, the distribution network is programmed to a technical minimum 24 hours a day.

, which was also limited by static tension control for the same period. In real time, at the request of the distributor in the area, renewable generation in Levante is limited by works on the grid.

Reserve margin: in real time, both on April 27 and on April 28, various thermal groups (combined gas cycles) are programmed to provide a sufficient reserve margin to be raised, both on the morning and afternoon ramp.

Reduction of renewable generation: in real time, reshipments are made to be lowered between 9:00 and 13:00 (up to a maximum of 579 MWh at 13:00, which never materialized).

PHASE 0. VOLTAGE INSTABILITY IN PREVIOUS HOURS AND WEEKS

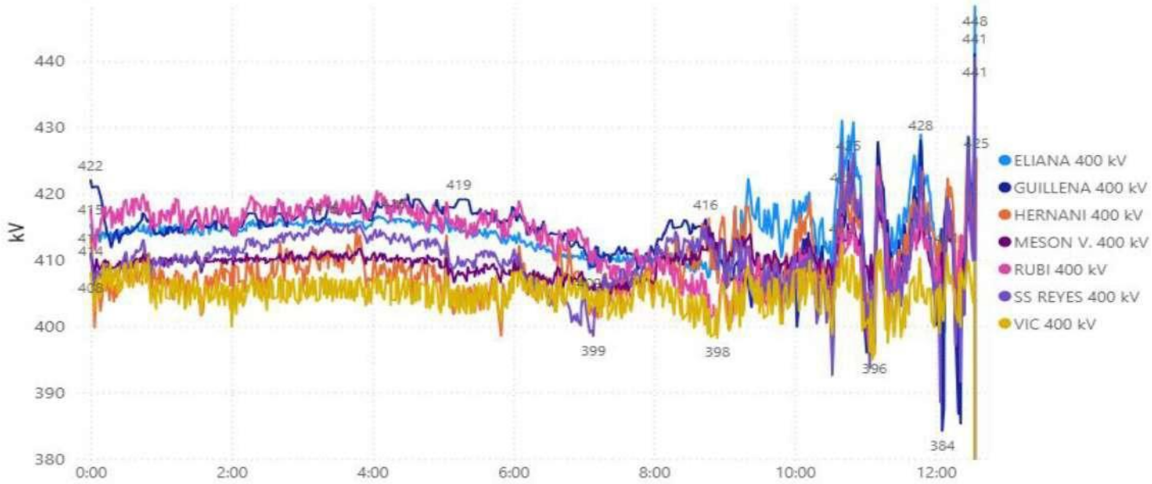
Note: A brief description of the fundamentals of the electrical system is included in Annex X for a greater context of the concepts developed below.

Previous Events

Some agents have referred to previous episodes of instability in tensions this year, citing 31 January, 19 March and 22 and 24 April, and have related the previous situation of the 28th with that of these precedents, particularly with that of 22 and 24 April. In the Analysis block, the episodes of variation of the aforementioned dates are described and analysed in greater detail.

Situation on the morning of 28A

During the morning of April 28, the peninsular electricity system registered a volatility in voltages (sudden increases and drops in voltage), which different agents have described as atypical.



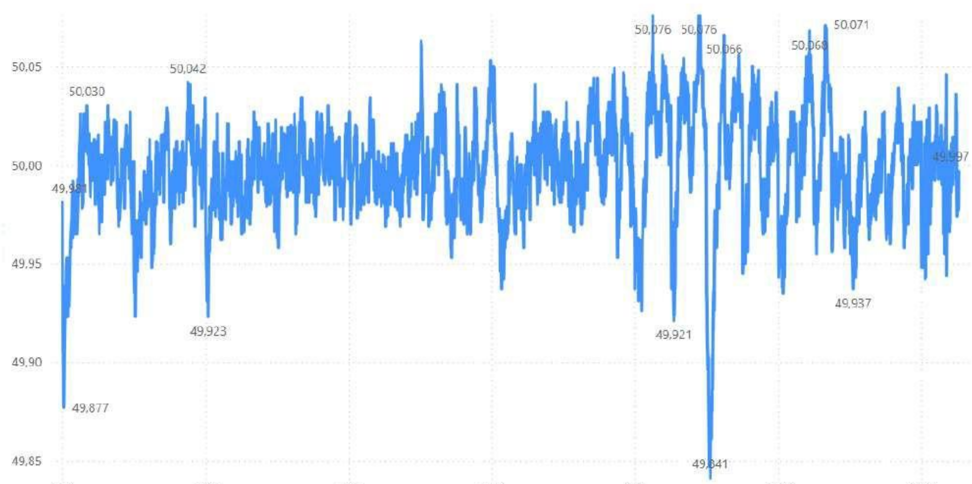
Graph 3 Evolution of voltages in the 400 kV network since 00:00 on 28 April. Source: REE

As can be seen in Graph 3, in general, the voltage profile up to 06:00 is stable, with typical values in system operation and with a variability of less than 5 kV. At 6:00 a.m., there is a change of program of approximately 1,000 MW in the interconnection with France (going from 2,590 MW export to 1,600 MW export). Shortly before the start of the program change, voltage variations were detected in all the pilot nodes of the 400 kV network, of relatively small size as can be seen in the graph.

Between approximately 6:00 a.m. and 8:00 a.m., voltages are reduced in general, in line with the rise in electricity demand at those times (higher levels of network load).

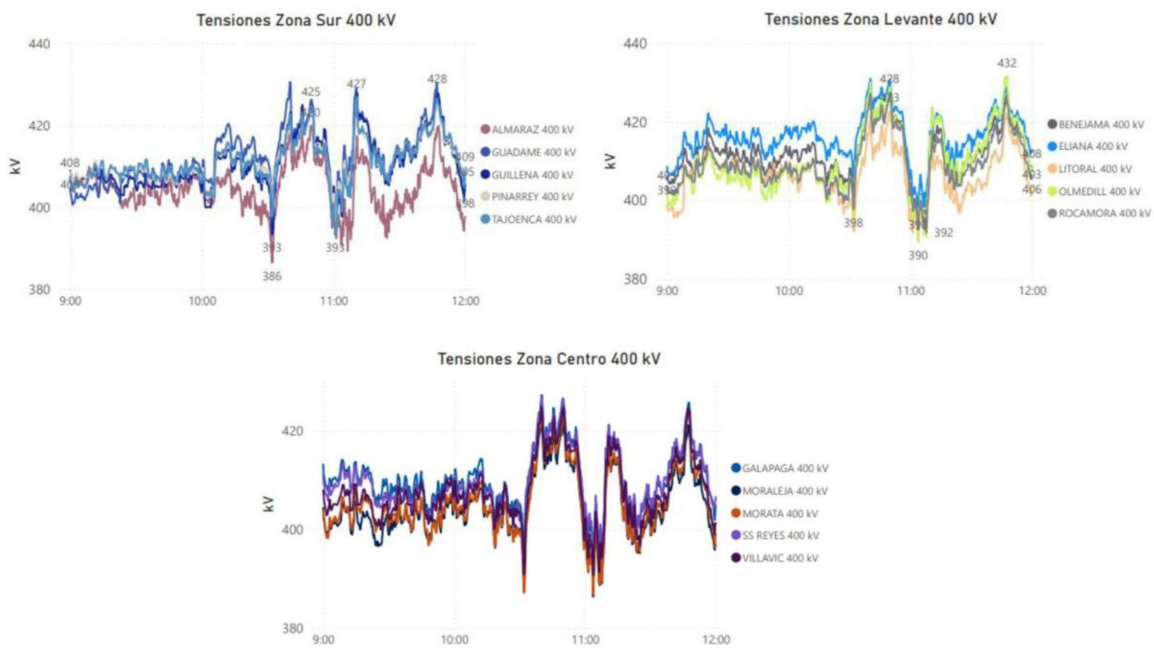
A frequency deviation has been detected in the system around 9:00 a.m. According to the System Operator, at 9:02 a.m. there is a frequency deviation of

-148 mHz, motivated by a change in international programs in Europe (mainly in France, Italy and Germany). Except for this deviation, no sudden variations in frequency are observed until around 12:00 p.m. (see phase 1 – oscillations).



Graph 4 Frequency evolution on April 28 until 12:00. Source: REE

From 9:00 a.m. onwards, greater variability in tensions is observed, initially without significant excursions. It is from 10:30 a.m. when a greater excursion is appreciated, that is, variations of greater amplitude in the values of the tension with respect to the standard values, as can be seen in Graph 5.



Graph 5 Evolution of voltages in the 400kV network on the morning of 28 April. Source: REE

Figure 1 includes a "heat map" that represents the evolution of voltages at different points of the peninsular network during the morning of April 28, in the 400kV network.

The committee has been aware of contacts with various agents and the control center of the System Operator, requesting information on the voltage variations observed,

According to the data provided by both the System Operator and the distribution network managers, although in the early hours of the morning of the event

In the light of the voltage variations, the voltage levels in the transmission network seem to remain within the levels set by operating procedures 1.1 and 1.3 (between 380 and 435 kV in the 400 network, and between 205 and 245 kV in the 220 network) throughout the period until 12:30 p.m.

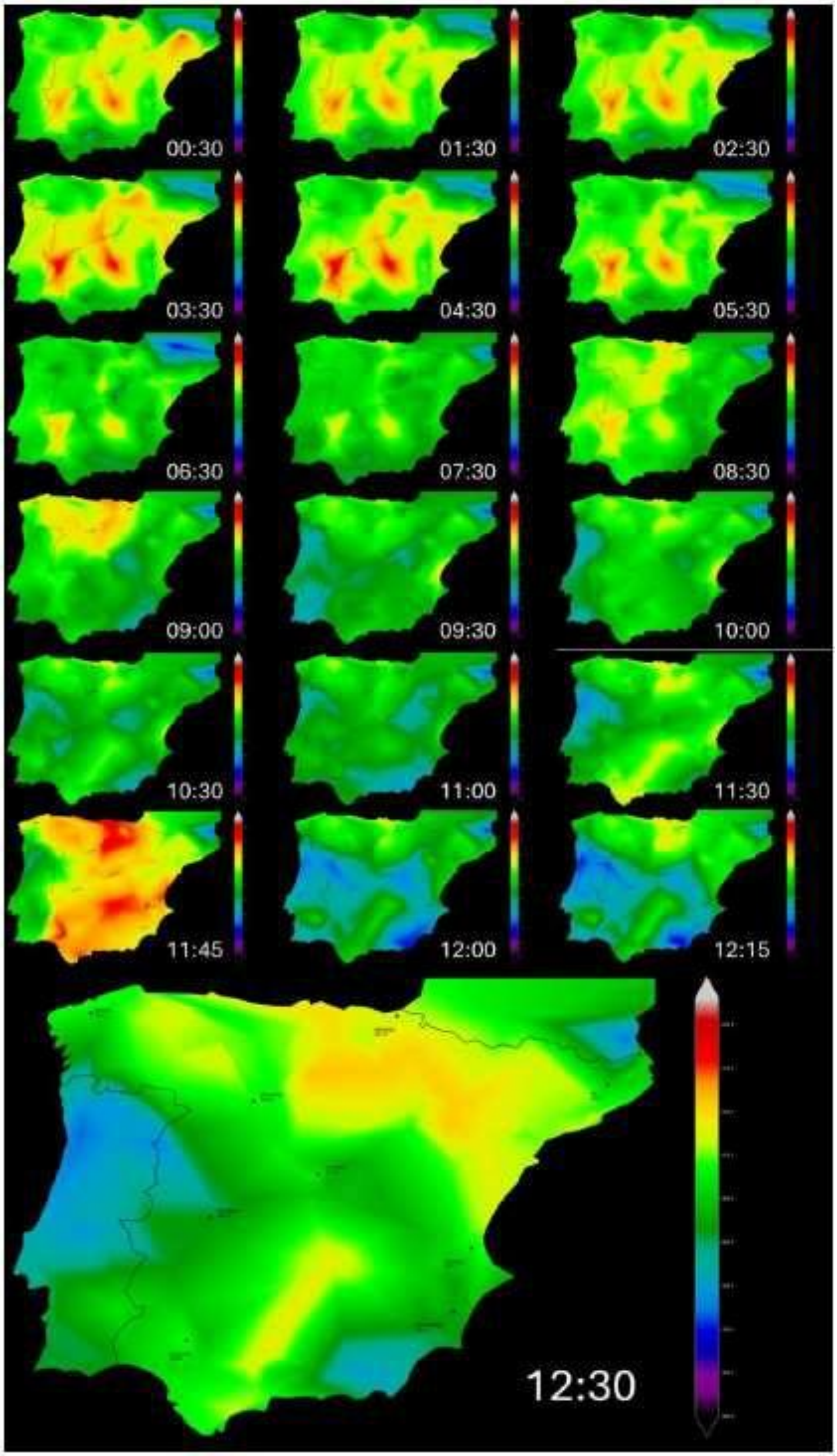

00:30
01:30
02:30
03:30
04:30
05:30
06:30
07:30
08:30
09:00
09:30
10:00
10:30
11:00
11:30
11:45
12:00
12:15
12:30

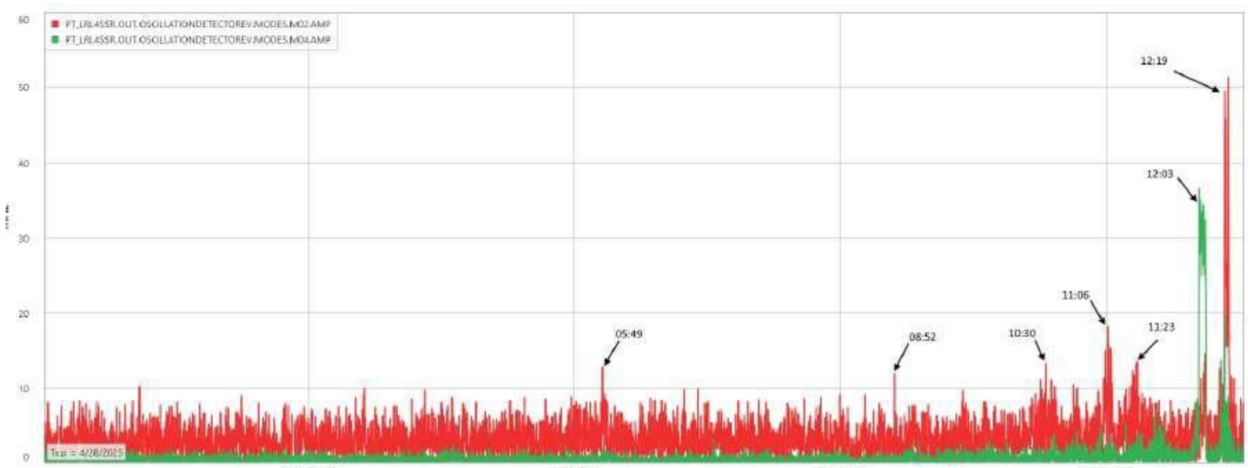
Figure 1 Heat map of the voltages in the 400 kV network on 28 April. Source: REE

PHASE 1. SYSTEM OSCILLATIONS

First oscillations

On April 28, before 12:00, up to five oscillations of small amplitude and reduced impact on the electrical variables are detected, which are dampened by the system without the need to adopt significant measures by the System Operator. These oscillations occur in the frequency range of 0.2 Hz and occur at 05:49, 8:52, 10:30, 11:06 and 11:23.

Figure 6 shows the amplitude of oscillations detected in the system at two frequencies: around 0.2 Hz (red) and around 0.6 Hz (green). The various "peaks" show the times when the oscillations acquire greater amplitude.



Graph 6 Oscillations recorded on 28 April, 0.2 Hz (red) and 0.6 Hz (green). Source: REE

The 0.2 Hz oscillations of 05:49 and 08:52 are of very low amplitude and have an almost imperceptible effect on voltages.

The 10:32 oscillation has a somewhat greater amplitude, causing a small voltage oscillation, up to 4 kV peak-peak amplitude at some nodes.

The 11:03 oscillation causes voltage oscillations of up to 7 kV peak-peak amplitude and is also reflected in power oscillations in the small-amplitude interconnection, which the system is able to dampen in about 6 minutes.

Finally, the oscillation at 11:23 is dampened in 2 minutes and has a similar amplitude to the previous one, causing oscillations in the voltage of about 6 kV peak-peak amplitude.

None of these oscillations of small amplitude and frequency of 0.2 Hz cause the voltage to exceed normal operating thresholds.

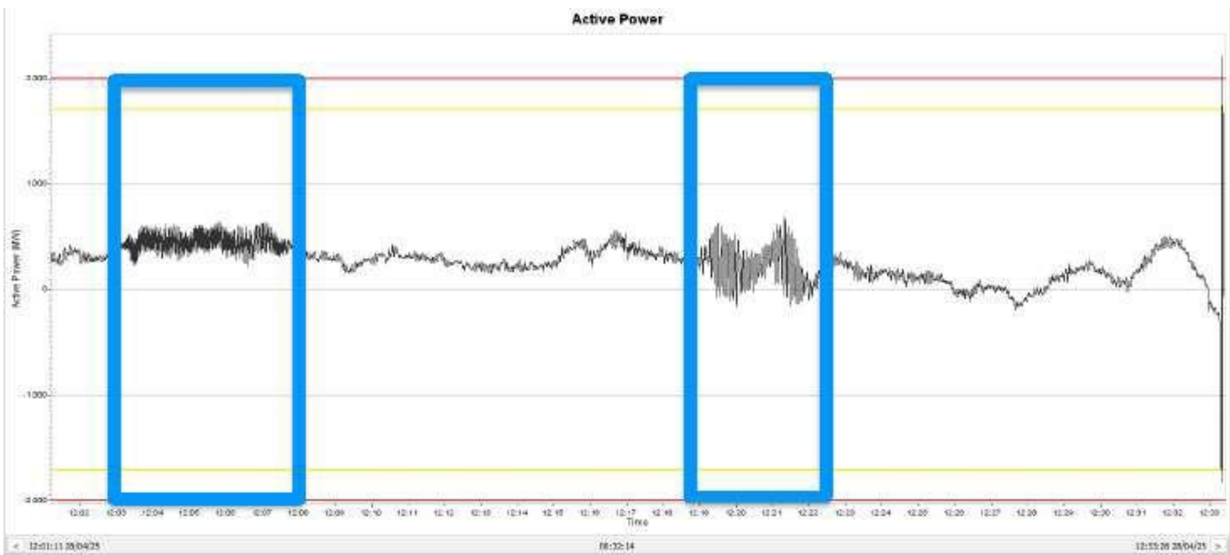
However, in the face of these oscillations, the System Operator, in order to increase the damping of the system, couples 3 400 kV circuits that were previously disconnected:

PINAR – TAJO (11:08)

ARCOS – GOAT (11:17)

PIEROLA – VANDELLOS (11:20)

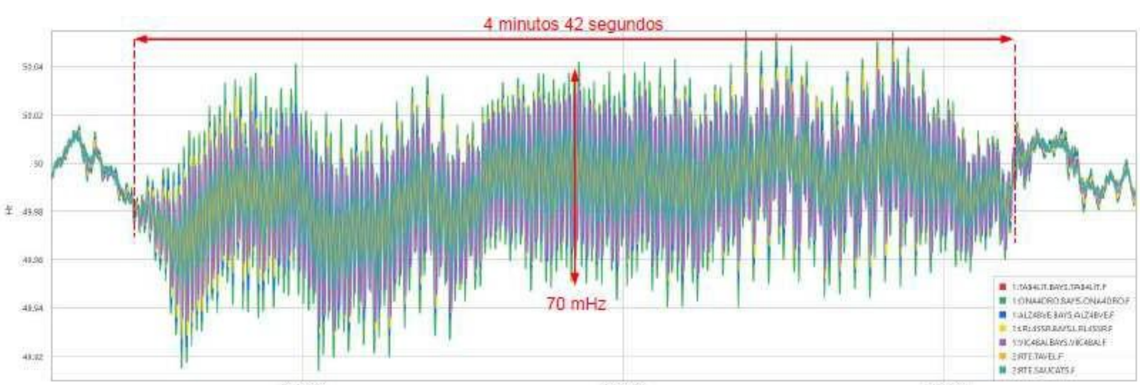
Subsequently, between 12:00 and 12:30 the electrical system registers two new oscillation phenomena, this time of more significant amplitude, which are detailed below.



Graph 7 Oscillations recorded between 12:00 and 12:30 on 28 April. Source: REE

12:03 oscillation

The first relevant oscillation occurs at 12:03, has a frequency of 0.6Hz and an amplitude of 70mHz. It is cushioned in 4 minutes 42 seconds.



Graph 8 First oscillation (12:03). Source: REE

This oscillation has a higher frequency (i.e. it is a "faster" oscillation) than the oscillations more commonly observed in the European system, and was detected in different parts of the EU.

Several operators have reported that this voltage oscillation was also recorded with great amplitude in Portugal. According to the System Operator, it was detected at least in Tavel (France), where it has been observed that the oscillation at that point is practically in phase with that recorded in the SE

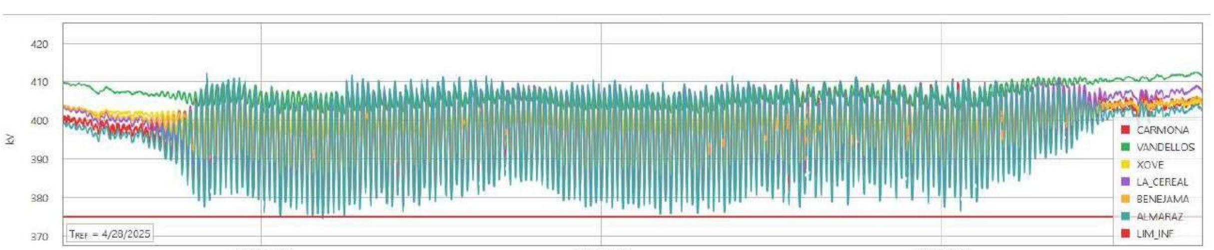
400 kV Carmona in the south of the Iberian Peninsula. Likewise, according to REE, this oscillation was also detected in the French substations of Loony and Albertville, where the amplitude of the oscillation is already less than half that observed in Tavel. Finally, it is recorded that it was also detected in Freiburg (Germany), also with a smaller amplitude.

During this disturbance, strong voltage oscillations occur, not only in frequency and power, mainly in the south and west of the Iberian Peninsula. Unlike the previous voltage variabilities detected that same morning or on previous days, in this case they are repetitive oscillations of voltage rise and fall in the space of seconds, which follow a specific pattern coinciding with the oscillation in frequency, as a "swing".

The voltage oscillation reaches a peak-peak amplitude of 31.2kV and 32.7 kV respectively at the Almaraz 400kV and Arroyo de san Serván 400kV substations, both in Extremadura, which causes the voltage at the Almaraz 400kV substation to drop slightly below the threshold of 375 kV (93.75%) at some point.

of the nominal voltage). There are also oscillations in power through the interconnection with France.

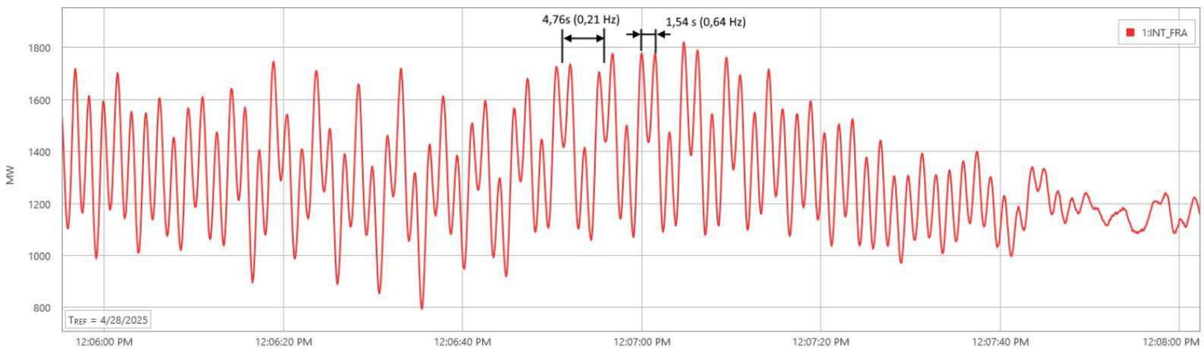
During this period, some calls by agents to the System Operator regarding the oscillations are reported.



Graph 9 Voltages at 400 kV nodes during the first oscillation (12:03). Source: REE

According to the System Operator, when the oscillation of 12:03 appears, a sudden drop in the damping of the system (this is an indicator of the vulnerability of the system to these phenomena) is detected in the face of oscillations of the range of 0.2 Hz. In other words, the calculations of the Single System Operator indicate that, with the appearance of the 12:03 oscillation, the system becomes more vulnerable or susceptible to oscillations of 0.2 Hz.

In fact, towards the end of this 0.6Hz oscillation, it is observed that a small frequency oscillation has also appeared around 0.2Hz that overlaps the 0.6 Hz oscillation.



Graph 10 0.2Hz oscillation that appears superimposed towards the end of the 0.6Hz oscillation. Source: REE

In response to this situation, a series of measures are adopted to increase cushioning:

In accordance with the protocols agreed with the French TSO, RTE, at 12:04 p.m. it is contacted to apply from 12:07 p.m. to 1:00 p.m. a reduction in exchange with France of 800 MW, setting a program of 1,500 MW of export.

Likewise, and also in line with these protocols, at 12:06 a modification of the operating mode of the direct current circuit (HDVC) of the interconnection was agreed with RTE, going at 12:11 from AC emulation mode (Pmode 34) to DC mode (Pmode 15) with a 1,000 MW export setpoint, which was maintained until the end of the incident.

The meshing of the network is increased, by connecting five 400kV circuits that were previously disconnected

. The connection of the first three circuits takes place at 12:07. According to information from the System Operator, the other two lines are added to improve the damping of the system at 12:08.

A few seconds after 12:07, this first oscillation is muffled.

At 12:15, the Spanish System Operator requests the Portuguese TSO, REN, to reduce the export exchange to 2,000 MW to reduce the flow of the 400 kV Cedillo-Falagueira line and to improve the buffering by trying to reduce the load on the lines. REN requests to maintain it at 2,500 MW at the current time, finally agreeing that the proposed reduction will be applied from 1:00 p.m.

At 12:16:45, taking into account the information of various agents, the frequency oscillation 0.6 Hz appears again. At this time, the amplitude attributable to the 0.6 Hz mode is around 30 mHz (slightly less than half of the previous episode).

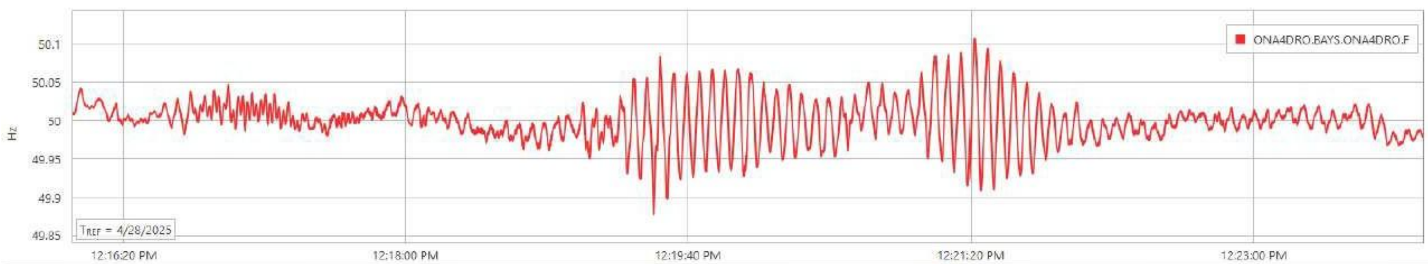
12:19 oscillation

As can be seen in Graph 11, after this new appearance of the oscillation at 0.6Hz at around 12:16, several agents report the appearance, at 12:19, of the second

4 A mode of operation in which the power activated by the link is defined in a manner similar to that of an alternating current line.

5 Flow at constant power according to the setpoint.

relevant oscillation in amplitude, with a lower frequency, in this case 0.2 Hz, but three times greater amplitude, up to 200 mHz.



Graph 11 Frequency from 12:16 p.m. onwards. Source: REE

As can be seen more clearly in Graph 12, it is cushioned in 3 minutes and 20 seconds.

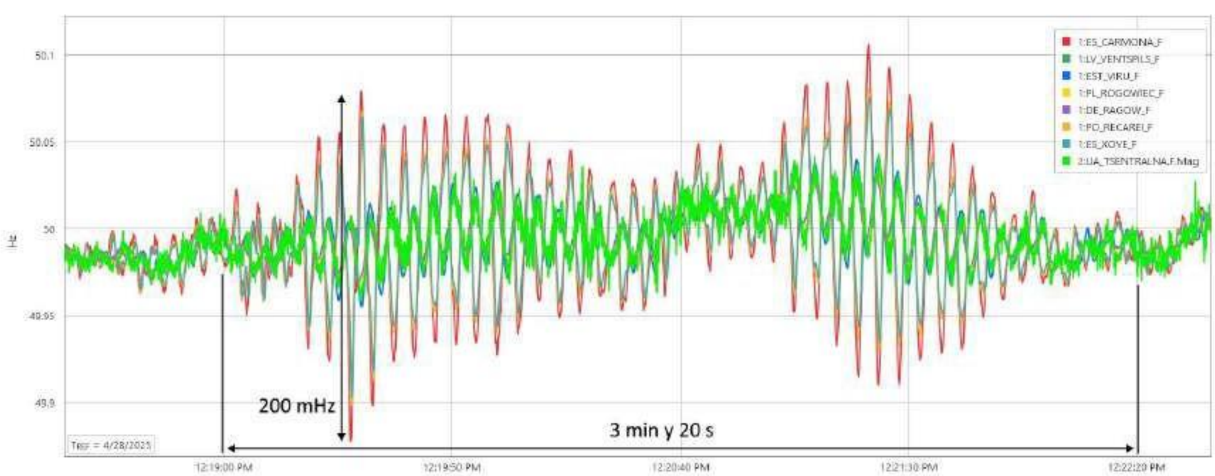
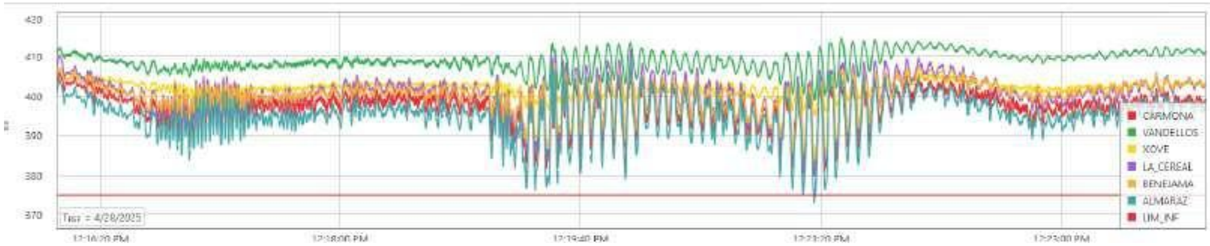


Figure 12 Second oscillation (12:19): Source: REE

During this oscillation, high amplitude voltage oscillations are observed, reaching a peak-peak amplitude of 23 kV in Almaraz 400kV. Although the voltage remained within margins for most of this period, at some point in the 400 kV Almaraz substation the voltage dropped slightly below the threshold of 375 kV (93.75% of the nominal voltage).



Graph 13 Voltages at 400 kV nodes during the second oscillation (12:19) Source: REE

This oscillation of 0.2 Hz corresponds to one of the natural oscillations of the European system, specifically with the East-Central-West oscillation mode, in which the Iberian Peninsula oscillates against the center of the European synchronous system -Germany, Italy, Austria, Denmark...- which, in turn, oscillates against Turkey. This oscillation has been detected and reported by agents from the rest of Europe.

As a result of these new oscillations, REE took the following dampening measures:

At 12:19 p.m., RTE is contacted to reduce the exchange with France again, to 1,000 MW from 12:20 p.m. to 2 p.m. During this phase, the previously established Pmode 1 HVDC interconnect operation mode is maintained.

REN is contacted at 12:20 to reduce the exchange with Portugal to 2,000 MW at 12:306. Subsequently, at 12:26, it is agreed with REN to reduce the program additionally from 12:45.

The connection of two other 400 kV circuits (at 12:21 p.m.

and at 12:25 p.m.), which join the five connected minutes before and the three connected before the 12:03 oscillation.

In addition, REE gave the order to couple thermal generation with voltage control capacity by setpoint, looking for the group that would couple faster in the southern zone7. It turned out to be the the

which gave the shortest time, 1 hour and 30 minutes, since it was hot from having undocked at 9:00 a.m. At 12:26 p.m., the owner of this plant is contacted to confirm the scheduling of this group at a technical minimum due to technical restrictions in real time from 2:00 p.m. However, he never got to

coupling because the zero tension occurred before.

On the other hand, another agent warned the System Operator that, in the context of the oscillations, could be disconnected, so as a precautionary measure (in preparation for the eventuality that it would end

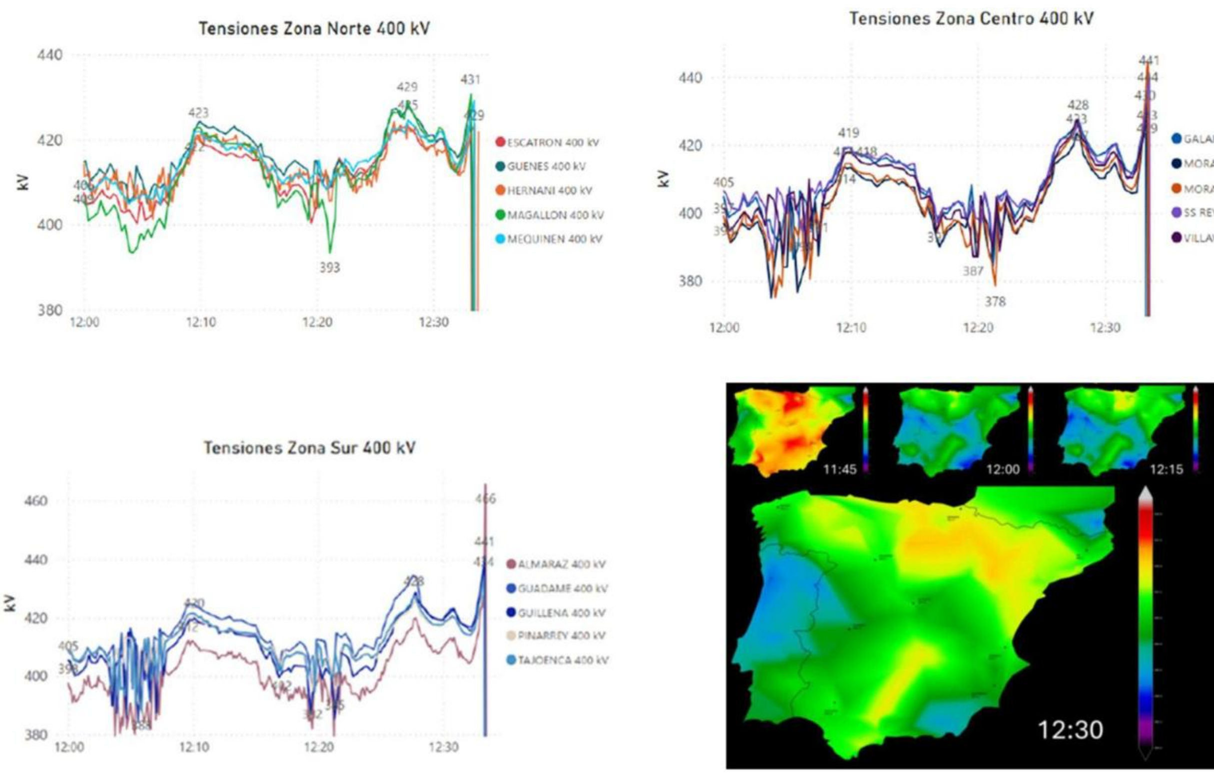
6 The program goes from 2,545.2 to 2,000 MW and began to be regulated at 12:27 p.m

7 Several generators confirm that at various times from 12:18 p.m. they were asked for availability and an estimate of the coupling time of groups in the area.

disconnecting) the System Operator asks at that time to start another control panel, which finally planned to be coupled by 3 p.m.

Evolution of tensions in Phase 1

During this Phase 1, the behavior of tensions remains volatile. Of note in this phase are the strong voltage variations around 12:05 and 12:20, which coincide with the two main frequency oscillations referred to, with the variations in the Central and Southern areas of the 400 kV network being more pronounced.



Graph 14 Evolution of voltages in the 400kV network between 12:00 and 12:35. Source: REE

The measures adopted to increase the cushioning against oscillations have an impact on the stresses, as described in the Analysis section.

To control and return voltages to nominal values, the system has different tools:

As indicated above, for this period several generation groups were programmed due to technical restrictions for voltage control, subject to the instructions of operation procedure 7.4.

Likewise, the System Operator performs topological manoeuvres in the network, coupling ballasts (at nodes with high voltages) and disconnecting them in

Otherwise. Specifically, after the oscillation at 12:03, since it caused minimum voltage values below 390kV, the operator decided to decouple several ballasts:

12:04 Villaviciosa 400 kV REA 1

12:04 Guadame 220 kV REA 3

12:05 REA 2 400 kV wheel

12:05 Aragón 400 kV REA 1

Subsequently, since the oscillation returns at 12:16 to reach low voltage values again in some parts of the system, further ballasts are switched off:

12:17 Cabra 400 kV REA 1

12:21 Peñaflor 400 kV REA 1

12:24 Palos 220 kV REA 1

12:24 Morata 400 kV REA 4

After the end of the second oscillation, at 12:22 p.m., there is a generalized trend of voltage increase from voltages close to the nominal to high values – but still within the operating limit – so the system operator decides to couple 5 ballasts (2 from the north zone, 2 from the south and 1 from the center) to reduce the voltage:

12:26 Vitoria 400 kV REA 2

12:27 Peñaflor 400 kV REA 1

12:27 Guadame 220 kV REA 3

12:27 Guadame 400 kV REA 2

12:28 Morata 400 kV REA 4

This phase ends with a downward trend of tensions that continues beyond 12:30.

In any case, the information received by the different agents does not identify that in this phase 1 (from 12 to 12:30 p.m.) voltage values have been given in the transmission network higher than the maximum thresholds provided for in the operating procedures.

PHASE 2. GENERATION LOSSES DUE TO OVERVOLTAGES

Situation of the system at the previous point in time

Before describing the generation loss events, a characterization of the system at that time is offered:

At 12:30, once the previous oscillations had been dampened, the system, after a maximum voltage a few minutes earlier, found itself with voltage values in a downward trend, but higher (between 410 and 420 kV) than the nominal values in the 400kV network.

Likewise, the system is with a frequency around 50 Hz, low damping and, as a result of the actions carried out in phase 1 above, limited flows in the interconnections, the HDVC interconnection with France with its power electronics in "DC mode" with fixed export flow of

1,000 MW (2 x 500 MW), a 400 kV network with a higher meshing level than initially planned after the coupling of 10 400 kV circuits in several stages from 11:10 a.m. and less flexibility for voltage control.

At that time, the demand of the Spanish peninsular system was 25,184 MW, a low demand, but usual taking into account the temperature (mild), the day (Monday) and the time (noon). At that time, there was 2,978 MW of pumping consumption (reversible hydroelectric plants that were taking advantage of low solar prices to pump water to the upper reservoir that could be turbined to generate electricity at later times). As a reference, the historical peak demand of the peninsula is 44,876 MW (17/12/2007).

The generation mix at 12:30, taking into account the market result and the application of technical restrictions, had 82% renewable generation, 10% nuclear (4 coupled reactors, two of them at full load) and the rest gas (3%, with 6 coupled plants), coal (1%) and cogeneration and waste (4%).

Specifically, at 12:30 there were 11 thermal power plants coupled with the obligation to regulate voltage by setpoint: 4 nuclear power plants

, 1 coal-fired power plant and 6 gas-fired power plants

, in addition to hydroelectric generation

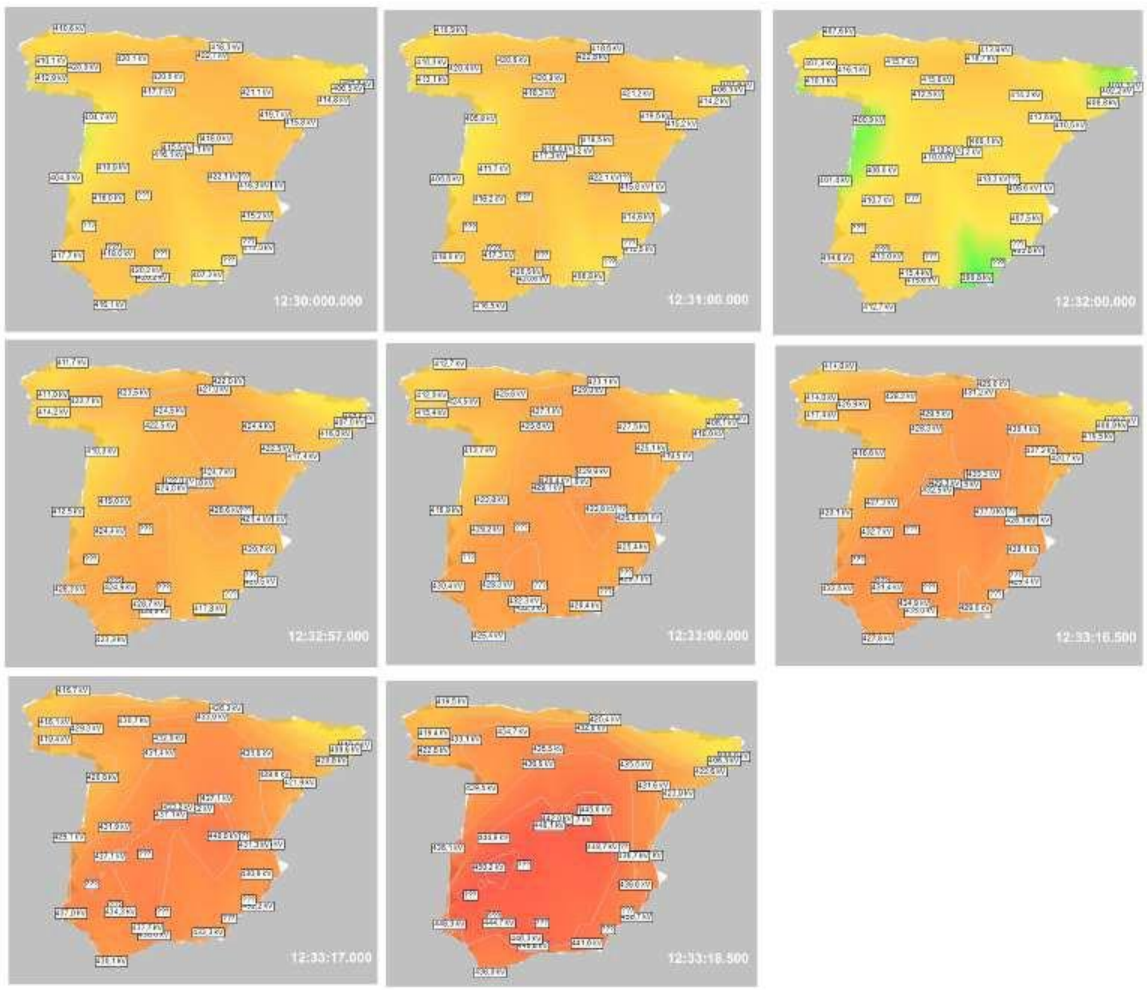
With regard to other dimensions of security of supply, the system operator indicates that before the incident the system had sufficient levels of inertia and reserves, as detailed in the Analysis section.

In the south-west zone, the groups with the ability to control voltage by setpoint in real time, and which had been programmed by technical restrictions for voltage control, were
and the combined cycle of gas , which was coupled

to a technical minimum.

Voltage surge at 12:32

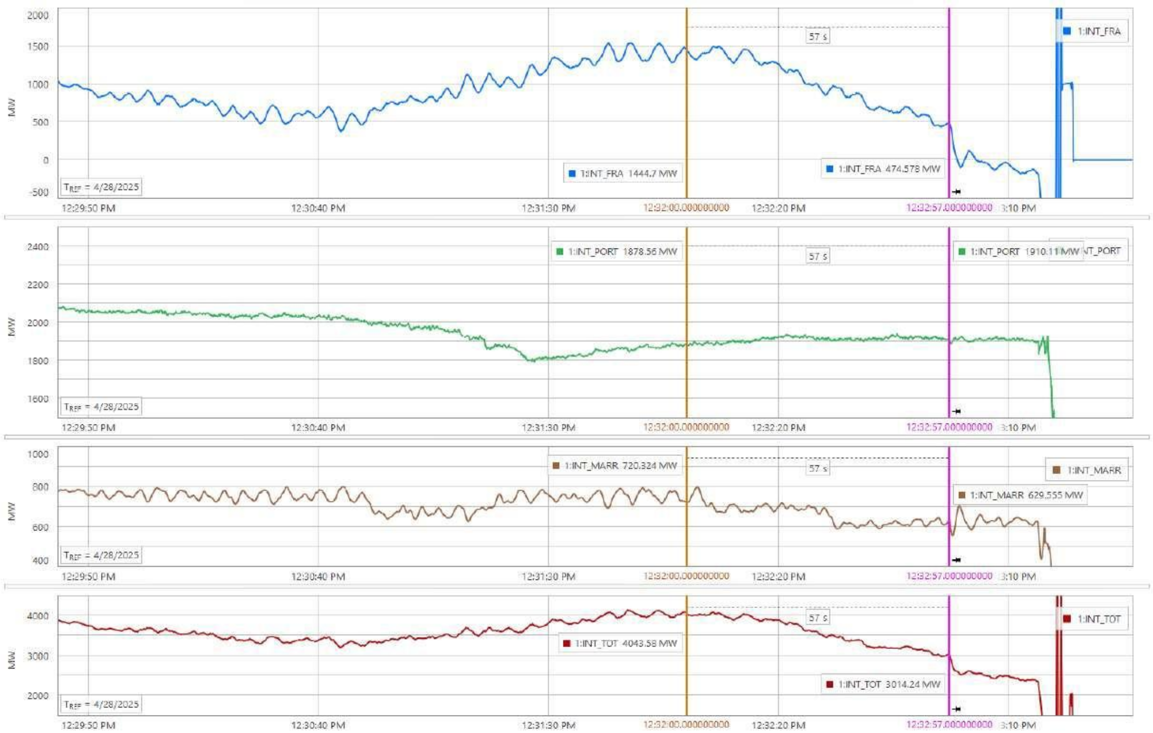
With this situation and system conditions at 12:30, from 12:32:00 onwards the voltages begin to increase throughout the transmission network in an almost linear manner, passing, for example, in the Olmedilla substation from 413 kV to 428 kV in 57 seconds or in the Arroyo de San Serván substation 400 kV from 411 kV to 424 kV in the same time.



Graph 15 Evolution of voltages in the 400 kV network during Phase 2 (12:32:00 – 12:33:18). Source: REE

According to the data provided by the owners of the distribution networks, voltage increases in their networks are observed in the same minute.

At the same time, as can be seen in Graph 16, during minute 12:32 there was a sustained reduction in exports through interconnections, mainly in the interconnection with France.



Graph 16 Evolution of international trade at minute 12:32. Source: REE

First generation losses detected

Then, following the increase in voltages in the system, a process of generation loss is initiated consisting of three main events initially identified. These three events are "visible" in the system's variables, in the form of sudden changes in border exchanges, frequency, and system voltage levels.

In addition to these three main events, the disconnection of lower power generation has been detected, interspersed with them.

Between 12:32:00 and 12:32:55, the system operator has identified losses of small power generation for 525 MW distributed throughout the territory, of which 317 MW would come from distributed generation of less than 1 MW.

The 208 MW of generation disconnection identified are:

Instante	Subestación aguas arriba	Generación perdida	Tecnología
12:32:05,000	[redacted]	2,6	[redacted]
12:32:09,000	[redacted]	21,6	[redacted]
12:32:09,000	[redacted]	5,9	[redacted]
12:32:09,000	[redacted]	4,8	[redacted]
12:32:09,000	[redacted]	2,9	[redacted]
12:32:25,000	[redacted]	19,2	[redacted]
12:32:25,000	[redacted]	3,4	[redacted]
12:32:29,000	[redacted]	22,4	[redacted]
12:32:29,000	[redacted]	55,6	[redacted]
12:32:29,000	[redacted]	2,3	[redacted]
12:32:45,000	[redacted]	0,6	[redacted]
12:32:49,000	[redacted]	13,3	[redacted]
12:32:49,000	[redacted]	1,1	[redacted]
12:32:53,000	[redacted]	11,9	[redacted]
12:32:53,000	[redacted]	20,0	[redacted]
12:32:53,000	[redacted]	4,8	[redacted]
12:32:53,000	[redacted]	10,0	[redacted]
12:32:53,000	[redacted]	6,0	[redacted]

Event 1: 12:32:57,140. Generation loss due to tripping (disconnection) of the generation evacuation position (Granada), into which 355 MW of active power were being injected at that time and 165 MVar of reactive power was being absorbed

In that position they evacuate even plants

attached to different generation control centres, which have a company that owns the common evacuation infrastructure (ICE) to the transmission network (see Annex III).

With the information provided by different agents, it is concluded that the trip occurs on the generation side (i.e., in the infrastructure collectively owned by the generators), due to overvoltage in the secondary of the 220/400 transformer.

The loss of generation in causes a drop in the frequency in the system, which is recovered after a transient of about 3 seconds, and by reducing the

generation in the Iberian Peninsula, means that the export flow in the interconnection with France is reduced by about 450 MW (going to zero).

However, the most relevant effect for the rest of the events is the contribution to overvoltages due to generation disconnection, as can be seen in the lower half of Graph 17 . These overvoltages are detected at various nodes in the network, which reach values above

430 kV8 at 12:33:00 although, depending on the system operator, lower than the 435kV indicated by the operating procedures

Event 2: 12:33:16,460. About 19 seconds after Event 1, another similar event occurs, which is reflected in a drop in frequency and an increase in the import balance with France.

The loss of generation occurs this time, at least, in the (Badajoz) substation, first in the renewable collector substation

(12:33:16,460) and a little later in the collector (12:33:17,520). Both collectors evacuate at the substation, at the

A loss of combined generation of about 730 MW (582 MW) is estimated

118 MW in). The configuration of this substation is similar to the previous case: in that position they evacuate

, attached to control centres (see Annex IV). With the information received by different actors, data compatible with a disconnection that is expected to occur in the evacuation infrastructure itself is identified.

This new loss of generation causes a further drop in frequency of 55 mHZ in the , which is dampened without recovering 50Hz, and that the flow in the interconnection with France becomes an importer at 895MW.

In the same way as the loss of previous generation, this also causes, a few moments later, a rise in voltages, contributing to the worsening of grid conditions, as can be seen in Graph 18.

Interleaved with the disconnections of the positions of , at least generation disconnections have been identified:

12:33:16,820 - The photovoltaic park, connected to the substation of

, which at the time was generating MW.

12:33:17,368 - 22,87MW of wind farms at the (Segovia) substation

Likewise, after the second disconnection at (12:33:17,520), a disconnection of wind and photovoltaic generation of about 33.8MW connected to the substation has been detected at 12:33:17,547

.

Event 3: 12:33:17,780. About 20.5 seconds after Event 1 (1.3 s after Event 2), there is another significant loss of generation, which is reflected in a further drop in frequency and an increase in imports from France.

This third loss of generation occurs in the substation

(Seville), in the renewable evacuation position, where 550 MW are lost.

The configuration of that substation is similar to the previous cases: in that substation and its three positions evacuate

attached to control centres (see annex V).

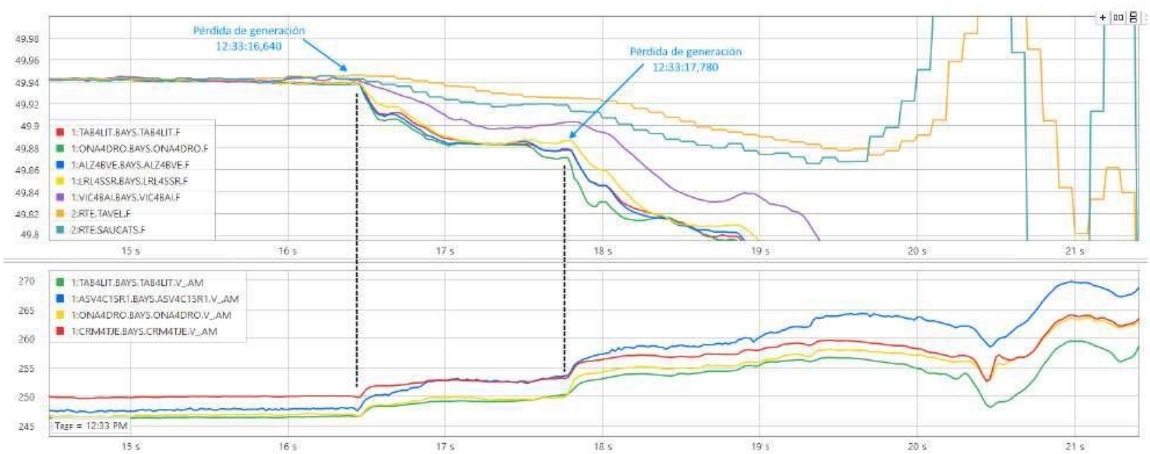
Immediately afterwards, the following generation disconnections have also been identified, of lesser magnitude:

12:33:17,975: PV plant disconnection , connected to (Cáceres) when it generated MW. The voltage reported by the system operator at this point from SCADA data is 240.89kV in the 220kV transmission network.

12:33:18,020: Disconnection of photovoltaic plants , owned by , connected to the substation of (Badajoz), when they generated MW respectively, in total

MW. The system operator reports, based on SCADA data, a voltage of 239.39kV in the 220kV network.

These generation losses cause a further drop in frequency, of 75 mHZ in the , which is no longer cushioned, that the import balance in the interconnection with France will increase by 1,510 MW and that the overvoltages in various nodes of the grid will be exacerbated.



Graph 18Variation in frequency (top) and voltage (bottom), indicating the time of Events 2 and

3. Source: REE

After this new loss of generation in just over 20 seconds, the variables in the system continue to evolve towards unsustainable values, with voltages rising and frequency falling, giving way to Phase 3 of the incident, which is described below.

PHASE 3. COLLAPSE TO ZERO VOLTAGE

Although the exact determination of the individual events in this phase is more complex – due to the high overlap of data and measurements related to events that are practically coincident in time – there is a high coincidence between the data analysed and the assessments made by the different agents in terms of the characterisation of the phase.

Thus, in this phase, two phenomena with a certain level of overlap are identified: firstly, there is a massive disconnection of generation, mainly due to overvoltage. Overlapping with this, although a few moments later, the drop in frequency reaches levels that cause, already in the last moments, disconnection of generation by underfrequency.

According to the information received, the bulk of this phase takes place in the space of just 5 seconds. Therefore, there may be slight inaccuracies or divergences in the order of events or the specific instant of time assigned to each of them, attributable to different data sources (local records, telemetry of the owner or the system operator) which, in addition, sometimes presents differences in the time configuration. It is recalled that the data for the approximate reconstruction of this phase that is detailed in the following sections has been provided by the agents. This does not prevent a proper understanding of this phase, linked to a "chain reaction" of generation disconnection and overvoltage, which in turn leads to a reduction in frequency.

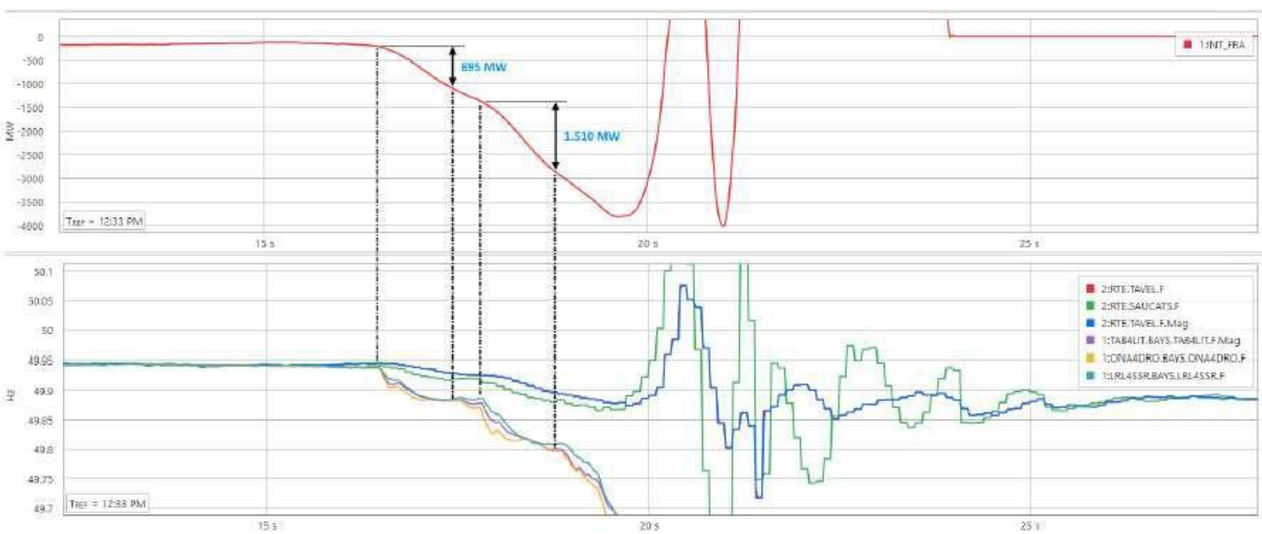


Figure 19 Exchange with France and frequency in Spain and France during Phase 3. Source: REE

Surge disconnections

Some of the events identified in this phase are listed below by way of illustration:

12:33:18,102 - Link Facility Disconnection Occurs

. At this moment it was generating MW. The voltage measured at the time of disconnection was 247.6 kV.

12:33:18,360: A decrease in steps in the power evacuated through the installation of

. The plants evacuating at this link facility were generating MW before the incident began and there is a first decrease of 16 MW. The final disconnection of all generation occurs later, at

12:33:23,260 h.

12:33:18,380: The disconnection of the plant that evacuates in when it generated MW. With the information available, the tension in at this point it was 443.8 kV, therefore exceeding the voltage that installations with a 400kV connection are obliged to withstand.

From this point on, it can be considered that, according to the information sent by the system operator, as the voltages that the generation facilities have to withstand have been exceeded in the system, the generation disconnection is expected, which in turn will continue to contribute to an increase in voltages and, with it, to a disconnection in the form of a "cascade effect" or "chain reaction".

12:33:18,540: The plant was disconnected when it was generating MW and absorbing Mvar.

12:33:18,846: The link facility trips The plants that evacuate at that link facility were generating

MW.

12:33:18,951: Link installation trip occurs

. The plants that evacuate through this link facility were generating MW.

12:33:19,000: A further decrease of 16 MW in production poured through the link facility occurs

12:33:19,040: the disconnection of the when it produced MW occurs. This wind farm discharges at 132 kV and is associated with the transmission network node

The voltage at 132 kV was 146.8 kV.

12:33:19,095: The DE is disconnected when MW was being poured through it.

12:33:19,131: Shoot the , by

14% (132kV) and 15% (220kV) overvoltages

12:33:19,252: Plant disconnection occurs when it generated MW.

12:33:19,260: There is a further decrease in MW in the production poured through the link facility

12:33:19,320: A change in the frequency is observed again, becoming more negative (falls more quickly). This is compatible with the loss of another additional generation quota.

12:33:19,296: The plant was disconnected when it was generating MW.

12:33:19,407: There is a decrease of 63.3 MW in the production discharged through the 400/132 kV collector transformer, which in turn discharges into the transmission grid in . The plants that poured through this transformer were producing MW prior to the incident; The transformer fires 1.24 seconds later.

12:33:19,620: At this moment the maximum import exchange with France is reached, reaching the loss of synchronism. The operation of the link with France is described in more detail in the section on disconnection of interconnections.

12:33:19,920: There is a decrease in MW in the production poured through the link facility

12:33:19,951: The trunking facility is disconnected

. At the time of the trip, the plants that were still connected generated MW, but prior to the start of the incident the link installation had 263.8 MW, which means that before this moment they had been lost

MW, which had previously been disconnected.

12:33:19,969: Shoot the park due to overvoltage

12:33:19,971: The firing of the line of due to overvoltage, with no effect on generation or consumption.

12:33:20,020: Disconnection from the entire generation that was pouring into

313 MW are lost.

12:33:20,040: The disconnection of the installation of

when evacuated through said facility MW. The voltage at that time was 252 kV at

12:33:20,100: The . This group in the moments prior to the incident was generating MW. The tension in

was 419.6 kV and the frequency at was 49.549 Hz.

12:33:20.180: Frequency crosses the first ballast shedding threshold of pumping facilities (49.50 Hz). The disconnection of pumping installations and demand shedding are described in the following section.

12:33:20,200 - Link Facility Disconnection Occurs

The plants that evacuate at that link facility were generating MW and absorbing Mvar.

12:33:20,225: PV plants are disconnected

when they generated and MW respectively. In total, they are lost

MW.

12:33:20,300 - Link Facility Disconnection Occurs

At this moment the link installation was carrying

MW, but prior to the start of the incident it carried MW so the other MW were disconnected before this moment. At this moment the tension in

was 255.3 kV.

12:33:20,420 - Link Facility Disconnection Occurs

when it was evacuating MW, prior to the incident it was evacuating MW so another 49 MW had to be lost in previous moments. The voltage was 250.1 kV.

12:33:20,476: Plants are disconnected

that are associated with the , when they generated MW respectively.

12:33:20,600: The frequency drops below 49.00 Hz which is the first demand shedding threshold (not pumping).

12:33:20,650: The overvoltage trip occurs

that pours into . At the moment of this trip by the transformer, MW was evacuated, the voltage in the era was 456 kV and the frequency was 48.914 Hz.

12:33:20,740: Disconnection occurs

when they generated MW between the three of them. These plants discharge into the associated kV distribution network

12:33:20.760: The frequency drops below 48.80 Hz which is the second demand shedding threshold.

12:33:21,000: The frequency drops below 48.60 Hz which is the third demand shedding threshold.

12:33:21,080: The disconnection of the

12:33:21,219 - The installation is disconnected

when it was transporting MW, which was what was there before the incident began. The voltage at that time was 260.7 kV.

12:33:21.380: The frequency drops below 48.40 Hz which is the fourth demand shedding threshold.

12:33:21,440: 26 MW decrease in production poured through link facility

12:33:21,503 - Link Facility Disconnection Occurs

At the end of , 230 ms disconnection occurs at the end of by remote shot reception. At the time of the trip, the link installation was carrying MW, which is approximately what it was carrying in the moments prior to the incident (MW). The voltage was 448.4 kV.

12:33:21,820: The frequency drops below 48.20 Hz which is the fifth demand shedding threshold.

12:33:22.040: The frequency drops below 48.00 Hz which is the sixth and final demand shedding threshold.

12:33:22,160: There is a decrease of 55 MW in the production poured through the installation of

12:33:22,330 - The disconnection of the installation occurs

MW were being poured through this link facility. The voltage was 465 kV.

12:33:22,460: There is a 52 MW decrease in production poured through the facility

12:33:22,470: Disconnecting the Link Facility

. At the time of disconnection, the plants evacuating in said link facility were producing MW, however, prior to the start of the incident they were producing MW, so MW had previously been disconnected.

12:33:22,560: The frequency derivative becomes more negative again, possibly due to the loss of more generation and as all the steps of deballast have been crossed, the Iberian system is heading for collapse.

12:33:22,600: Half of the

that pours . There is a loss of 117.5 MW.

12:33:22,702: The when it was generating MW. The voltage was 436 kV and the frequency was 47.79 Hz, thus approaching the value of 47.5Hz, which is the lower limit of subfrequency that generators are obliged to withstand.

12:33:22,860 - Link Facility Disconnection Occurs

generation 220 kV when it had MW that coincides with what it carried in previous moments. At the time of the trip, the voltage was 257.5 kV.

12:33:22,900: The generation that discharges through the link installation is disconnected when it was producing MW.

12:33:23,076: The line of

by performance of the function of overvoltage of the extreme of

, which sends a teleshot to The adjusted tension threshold

The firing is 1.2xUn, i.e. 480 kV. The voltage measured at the time of the trip was 485 kV.

12:33:23,140: Half of the plant's power is disconnected due to the tripping of one of the two transformers by which it

evacuate. This plant pours over . 125 MW of generation is lost.

12:33:23,260: 51 MW decrease in production poured through link facility

12:33:23,360: The other half of the plant's power is disconnected due to the tripping of the second of the two transformers by

those that it evacuates. The disconnection of

I wasn't generating. These plants pour over MW of generation in total.

12:33:23,360: Half of the photovoltaic plant that discharges into the PV plant is disconnected. . A loss of MW.

12:33:23,400: The generation of the plant was disconnected when it was producing MW.

From this point, according to the information provided by the system operator, the frequency has exceeded the lower threshold of subfrequency set out in Order TED/749/2020 that must be able to support generation.

12:33:23:515: it is disconnected by underfrequency. It was producing MW. The voltage was 433 kV and the frequency was 46.15 Hz. it had reached 469.3 kV. According to its operator, it even absorbed MVAr in its attempt to stabilize the voltage in its evacuation network, which caused the plant's steam condenser to overheat.

12:33:23,590: Disconnection occurs

when they were generating MW respectively. The frequency was 45.89 Hz.

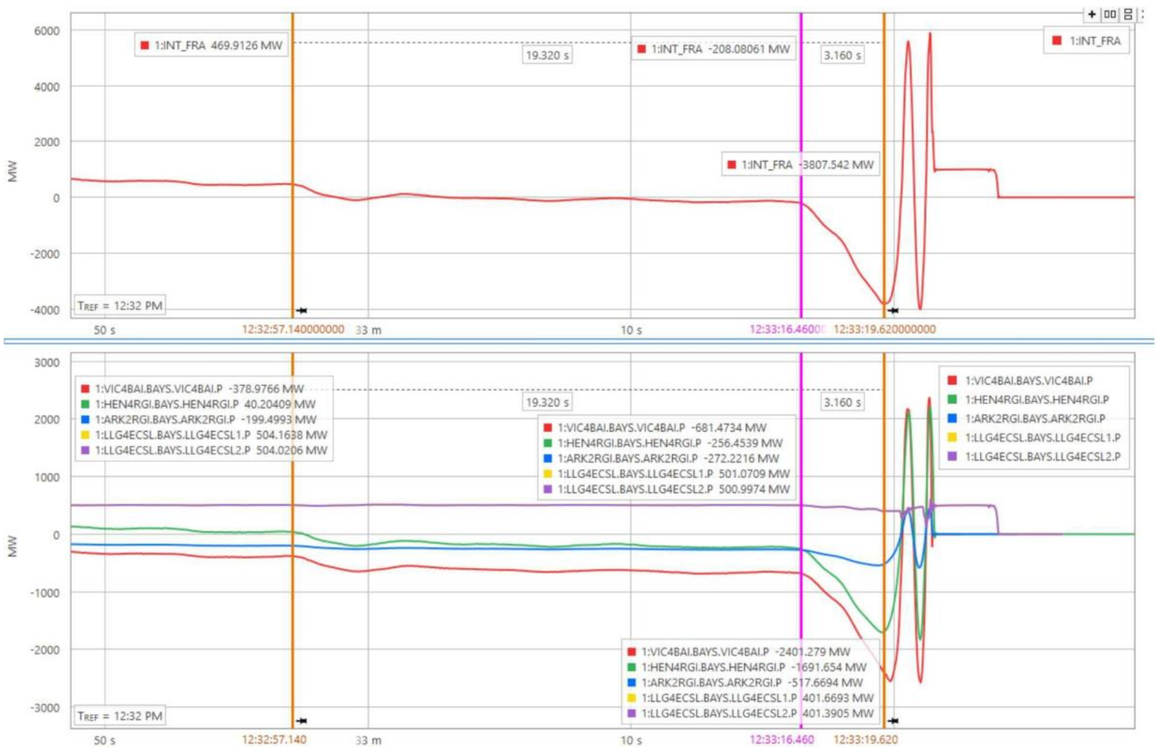
12:33:29,741: Zero Voltage in after the last group shot.

After this moment, there is zero tension in the Spanish peninsular system.

Link disconnections

The events listed in this section partially overlap in time with those indicated in the previous section, and are collected here to facilitate an easier understanding of the functioning of the different links of the Spanish peninsular system.

Spain-France interconnection



Graph 20 Exchange on each of the interconnection lines with France. Source: REE

12:33:19,620: At this moment the maximum import exchange with France is reached, reaching the loss of synchronism.

At this time, the net import value reached 3,807 MW (4609 MW were imported through the AC lines and the HVDC returned 802 MW to France), reducing thereafter. From this moment on, the angular difference between France and Spain was so great that there was a loss of synchronism between the French system and the Iberian system, and the energy provided by France began to fall. Loss of synchronism will produce a "back and forth" effect on the behavior of the interconnect.

12:33:20,260: The exchange with France becomes zero and it begins to become an exporter.

12:33:20,520: The export exchange to France reaches a maximum —5,587 MW— and from this moment on it begins to decrease due to the effect of the aforementioned loss of synchronism.

12:33:21.407: the Baixas position is opened in the Vic 400 kV substation by the loss of synchronism protection function after the second cycle or "beat" import-export caused by loss of synchronism. The line shoots at both ends.

12:33:21.535: The opening of the Argia position (third AC interconnection with France) takes place at the Hernani 400 kV substation. At this moment the Iberian Peninsula is disconnected from France by alternating interconnections. However, about 1,000 MW are still being shipped to France via the HVDC link. At this moment the frequency was 48.458 Hz.

12:33:23,960: The voltage collapses at the Santa Llogaia 400 kV substation and the France-Spain HVDC is blocked, ceasing the transmission of power to France.

12:33:27,930: Andorra's electricity system is disconnected from the peninsular system due to the action of the minimum voltage protections in the Adrall 110 kV substation.

12:33:32,000: The disconnection of the

in the south of France. This disconnection would not have had an impact on the peninsular electricity system as it was already completely separated from France and with zero voltage.

Spain-Morocco interconnection

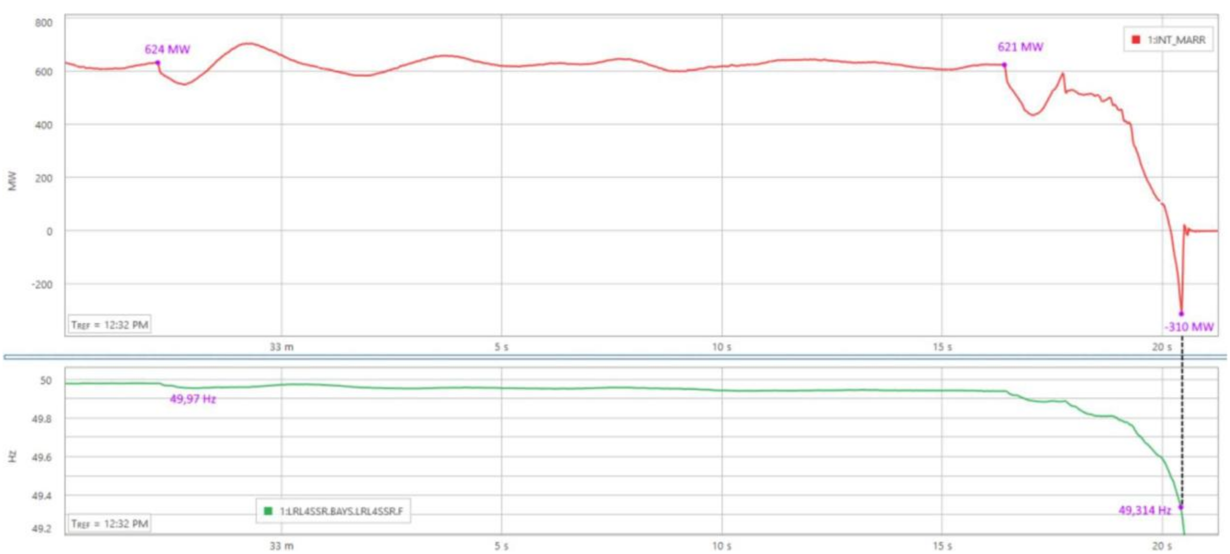


Figure 21Trade in the interconnection with Morocco. Source: REE

12:33:20,229: the Beni Harchen 400 kV substation (Morocco) is tripped at the Puerto de la Cruz position, which corresponds to one of the two Spain-Morocco interconnections. This opening is probably caused by a relay of

sub-frequency on the Moroccan side, as occurred in the incident of July 24, 2021 (there was hardly any flow at that time on that line).

12:33:20,390: The disconnection occurs in SE Puerto de la Cruz 400 kV of the Beni Harchane position due to the sending of telegunfire from the Moroccan end. The line was already open from 161 ms before, which was when the Moroccan winger opened.

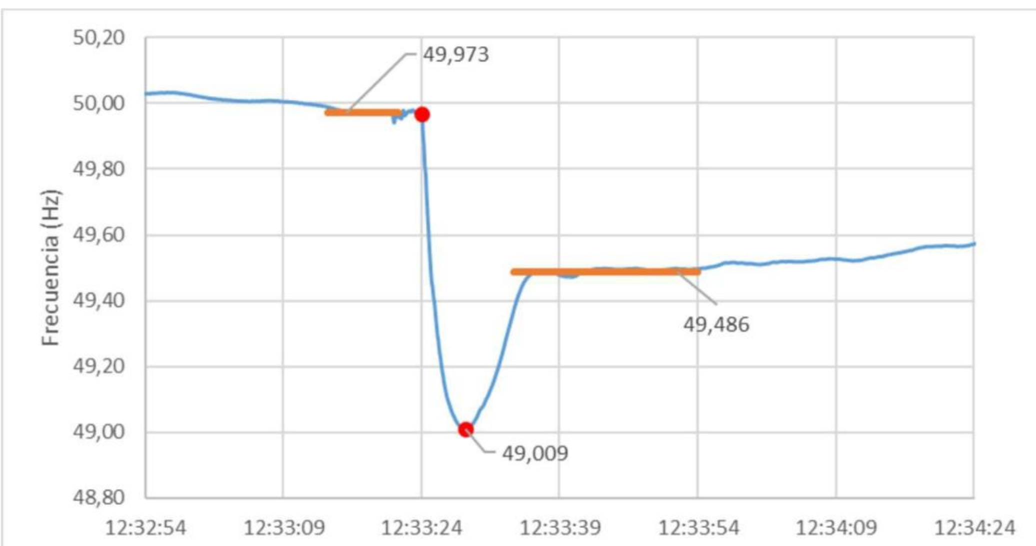
12:33:20,473: the Mellousa 400 kV substation is fired from the Puerto de la Cruz 2 position, which corresponds to the second interconnection with Morocco. At the time of the trip, Morocco was separated from Spain when the frequency was 49.314 Hz and Morocco was contributing 314 MW to the Iberian system.

12:33:20.564: The disconnection occurs in SE Puerto de la Cruz 400 kV of the Melloussa 2 position due to the sending of telegunning from the Moroccan end. The line was already open from 91 ms before, which was when the Moroccan winger opened.

Iberian Peninsula - Balearic Islands link

12:33:23,520: the voltage collapses at the Morvedre 400 kV substation and the HVDC Peninsula – Mallorca link is blocked. The Balearic system loses 96.5 MW and the frequency drops to 49.009 Hz.

The existing generation in the Balearic Islands responded adequately through inertia and primary regulation, allowing the frequency to be recovered and avoiding loss of supply in this system.



Graph 22 Frequency at the Santa Ponsa Converter substation 220kV (Balearic electrical system). Source: REE

Deslastres

This section contains additional information corresponding to ballasts: pumping or demand disconnections when certain frequency thresholds have been crossed.

12:33:20,240: Pumping ballast when it consumed MW and with a frequency of 49.478 Hz.

12:33:20.500: Frequency crosses the second ballast shedding threshold of pumping facilities – 49.30 Hz – 588 MW of pumping is deballasted.

12:33:20,8000: The disconnection of the pumping groups by activating the first two steps of automatic deballasting is completed. In total, 2,037 MW are unballasted.

12:33:20.760: The frequency drops below 48.80 Hz which is the second demand shedding threshold.

12:33:21,000: The frequency drops below 48.60 Hz which is the third demand shedding threshold. Some 1,402.5 MW of total ballast of consumers connected to positions in the transmission grid have been recorded up to the third step.

12:33:21,820: The frequency drops below 48.20 Hz which is the fifth demand shedding threshold.

12:33:22.040: The frequency drops below 48.00 Hz which is the sixth and final demand shedding threshold.

12:33:22,140: A large decrease in frequency derivation is observed for 520 ms, which is compatible with the activation of the last step of deballast.

PHASE 4. REPLENISHMENT OF SUPPLY

Once it has been verified that the peninsular zero has occurred, the emergency and replacement procedure begins, regulated in "Operation Procedure 1.6. Establishment of security plans for the operation of the system". The replacement service is a service that is mandatory for certain installations.

The replacement strategy is based on the creation of various energy islands, based on the interconnections with France and Morocco and the plants with autonomous start-up capacity (hydraulic).

Specifically, the service restoration plans designed by the System Operator together with the owners of the generation plants are based on the autonomous start-up capacity of the hydroelectric plants in accordance with the information exchanged between them and the operator. Specifically, service restoration plans are established for various geographical areas:

South Zone

Tagus-Center

Levante Zone

Galicia-León Zone

Asturias-Cantabria Zone

Aragon-Catalonia Zone

Douro area-France

Once an island is stable, generation (combined cycle gas) and demand are gradually added. When they are large enough and stable, the islands are joined together and the process continues until the total replacement of demand by the distributors that feed the transmission network.

It is necessary to distinguish several key points in the replacement process at each specific point: firstly, the moment when the corresponding node of the transmission network recovers tension; secondly, the available capacity that is enabled at that point, usually in "blocks" or "steps" depending on the

coupled generation and the robustness of the corresponding island; and thirdly, the connection of demand according to these steps.

The chronology of the revival is first collected, highlighting the main milestones. Annex VI provides details of the evolution of the cargo replaced, with information on the contribution from France at all times (there was also a contribution from Morocco until 02:18 on 29 April).

As can be seen in the evolution of the replenishment of the cargo, at 10:30 p.m. on the same day 28 practically 50% of the demand had already recovered the supply and at 7:00 a.m. on the 29th, 99.95% of the supply was restored.

The replacement process has been based on three main islands: Catalonia with support from France; the Basque Country with support from France; and South with support from Morocco. Islands are also created in Duero, Galicia and Asturias-Cantabria, from hydroelectric power plants with autonomous start-up, which are incorporated into the previous ones.

Subsequently, identified elements that could have influenced the duration of the replacement process are listed.

Timeline of the replenishment process

APRIL 28

At 12:44 p.m., tension is received in HERNANI from France and the planned support is activated.

At 13:07, the first load is fed into the Spanish system through the TRP1 220/30 kV IRUN. A demand of 31 MW is powered.

At 1:04 p.m., tension is received from Morocco. A 100 MW ONEE support is received through ESMA 1. After an untimely disconnection at 2:34 p.m., voltage is received again from Morocco and the South Island restarts.

At 1:31 p.m. it is confirmed that the POI (Island Operation Plan) of Ribarroja has been created to guarantee the supply of auxiliary services in

At 1:35 p.m., voltage is received in VIC from France and the planned support is activated.

At 2:46 p.m., after coupling transformer 1 in , all the Nuclear Power Plants confirm that the power supply of their auxiliary services from the outside is guaranteed.

At 3:14 p.m. the first thermal unit is coupled

At 3:59 p.m., Link 1 of the link at HVCD Baixas-Sta-Llogaia begins to transmit power.

At 5:49 p.m., the islands of Duero and the Basque Country join.

At 6:43 p.m., the islands of Asturias-Cantabria join Aguayo and the Basque Country.

At 7:32 p.m., the island of Douro joins the island of the South.

At 7:40 p.m., the island of the Center joins the island of the South.

At 7:53 p.m., the islands of Catalonia and the Basque Country join

At 9:20 p.m. there are 13 thermal generators coupled in the system.

At 9:58 p.m., circuit 2 of the Baixas-Sta-Llogaia HVCD link begins to transmit power.

At 11:32 p.m., 21 thermal generators are coupled to the system.

At this point, practically 50% of the demand has recovered supply.

At 11:37 p.m. it reports that it has replenished its entire market in Asturias.

At 11:46 p.m. it reports that it has its replacement market in Asturias.

APRIL 29

At 00:06 a.m., the CPR (Peninsular Shared Regulation) starts. At this time, only participate .

At 00:30 a.m., the supply to Madrid has been restored in its entirety.

At 00:46 a.m. it begins to participate in CPR

At 01:00 a.m. he begins to participate in CPR

At 01:16 he begins to participate in CPR

At 02:18 a.m., support is withdrawn from ONE (Morocco).

At 02:30 h which has replenished its entire supply in

At 03:09 h there are 31 thermal units coupled in the system.

At 04:06 he reports which has replenished all its supply in its distribution area.

At 06:30 h You have your entire supply replenished.

At 7:00, 99.95% of the supply has been restored.

At 07:03 the limitation on RCR generation is withdrawn.

At 09:18 a.m. he begins to participate in CPR.

At 10:56 a.m., tension is sent to Andorra.

At 10:58 a.m. he has all his supply replenished.

At 11:39 a.m., market participants are informed via eSIOS that market activities are suspended, and it is indicated that the OS has already communicated to the market operator the restoration of market activities for the April 30 schedule.

At 12:00 p.m. it announces that it has replenished all its supply from Galicia.

At 12:15 p.m. it announces that it has replenished all its supply in Madrid.

At 12:29 p.m. he has all his supply replenished.

At 12:55 p.m. it announces that it has all its supply replenished.

At 1:17 p.m., the secondary requirements for the following day are published.

At 2:13 p.m., the Peninsula-Balearic Islands interconnection will be energized.

At 2:34 p.m. the daily PDVP program for 04/30 is published.

At 2:36 p.m., the state of Emergency is changed to Alert, in coordination with REN, and ENTSO-E is informed. 100% of the spare supply is considered.

Since April 30, the system has been operating normally, although the system operator is applying reinforced safety standards.

Contribution to the replenishment in Portugal

According to the information provided by the system operator, the Spanish and Portuguese operators were in constant contact after the incident to confirm the status of the respective systems.

At around 6:30 p.m., once the voltage reaches the Aldeadávila substation with voltage from France, the Spanish operator proceeds to send voltage to the Portuguese electricity system sequentially through the different connection lines:

18:36: the L-220 kV ALDEADÁVILA-POCINHO 1, sending voltage to the Portuguese electricity system for the first time in the replacement process. This milestone means that the Portuguese system has a European frequency.

19:57 h: L-220 kV SAUCELLE-POCINHO docks.

19:58 h: L-220 kV ALDEADÁVILA-POCINHO 2 docks.

8:47 p.m.: L-400 kV ALDEADÁVILA-LAGOAÇA docks.

9:34 p.m.: The L-400 kV PUEBLA DE GUZMAN-TAVIRA is coupled.

9:37 p.m.: The L-400 kV CARTELLE-LINDOSO 1 is coupled.

9:39 p.m.: An attempt is made to couple the L-400 kV CARTELLE-LINDOSO 2, but the 522-4 switch at the CARTELLE 400 kV substation has anomalies that prevent coupling.

10:33 p.m.: L-400 kV CEDILLO-FALAGUEIRA docks.

02:37 h: The L-400 kV CARTELLE-LINDOSO 2 is coupled once the anomalies of the switch that prevented it have been solved.

1:39 p.m.: The L-400 kV BROVALES-ALQUEVA is coupled. This interconnection line was unavailable due to work at the time of the incident, so in order to energize it, the work was previously returned.

Analysis

In the meetings that have been held with different agents of the system, a high degree of agreement has been found in the complexity of both the analysis and the probable causes of the peninsular zero voltage, due, in all likelihood, to a combination of conditions that led the system to the point that it triggered a "chain reaction" of overvoltage. no "single failure" has been identified that can explain the system crash on its own.

For this reason, an exhaustive analysis is carried out below with the available information, with the aim of identifying the elements that have with high probability have contributed to the fall of the peninsular electricity system.

Obligations and resources for voltage control

Due to its relevance in the analysis of the incident, a description of the framework related to voltage control is provided below.

Voltage is an indicator of the "quality" and efficiency of the energy flowing through the grid, i.e. whether reactive energy levels are limited. When there is a lot of reactive energy generation that is not consumed or counteracted, voltages rise, producing surges.

In an electricity system, reactive energy can come from certain types of consumption or from the power lines themselves. Specifically, underground cables are more likely to generate reactive energy; Similarly, in general, highly meshed electricity grids at times of low consumption (and therefore low energy flows in these networks) have capacitive effects and tend to generate more reactive energy, contributing to voltage increases.

Operating Procedures of the electricity system 1.1 and 1.3 establish that the voltages in the transmission network in a stable situation must be between 380 and 435 kV in the 400 network, and between 205 and 245 kV in the 220 network. However, it is not advisable for the system to operate close to these limits, for which in 2021 agreements were established between REE and the distribution network operators for voltage control at certain reference nodes. In this area, which, although it is not part of the regulations, but is a reference for the

system operation, the "normal situation" ranges of 380-420 kV and 204.6-234.96 kV were defined in the 400 and 220 kV networks respectively. These agreements also provide for the adoption of "coordination measures" in the ranges 234.96-245.96 kV and 420-435 kV, and "exceptional measures" above the upper values, which already coincide with the upper limits provided for in the operating procedures referred to above.

In addition, the operating procedures mark the need for the non-existence of a condition of voltage instability that could lead to a situation of voltage collapse. This requirement may be more restrictive, in certain cases, than the condition of maintaining tension.

For voltage control, the regulations oblige all agents (system operator, generators, transmission and distribution system operators, consumers) to adopt certain measures. Thus, the Operating Procedure

1.1 must be applied by the system operator (SO), both in the operation scheduling studies and in real-time operation, and affects all the facilities of the network managed by the operator in the peninsular electricity system and all the production facilities directly connected to this network.

The system operator has different tools to act on the voltages.

On the one hand, equipment integrated into the transmission network itself: currently the main tool that REE has are ballasts, whose connection absorbs reactive (low voltage at the node), and vice versa. However, reactances do not generally allow for a gradual adjustment of voltages, but only their connection or disconnection ("all or nothing") is possible, which limits the ability to laminate voltage variations in the network using this technology. For this reason, there are also other types of equipment (such as synchronous compensators, FACTS and STATCOM), which have already begun to be incorporated into Spanish electricity systems, which reinforce the inherent capacity for voltage control in the network.

On the other hand, the operator resorts to technical restrictions, in which it schedules the connection of certain generation infrastructures according to the criteria "dynamic voltage control" or "static voltage control", based on its capacities and obligations of voltage regulation, to ensure that there is sufficient voltage control in the system

Active voltage control capability. The generation groups that are programmed for these functions are the thermal generators, which according to Operating Procedure 7.4 have the obligation to provide voltage control by setpoint: they "observe" the voltage of the grid and modify its power factor to contain voltage deviations, in particular by absorbing reactive energy based on the observed voltage. Specifically, this means that, with certain thresholds, the greater the overvoltage, the greater the reactive energy that the generation must absorb, to help contain the voltage.

On the other hand, the regulations require other types of installations to control "static" voltage by means of power factors.

Thus, Operating Procedure 7.4 obliges distribution networks and large consumers directly connected to the transmission network to operate within specific parameters, participating in the control of voltage at a fixed power factor (in which the active and reactive output power values must maintain a specific relationship).

For their part, renewables, cogeneration and waste, within the framework of Royal Decree 413/2014, of 6 June, are subject to a power factor, although for years renewables have already had the technological capacity to operate by consignment, although the regulations do not yet require or allow it.

PHASE 0. VOLTAGE INSTABILITY IN PREVIOUS HOURS AND WEEKS

The analysis is based on a context of system operation at structurally high stress levels, related to lower demand, especially in spring time, which, together with a very meshed network, causes capacitive effects (reactive generation) that pushes tensions upwards. As usual in a context of low demand, some of the lines of the system were decoupled, with the aim of avoiding excessive meshing of the network that could lead to surges.

Situation on the morning of 28A

During the morning of April 28, the peninsular electricity system registered a volatility in voltages (sudden rises and falls in voltage), which multiple agents have described as atypical and extraordinary.

The atypical and extraordinary nature that several agents give to the variations in tension on the morning of April 28 are exemplified by different casuistry such as the following:

An agent refers to an incident at 9:10 a.m. at a generation plant

Cáceres

. With the information received from both the system operator and the owner of the installation, it is concluded that the voltage before and after the disconnection of the plant at that node of the transmission network was 404 kV-412 kV, that is, within the parameters, and there is no relationship between this event and the zero voltage of April 28.

An operator reports the disconnection of hydraulic units due to voltage oscillation shortly before 10:40 a.m.9.

Around 11:10 a.m. the disconnection of

(Zaragoza). According to REE, the voltages at these nodes in the network during the incident reached values close to, but below, 435 kV (425 kV in these two substations and 429 kV in the nearby one), and therefore within limits. However

, for his part, he said that both installations were disconnected due to undervoltage, reconnecting a few seconds later. It also states that the voltage variations continued to occur for the rest of the morning, which forced continuous regulation through the tap exchangers, until the definitive disconnection with zero voltage.

Analysis of voltage variations

Regarding the possible explanations for the variations in voltages on the morning of April 28, evidence compatible with an absence of sufficient capacity for dynamic voltage control is observed during this phase, since different events that are common in electrical systems caused, on that day, a level of variations

9

Relevant. The context of voltage control capability is described in more detail in the relevant section.

It has been observed that there is a correlation between changes in generation production, voltage value and flows in the interconnection with France. In particular, looking at the period between 10:30 and 11:10 in the morning, it can be seen in Graph 23 that the rise in voltages that occurs at that time coincides with a fall in generation, in this case solar generation, probably due to market signals, as indicated below, and that it is accompanied by a decrease in exports due to a change in the program (which become negative, that is, it begins to be imported from France). In other words, tensions rise when solar production is suddenly reduced, coinciding with a change in the exchange program in the interconnection.

Graph 23 Voltage evolution, exchange with France and photovoltaic production on 28/4. Source: REE

Given the timing of this drop in solar generation, in the middle of the ramp of increase in production and without any meteorological phenomena to explain it, the most plausible explanation is that it is for market reasons (prices).

In this sense, as can be seen in the graph below, the price of the intraday market in that period (10:30-11:15) showed negative values, both in the continuous intraday market and in the two sessions in which that period was traded (the data for session 1 is shown), with prices close to -€10/MWh. In other words, there was excess generation in the system and producers charged up to €10/MWh for the energy they withdrew from the market. In addition, specifically between the second and third fourth hour period of the 10th hour, prices go from positive to negative values, with the consequent impacts on the programming of the different systems.

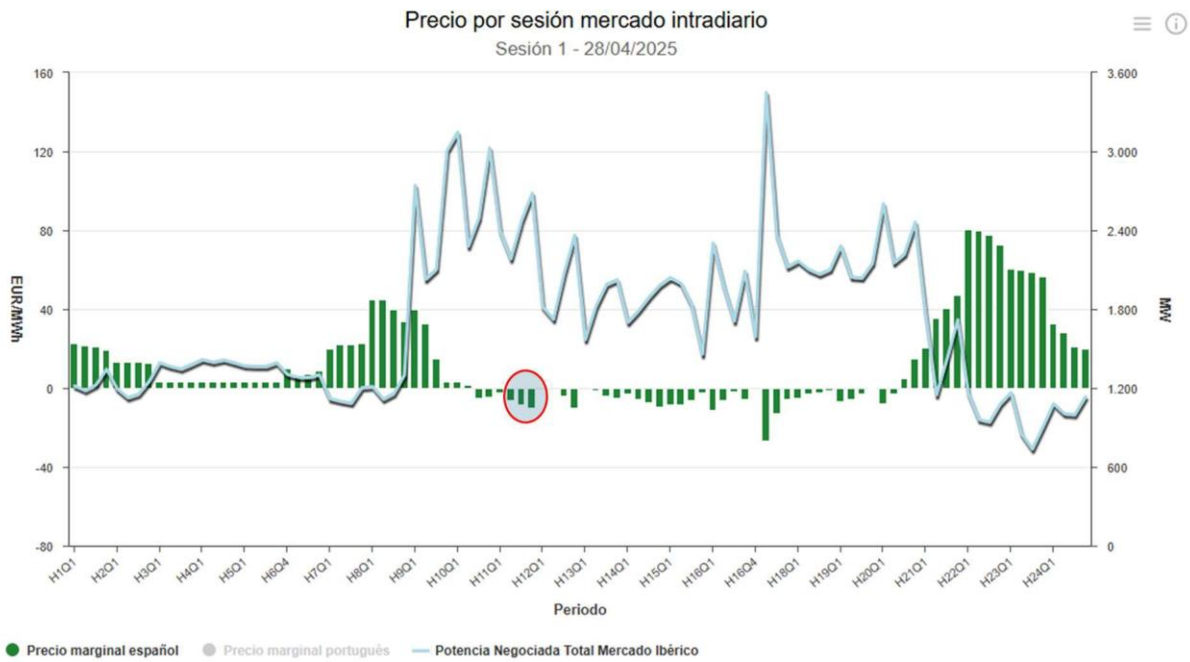


Chart 24 Prices and energy traded in the intraday market (session 1 28/04/2025). Source: OMIE

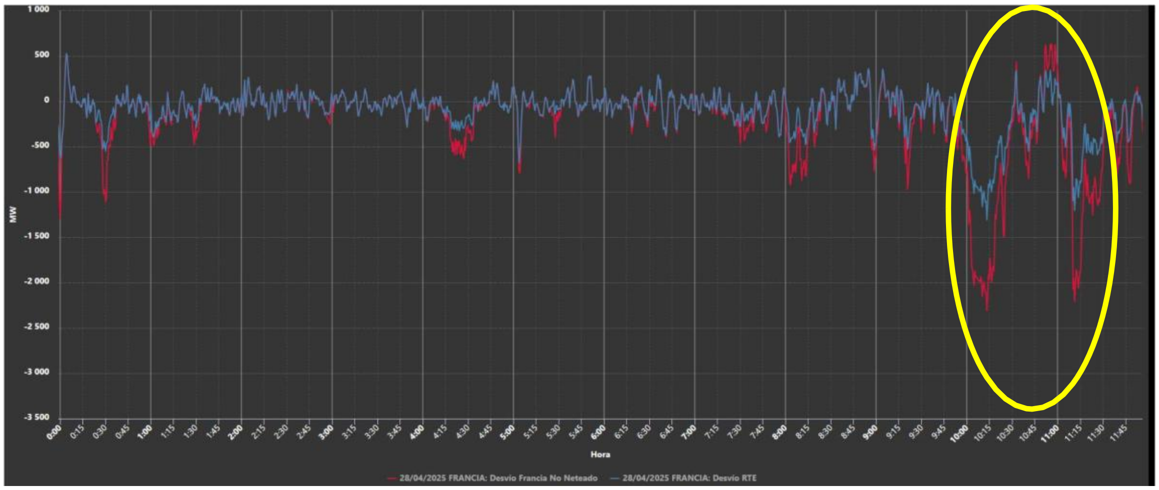
Beyond the specific episode of 10:30 – 11:15, a correlation can be seen both on that day and in the previous weeks and months, between the variations in production power of the generation facilities of the peninsular system, the voltage profiles in the network and the flows in the interconnection. Changes in production can be due to physical issues (such as growth or decrease of the renewable resource), market (daily, intraday or balancing markets) or technical restrictions.

These changes in production can be of a significant amount (if the price signals from the markets are strong enough) and affect energy flows in the networks and tensions in the nodes.

Regarding the correlation between changes in generation and voltage: if the generation that operates at the power factor falls (with the existing regulation, renewable), there is a decrease in the reactive energy absorbed by these facilities (since it is reduced in proportion to the reduction in generation). Additionally, as the energy transmitted by the networks decreases due to this reduction in generation, the capacitive effects of the electrical circuits increase as they become more discharged, which causes an increase in reactive energy. Both effects (greater production of reactive energy by the circuits and lower absorption of it) push voltages upwards. The opposite occurs if the generation of these facilities increases: the greater the renewable generation, the greater the absorption of reactive energy, and the greater the load of the lines (therefore, the lower the generation of reactive energy) and, therefore, the tendency to lower voltages.

For its part, the flow through the interconnections reflects the variations in the active power of the peninsular system, responding to the temporary deviations between generation and demand. In the early morning and morning of 28 April, significant deviations were observed in the scheduling of exchanges with France.

In particular, on the morning of 28 April there were two significant deviations (difference between the programmed flow and the actual flow) in the exchange with France: one at 10:00 and the other at 11:00, which are analysed in greater detail in the section on the behaviour of interconnections.



Graph 25 Scheduled (blue) and actual (red) trade with France on 28 April. Source: REE

Deviations in interconnections and, in general, variations in flow a, have an effect on voltages since they vary the load of the transmission lines, which can cause voltage variations in the system: the greater the flow in the interconnections, the greater the flows of energy in the country to carry the energy to/from the border. A reduction in flow in interconnections reduces internal flows, discharges more lines and, therefore, contributes to a rise in voltages.

As indicated above, programming changes within the framework of the normal functioning of the markets are common and expected events in the electricity system. The fact that on April 28 they led to significant voltage variations is associated, as explained below, with a context of lack of sufficient voltage control capabilities.

PHASE 1. SYSTEM OSCILLATIONS

Oscillations and damping

In electrical systems, oscillations can occur between different areas of the interconnected system and where they are most noticeable is in the most peripheral areas or electrically distant from the "center of gravity" of the system, such as the Iberian Peninsula (which is far away due to its weak interconnection with the continent) and in particular in the areas that are electrically furthest from the rest of the continent. It could be described as a "bullwhip effect," in which a small movement or oscillation near the center generates a large movement at the end.

Oscillations may also appear between a few elements within a more local zone of the system. These have higher oscillation frequencies than inter-area ones (up to more than 1Hz), although this will depend on the origin (mechanical, electromechanical or electronic/control) and the type of generator or demand involved.

Oscillations are dangerous because, if they are not dampened, they are amplified and continue to grow, and can cause the disconnection of the different parts of the system and a total collapse. On 1 December 2016, an inter-area East-Central-West oscillation in the European interconnected system caused the disconnection due to loss of synchronism of several areas of the system. The European electricity system is constantly evolving, which can have implications for the oscillatory modes that can affect the system. As an example, in March 2022 the electricity systems of Ukraine and Moldova were synchronized with the European mainland grid, thus expanding and modifying the electricity system on the continent. More recently, in February 2025, synchronisation with the European system of the Baltic countries (Estonia, Latvia, Lithuania) has been completed.

The ability of an electrical system to neutralize any oscillation that may occur in its fundamental variables and to quickly return the system to its equilibrium state is called damping. It is a parameter that can be measured at any time, it is specific to each node of the network and different for each mode and frequency of oscillation.

Damping and protection against oscillations can be achieved in several ways:

The adoption of topological measures: in general, damping is increased by increasing the meshing of the network (connecting circuits that were open), contributing to "tie" the system more together.

Systems so that generation, demand or the grid itself can contribute to cushioning fluctuations. Special equipment (power electronics) can be installed for this purpose.

In the case of synchronous generation, these are the "power stabilizers" or PSS (Power System Stabilisers) that must be correctly adjusted to the specific oscillation frequencies that may appear in the system. In

specifically, in Spain since 2016, a review and adjustment of the PSS in the system's combined cycle plants has been carried out to contribute to the damping of oscillations. Likewise, the system operator and the companies owning the nuclear power plants analysed the feasibility of installing PSS equipment in these facilities, with the conclusion that it was not feasible to equip them with these systems, with the exception

For asynchronous generation and HVDC links, with power electronics, there are similar solutions called POD (Power Oscillation Damping) systems.

In the case of the network, STATCOM devices with POD functions can be installed.

Coordinated actions between the operators of the electricity systems. Operators have protocols to reinforce the damping of the system when they observe that it is reduced and is not able to neutralize an oscillation. Thus, the operators of the Spanish and French system have agreements not to carry out certain topological manoeuvres near the border with a negative impact on the stability of the system's small signal, and have agreed procedures for action in the event of undamped oscillations ("OPERATIONAL COMMON PROTOCOL: Monitoring and coordinated actions in real-time of the French-Spanish interconnection"). This protocol identifies that there is a risk of oscillations when a damping below certain thresholds is detected, or a high amplitude of the oscillations observed in real time without the amplitude being reduced in a few seconds. In these situations, the protocol indicates that one or more of various corrective actions must be carried out:

Operate the HVDC in Pmode 1: flow at constant power (compared to the usual mode of operation, in which the power activated by the link is defined in a similar way to that of an alternating current line – Pmode 3-). If it was already operating in Pmode 1, increase the active power flow setpoint by the HVDC link (PSP – Power Set Point).

Close lines or transformers with a positive impact on damping.

Increase pumping in Spain.

Reduce international trade in the direction of Spain towards France.

Contact the Ukrainian or Hungarian TSO to reduce exports from Ukraine to central Europe.

Classification of oscillations according to the territorial scale

Several main modes of oscillation have been identified in the European electricity system:

North-South oscillation mode, with a frequency of about 0.3 Hz, in which generators in Italy oscillate against those in Denmark and northern Germany.

East-West oscillation mode, at approximately 0.15 Hz, where the generators of the Iberian Peninsula oscillate in counterphase against Turkey and Ukraine.

East-Central-West oscillation mode, at approximately 0.2 Hz, in which the generators at the western and eastern ends of the system (Iberian Peninsula and southern Balkan Peninsula and Turkey) oscillate in phase with the generators in the center of the European continent (Denmark, Germany, Poland, Switzerland, Czech Republic and Ukraine). This mode of oscillation became particularly relevant after a significant incident in the European electricity system in 2016.

On the other hand, depending on the system operator, oscillations of a more local type have been identified, with a higher frequency, in which one or two generators usually participate against the rest of the system or between them. The system operator indicates that, in the case of Spain, historically only two local (intraregional) oscillation events have been detected that have been considered more severe when reaching amplitudes of up to 60mHz:

In August 2022, an oscillation of 0.18Hz, with an amplitude of about 60mHz peak-peak detected in the area of Seville in which a nuclear power plant in France participated.

In March 2024, a 0.8Hz oscillation in which he participated

connected to the substation later in more detail.

12:03 oscillation

It is found that this oscillation:

and what is described

It has a higher frequency (0.6Hz) compared to the most common in the European system (0.2Hz).

As for its geographical scope, as indicated, it was detected outside Spanish borders in at least France and Germany, with a breadth that decreases with distance.

According to the system operator, the fact that the wave detected in Tavel is in counterphase with the one detected in the southwest of the Iberian Peninsula may indicate that this part of the peninsula is oscillating in the system against this part of France or an area close to it.

According to another operator, the relatively high frequency and angular offset between Porto and Malaga suggests that this is an intra-peninsular oscillation. In fact, it indicates that Porto oscillates more (and the oscillation starts earlier) than Malaga.

The characteristics of the oscillation could indicate, with the information available, that this oscillation is of a more "local" type than those that are more common in the European system as a whole, and that it originates in specific installations or systems (in particular

indicates that it could be associated with tension controls).

As for the possible origin of this oscillation, the following analyses have been carried out:

Regarding the previous state of the network, the System Operator indicates that from 11:50 a.m. to 12:02 p.m. no disturbances have been identified in the transmission network of the peninsular system. In this period, the voltage values in both the 400 kV and 220 kV networks are within the ranges defined in P.O. 1.1. The system frequency does not go beyond the normal operating ranges defined in P.O. 1.4, which sets the limit between 49.85 Hz and 50.15 Hz.

The amplitude of the voltage oscillation at different points of the network has been analysed, identifying a greater amplitude in the southwest of the peninsula. In particular, the points with the highest peak-peak amplitude detected are the Arroyo de San Serván 400kV, Almaraz 400 kV and Carmona 400kV substations.

Likewise, the behaviour of the generation plants that were operating at that time has been analysed, especially in the southwest area, according to the information provided by each of the owners of the facilities. In general, in all the cases analysed, it has been identified that renewable generation (photovoltaic), from different owners, had a "flat" generation (i.e. not affected by the oscillation), with the exception of one installation, as explained below.

However, an anomalous oscillatory behavior has been identified in the active and reactive power output of the photovoltaic plant

of installed power, MW of access to the grid and that at that time was producing a few MW. This floor is connected to the node , in Badajoz,

As can be seen in the image, at around 12:03 and with the information collected, the power output of this plant begins to oscillate in a pattern apparently coinciding with that of the oscillation detected. In a few seconds, the plant's generation oscillates with a peak-peak amplitude of around 70% of the production it had immediately before the oscillation.

This behavior contrasts with that of other plants of the same technology connected at the same node or nearby nodes, as can be seen in the following graphs.

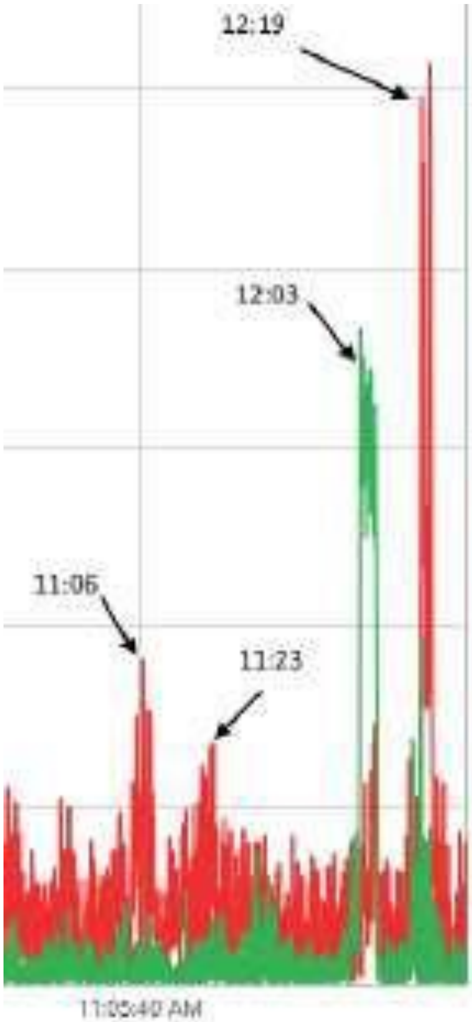
An oscillation in these variables would be, in any case, more typical of synchronous technologies subject to voltage control by setpoint, since they "see" the voltage of the network and modify its power factor to keep the voltage constant. However, in a photovoltaic plant, which is subject to a fixed power factor, the output power value, especially the active one, should be constant, as can be seen in the rest of the installations of the same technology analysed (Graph 27 compares the installation of,

, for that same time period).

Likewise, in order to continue analysing the oscillations of the 0.6Hz mode detected on 28 April, part of what was previously collected in Graph 6 is recovered below, from 11:00 a.m., in Graph 28.

First, it can be seen that a few moments after the peak of the oscillation of 0.6 Hz begins at 12:03 (in green), the amplitude of oscillation also increases to 0.2 Hz (in red). This coincides with the appearance of the oscillation at 0.2 Hz that overlapped the 0.6 Hz oscillation described above and as seen in Graph 10.

Secondly, it is interesting to note that, in addition to the peak at 12:03, which corresponds to the oscillation analysed so far, two secondary peaks are observed, one a few minutes after 11:20 and the other, a few minutes before 12:19.



Graph 28 Extract of the oscillations recorded on 28 April: 0.2Hz (red) and 0.6Hz (green). Source: REE

Analyzing the generation data of at the times corresponding to these secondary peaks in the 0.6Hz oscillation mode to check possible correlations, it is observed (Graph 29) that the active power of the installation oscillates throughout the period, although with a greater amplitude around 11:35-11:36, with a maximum detected peak-peak amplitude of 25MW, with a granularity of available data of 2-3 seconds. In the case of the oscillation that precedes 12:19, this moment coincides approximately with the beginning of an oscillatory movement, in this case, in the reactive power of the same installation.

History of similar oscillation one year earlier

Another episode with an oscillation has been identified

an oscillation was detected,

. This oscillation lasted about 2 minutes and 15 seconds, although with a phase of greater amplitude of about 25 seconds, reaching a maximum peak-peak amplitude of 64 mHz and 20 kV in the frequency and voltage waves, respectively (a similar order of magnitude , to the one detected at 12:03 on 28 April 2025,

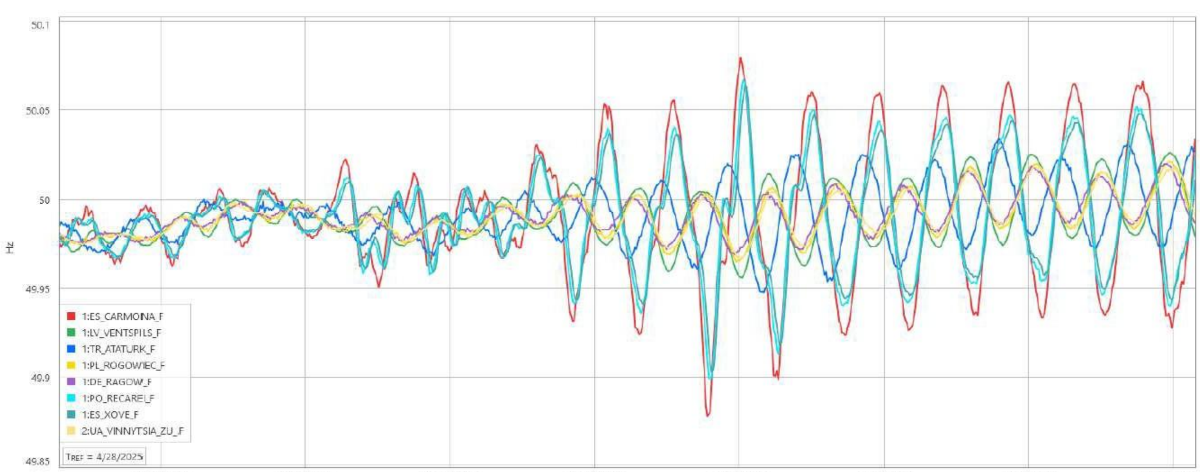
).

12:19 oscillation

According to the system operator's analysis, at around 12:16 the 0.6Hz oscillation appears again, shortly before the 0.2Hz mode oscillation appears at 12:19. This correspondence can also be seen in Graph 28, in which it can be seen that the peak (red) at 12:19 is preceded by a peak (green) corresponding to the oscillation of 0.6 Hz which, as mentioned, coincides in time with an oscillation in reactive energy of the installation mentioned above.

The oscillatory mode that appears in the 12:19 oscillation is the East-Central-West mode. In this way, the Iberian Peninsula oscillates against the center of the European synchronous system – Germany, Italy, Austria, Denmark – which in turn oscillates against Turkey. Graph 32 shows how the peninsular system (Carmona substation, in red or Recarei in Portugal, cyan) oscillates in counterphase with countries in the center of the system (in yellow Rogowiec in Poland, in purple Ragow in Germany), while the signal measured in Turkey (dark blue) is also observed.

The graph shows how locations located on the periphery of the system, such as Spain or Turkey, show a greater amplitude of oscillation in this same episode than locations near the center of the system such as Poland or Germany. It could be described as a "bullwhip effect" or "seesaw", in which locations farther from the "center of gravity" of the system, especially when there is weak interconnection, perceive the oscillations more intensely and are therefore more vulnerable to them.



Graph 32 Detail of the 0.2Hz oscillation. Source: REE

The graph below shows the maximum peak-peak amplitude values of the frequency and voltage oscillations during the 0.2 Hz oscillation at 12:19

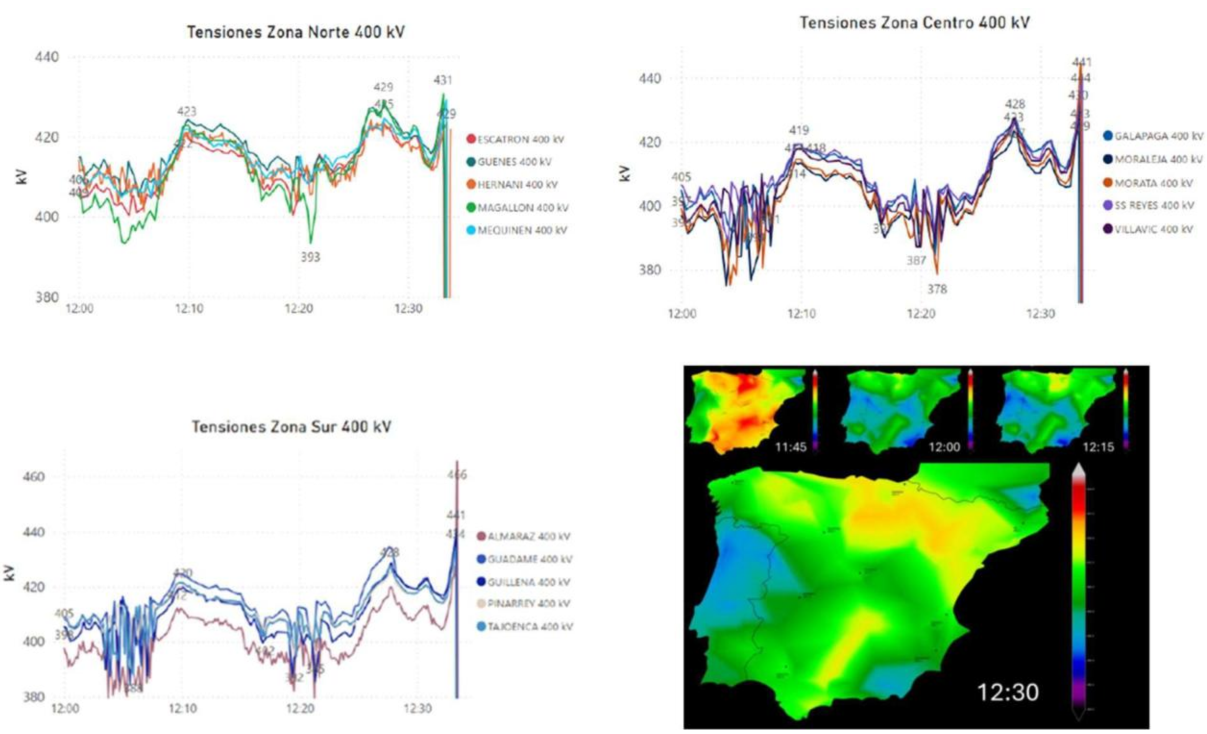
Figure 33 Amplitude of voltage and frequency oscillations at 12:19.

Next-generation programming

In view of the measures adopted to dampen the oscillations and in view of their impact on voltage control, the system operator decided to couple new conventional generation, in particular in the southern area, with the obligation of dynamic voltage control in accordance with OP 7.4, and with the capacity to dampen inter-area oscillations by means of the PSS systems available to some generation plants.

For this reason, from around 12:18 p.m. he requested connection times from several agents, finally opting for which gave a shorter time (1 hour and 30 minutes), whose schedule was finally confirmed around 12:26 for 14:00. When the zero occurred at 12:33, this plant did not manage to dock in time.

Analysis of the evolution of tensions in phase 1 and measures adopted



Graph 14 Evolution of voltages in the 400kV network between 12:00 and 12:35. Source: REE

Recovering Graph 14 that shows the evolution of voltages in the transmission network in phase 1, in addition to a high volatility in voltages comparable to the previous hours, the effect of the oscillations described above (12:03 and 12:19) can be clearly observed.

After each of these oscillatory phenomena, a rise in voltages is observed, which can be explained by several phenomena that complement each other:

Firstly, as described in the section on oscillations, the measures taken to strengthen damping include several measures that may be aimed at increasing the voltage:

The increase in the meshing of the system by connecting lines (which were previously open, in a context of low demand, precisely to avoid overvoltages). The connection of these lines reinforces the system in the face of oscillatory phenomena, but it is a factor that contributes to the rise in voltages in a context of low demand.

The reduction of export capacity in the interconnection to improve buffering against oscillations also contributes to an increase in voltages for several reasons:

With a specific demand, reducing export capacity forces a reduction in domestic generation to ensure a balance between generation and demand. As explained above, a reduction in the generation of technologies at a fixed power factor means a double upward pressure for voltage (less absorption of reactive energy, and greater production of reactive energy in less loaded grids).

The further the generation is from the interconnection, the greater the effect on the lines. For example, by reducing the exchange with France and generation in the south, there is also a reduction in flows from the south to the north, generating a lower load on the lines and, therefore, contributing to a rise in voltage.

These damping measures increase the voltage progressively as they are implemented. For example, the effects of changes in the scheduling of interconnections develop as the program is updated.

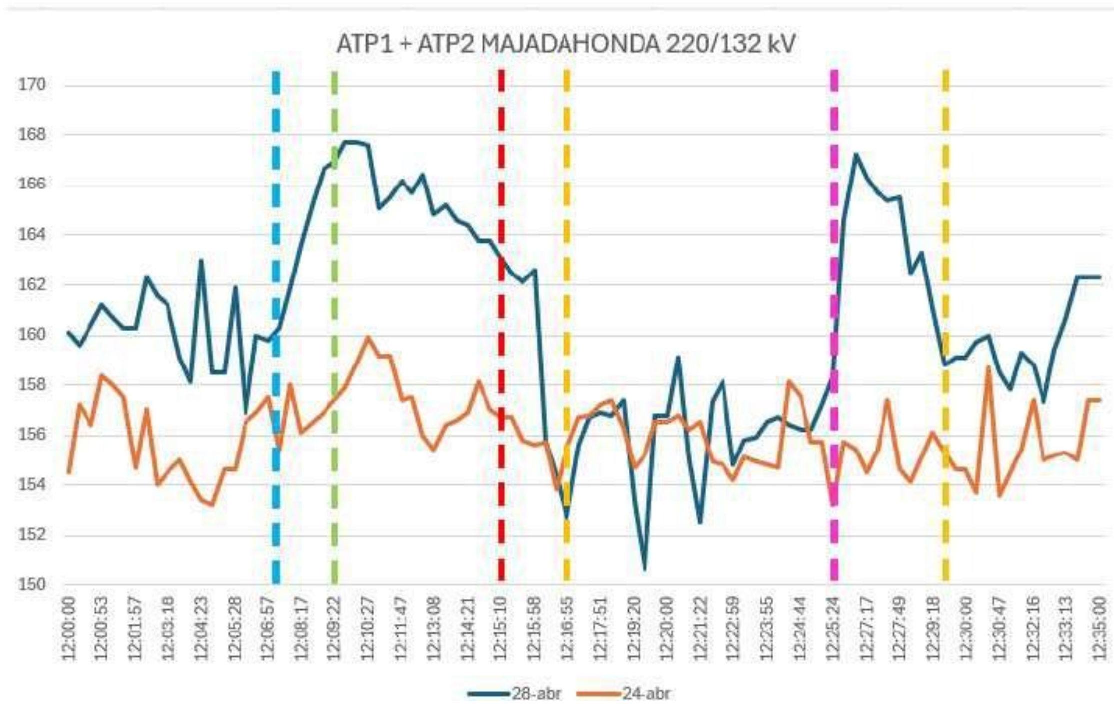
In addition, the damping measures entail a different configuration of the system (in terms of connected lines, configuration of the interconnections...) with respect to the previous situation.

Secondly, since each of the oscillations caused undervoltage values (specifically minimum voltage values below 390kV in the 400kV network), the operator decides to decouple ballasts after each of the oscillations.

These topological manoeuvres carried out by the system operator, which provide a discrete ("jumping") regulation of the voltages, are compatible with the voltage surges observed after both oscillations.

Thirdly, the system operator has also analysed whether during this period the generation connected to distribution and not observable directly from the transmission grid (because it is < 1MW and is not obliged to be attached to a control centre or because it is self-consumption) could have affected the evolution of voltages between 12:00 and 12:30.

To this end, it has analysed the flow of power at transport-distribution border points, in order to identify possible anomalous changes (increases or decreases in demand that are not explained by the expected evolution of the demand curve and that could be an indication of disconnection or connection of distributed generation).



Graph 34 Active power at border point on 28/4 and comparable day

Taking a specific pilot node (220/132 kV transformers in Majadahonda, Madrid), an anomalous increase in load can be seen between 12:07 and 12:15 hours and a new increase in load between 12:25 and 12:29 h, both after two

oscillations suffered in the system. This phenomenon would be compatible with the hypothesis that the oscillations affect the generation embedded in distribution and that it is disconnected for a few minutes after the voltage oscillations. This behavior is common in some inverters, after a blockage or a trip they stop working until the grid voltage is stable and within margins for a few minutes (typically 3-5 minutes).

The increase in demand at the port-and-distribution border, and the subsequent reduction a few minutes later (i.e., when the generation facilities would be reactivated) is reflected in the flow of the interconnection (reducing and subsequently recovering exports), as can be seen in Graph 35.

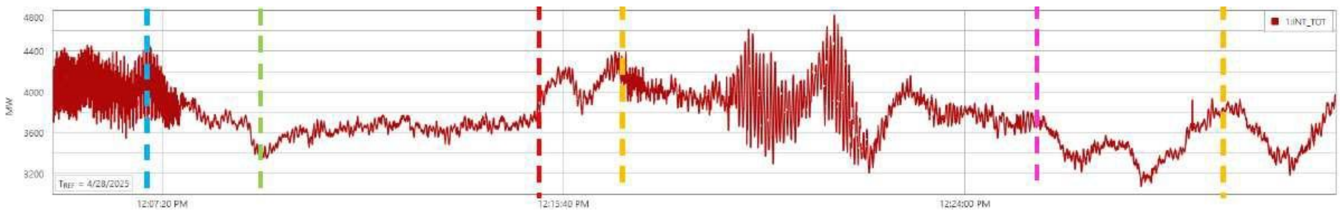


Figure 35 Changes in international interconnections after fluctuations

In order to test this hypothesis, the Committee has requested information from both distribution system operators and inverter suppliers, whose information should provide greater visibility to what is happening downstream in the system.

In the case of distribution system operators, peaks in demand are indeed detected that "appear" at the border points of the distribution network coinciding with what has been described above.

In the case of inverter manufacturers, of the requests made to five business groups, a response has been received from some of them.

In the case of , a response is observed that is consistent with the hypothesis described above: generation losses and voltage surges in the moments after the oscillations. As can be seen below, the answer is different depending on the voltage level at which the generation is connected:

In inverters connected at low voltage (Graph 36), alarm peaks associated with inadequate voltage levels are detected around 12:10 and 12:27, which in turn coincide with a reduction in the aggregate generation that these inverters represent together.

In inverters connected to high voltage (Graph 37), voltage-linked alarms are also detected at the same times, although additionally alarms are detected at around 12:16, coinciding with the reappearance of the 0.6Hz oscillation. However, in terms of generation drop, only the event around 12:27 is relevant.

In any case, it should be noted that, in the case of this particular manufacturer's farm, the generation losses detected in these phases represent only a small proportion of its total generation, in any case less than 10%, as can be seen in Graph 38. In other words, it cannot be said that a relevant proportion of the generation was disconnected, either connected to high voltage or low voltage, at least in the case of reported investors.

The loss of distributed generation can have effects on grid voltages, in different ways: the deviation it causes in the interconnection can activate secondary regulation and causes changes in energy flows through the transmission and distribution networks that, depending on their characteristics (X/R ratio) and the net energy balance at the border, they can push tensions up or down. Similarly, reactivating the generation a few minutes later can have the opposite effect on the system.

After finishing the second oscillation, the system operator detects a generalized rise in voltage levels, so he decides to couple 5 ballasts, which are connected between 12:26 and 12:28. This moment is compatible with the "peak" of tensions around 12:28, after which tensions are observed to fall again. This moment would also be compatible with the recovery of disconnected generation after the second oscillation.

In short, in this phase, voltage effects have been identified that coincide with different events that occur over time and that are related in one way or another to the oscillations that the system has experienced, such as the connection and disconnection of ballasts, the adoption of measures to cushion the system against oscillations (meshing of the network or reduction of the exchange in the interconnections) or the disconnection and subsequent disconnection Generation reconnection.

In any case, as in Phase 0 above, the high and abrupt upward and downward variation of voltages during this phase shows a lack of dynamic voltage control capacity, as described in the corresponding section.

PHASE 2. GENERATION LOSSES DUE TO OVERVOLTAGES

Voltage surge at 12:32

During this minute, there is a sustained increase in voltage, which coincides with a reduction in exports in international interconnections of approximately 1,000 MW in 57 seconds.

In the opinion of the System Operator, this linear increase in voltages is explained by the following factors:

At 12:27 p.m., the adjustment of the schedules in the Spain-Portugal exchange begins, which had been agreed at 12:20 p.m. for 12:30 p.m. between REE and REN as a cushioning reinforcement measure. The adjustment window for these schedule changes ranges from -5 to +5 minutes, and it is common for there to be transient imbalances between the schedules to be raised and lowered on both sides of the border as a result of the change in the interconnection schedule. These imbalances can lead to fluctuations in voltage, which must be managed by installations with dynamic voltage control (since transmission system installations offer static control).

During this minute, therefore, a reduction in generation is observed – partly due to regulation, as a result of programming changes – which regulates the absorption of reactive with a power factor, which implies a rise in voltage in the places where the reduction is applied.

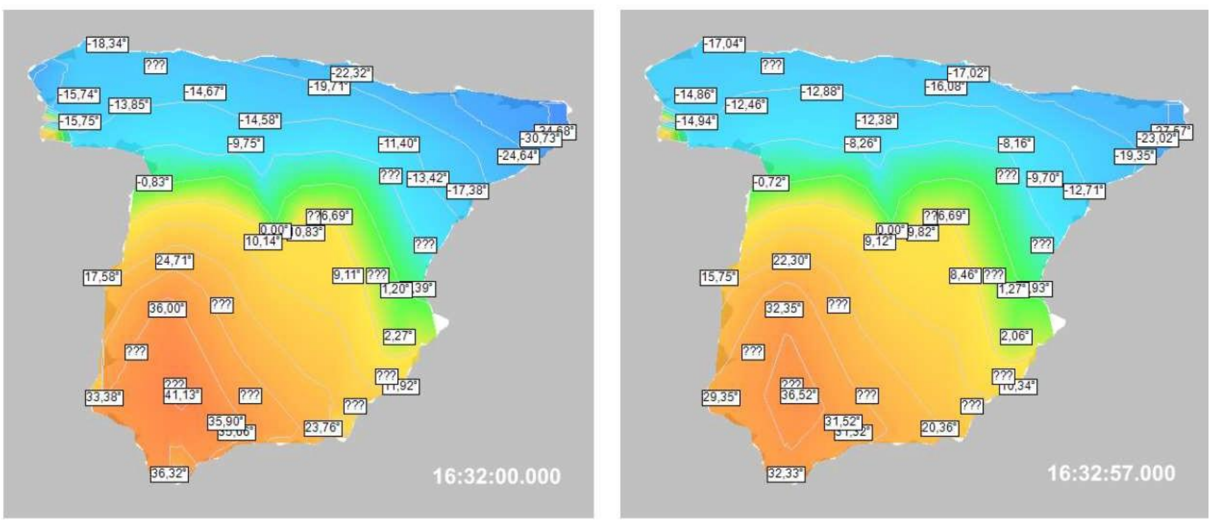
Generation shots are also observed, both isolated and in distributed generation.

Between 12:32:00 and 12:32:57, the exchange with France fell by 1,030 MW. Of these, 480 MW are due to a reduction in observable renewable generation, both due to the allocation of secondary to be lowered and by isolated trips. Synchronous generation varies minimally in the same period, while the rest of the interconnection corresponds to observed demand variation, compatible both with the loss of "unobservable" generation in the distribution network and with the electrotechnical effect generated by a demand surge with the voltage surge.

Since the system was recovering from low-voltage conditions, the operator infers that the transformer tap changers in the distribution network were programmed to maintain adequate voltage levels. These tap changers may not have responded quickly enough, potentially generating overvoltages in secondary distribution networks, even if the primary voltage values remained within acceptable limits. This overvoltage in the distribution network would be compatible with generation losses in distribution.

By lowering the transmission from the south to the interconnection, a voltage increase is caused in the network (due to the effects explained above: a lower load on the networks – in this case, on the lines that connect the south with the north – means an increase in reactive energy and with it an increase in voltages)

Insufficient absorption of reactive by generation that has dynamic voltage control (large synchronous generators such as nuclear or combined cycles).



Graph 39 shows the variation of the angular difference with respect to a substation in the center of the peninsula, where a reduction is observed, between 12:32 and 12:32:5, in the angular difference between the south and the center of the peninsula, indicating a reduction in flows between these areas, compatible with the effect described above.

Graph 39 Variation of the angular difference with the La Cereal 400 kV substation (the greater the angular difference, the more south-north flow). Source: REE

First generation losses detected

At this point of the committee's analysis, it focuses on the characterization of the identified trips in order to determine both the way in which they were produced, and their impact on the increase in voltages that resulted in the peninsular electric zero.

Event 1: 12:32:57,140: disconnection in (Granada)

According to REE, the voltage at the transmission grid substation on the 400 kV side was at 418 kV at the instant prior to the trip, and at 423.9 kV on the

a later moment and, therefore, within the limits allowed by the regulations and in which it would be expected that the generation infrastructure would remain connected to the system.

On 14 May, a request was made to the company that owns the common evacuation infrastructure, ICE,

. The request for information was expanded with new letters addressed to society on May 26 and 27.

On 28 May, a first response was received from the company that owns the ICE, consisting of a technical report signed on 7 May, which confirms the time of the incident and explains that the disconnection of the entire generation and evacuation network occurred when the overvoltage protection of the secondary of the 400 kV / 220 kV autotrafo was acting. due to overvoltage on the 200 kV side caused, in turn, by the 400 kV network. The officer also states that the protection was properly adjusted and that it worked properly:

Once the 220 kV busbar switch was disconnected, the entire downstream network was islanded and the collector substations were tripped by undervoltage or overfrequency (as there was an unloaded generation island to supply except for auxiliary services). This information is consistent with that provided by downstream generators.

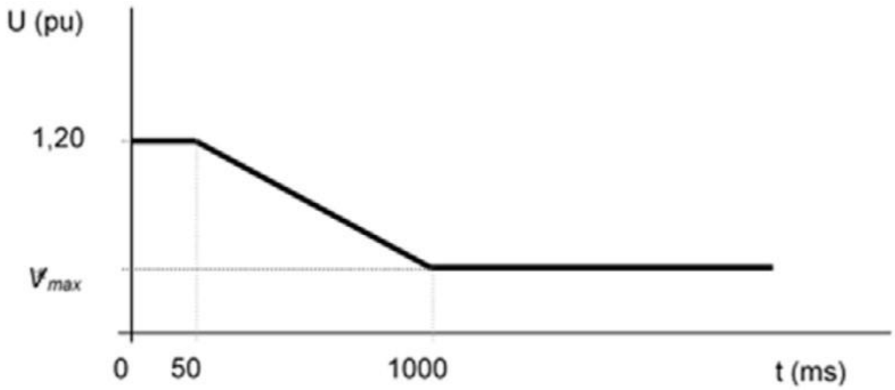
However, there are several elements to clarify regarding the shot:

According to the information on the setting of this protection, the transformation ratio of the voltage measurement transformer and the voltages measured at the time the protection was activated, the voltage on the 220 kV side of the autotrafo at that time exceeded the threshold of 70 V x 2,000 x 1.73 = 242.5 kV, which effectively corresponds to more than 110% of the nominal voltage of 220 kV. Specifically, 70.14 V are reported in the phase (equivalent to 242.97 kV on the 220 side) and that 55 ms later the phases jumped to each of them 70.53 V (equivalent to 244.32 kV).

On the one hand, it is common ground that downstream of   Facilities

generation to which Order TED/749/2020 applies, which requires

withstand overvoltage transients above voltage for a specific amount of time, as illustrated below. However, the setting of the protection seems to entail an immediate disconnection when exceeding the reference voltage, which would not be expected taking into account the generation connected to this node.



Graph 40 Minimum surge times. source: Order TED/749/2020

On the other hand, there are divergent data regarding the tripping voltage, since, as has been said, REE states that the voltage in the 400 kV network at that point and at that same time was 424 kV. Applying the nominal transformation ratio (220 / 400 = 0.55), the at least 242.5 kV reported by the ECI would correspond to 440 kV (16 kV more than those reported by REE). Similarly, the 424 kV referred to by REE would translate into 233.2 kV on the 220 kV side, which is 10 kV less than those measured by the ICE protection.

This issue could be compatible with a less rapid regulation or upgrade of transformer sockets than necessary, which could be suitable for a lower voltage level in the transmission network, but apparently not the one reached at the time of tripping.

On 28 May, the company that owns the ICE was asked for additional information on the transformation ratio of the 220 kV/400 kV autotrafo at the instant prior to the overvoltage tripping of the switch, as well as a description of the regulation mode of the autotrafico tap changer, specifying whether it is automatic or manual. the number of jumps/steps and their % variation, as well as a list of the changes made in the hours prior to April 28. To contrast with other voltage measurements, the voltage values (in kV) recorded on both sides of the autotrafo by the transformers of

and in any other available measurement record of the voltages in the primary (400 kV) and secondary (220 kV) of the aforementioned transformer.

On June 10, the agent reports not having precise information on the changes of taps during April 28, nor the exact transformation ratio at the time prior to the trip of the substation. However, it has sent oscillographic records of the installation, which contain voltage measurements at various points of the 220 kV and 30 kV indoor network.

Although it is not possible to make an exact identification of the points where 30 kV is measured from the information sent by the ICE, those of 220 kV could correspond to those marked in red in the single-line diagram:

As can be seen in the table of values of the oscillographic records sent to the committee, at the time of the trip (12:32:57), no voltage measured in the ECI at 30 kV and 220 kV was above 1.08 pu:

Therefore, with the information currently available, the data could be compatible with an "early" trip (i.e. before reaching the expected voltage) of the generation position.

The effect of a loss of instantaneous renewable generation on the voltages at the nodes of the grid is twofold: on the one hand, this generation, although it did not carry out voltage control by setpoint, was subject to a certain operating power factor that caused the plants to absorb a certain amount of reactive energy from the grid (MVAr) that is no longer absorbed with disconnection; on the other hand, when the plants are disconnected, the nearby grid stops transporting energy and increases its capacitive effect, generating more reactive energy. The combined result of both effects is an increase in the reactive generated and in the voltages in the network.

Event 2: 12:33:16,460: disconnection in (Badajoz)

Below is the single-line of the substation, to which they connect:

The central , owned by .

Line , owned by

In turn, it connects with downstream infrastructure at 220kV.

Figure 42

The information provided by the generators connected downstream of this evacuation facility indicates that the disconnection would occur in the evacuation facility itself.

evacuation infrastructure. Specifically whose plants inject in two

Collector substations ( ), both connected to the substation

Collector states that collector substations

detected an upstream disturbance, not observable by them, at 12:33:16:433, which left the entire 220 kV network on an island and caused the disconnection of the inverters from their plants due to overfrequency and the evacuation lines due to overvoltage.

On May 15, a request was made to the joint venture that manages the evacuation to provide information on the circumstances of the disconnection. Different responses have been received since May 26. With the data provided by the joint venture, it is confirmed that the first disconnection occurs in the evacuation infrastructure.

For its part, the installation of claims to have disconnected at 12:33:17,527, that is, after the previous event.

As for the tension at the time of the first shot:

The voltage reported by your facility from the information in your control center has a time interval of 10 seconds. The last value recorded before falling at 12:33:10 is 428.87 kV and therefore within operational limits, although no information closer to the moment of the shot (about 6 seconds later) is available.

Based on SCADA measurements, before firing there are no measurements exceeding 435 kV. As can be seen in Graph 43 and as indicated by the system operator, the voltage was around 430-435kV, depending on the phase and the specific location, prior to 12:33:15.

Figure 43

Therefore, with the available data, no values have been detected in these measurements that exceed the voltage limit that the generation must withstand before disconnection,

although it cannot be ruled out that, at the moment of the first shot, a few moments after this measurement, it would not have exceeded it.

On the other hand, at the time of the second trip, the oscillography data indicate an overvoltage, registering a value of 443kV, that is, higher than the limits admissible in the system.

of the first disconnection of (360 ms later, at 12:33:16.820) the disconnection of the wind farm is recorded, connected to the substation of about which a report has been requested from the owner of the installation. The technical report received concludes that the trip is caused by an overvoltage of more than 435kV for a space of more than 1.5 seconds, and exceeding 440kV before the trip.

Based on calculations according to the data measured in a nearby REE PMU indicate a voltage of 432kV.

As contrast information, voltage data have been obtained from the

, which measure 424.8kV at 12:33:10, i.e. several seconds before the shot. The next available data, 475.3kV, is given at 12:33:30, that is, after the rest of the events.

Therefore, the available information does not allow the nature of the trip to be determined, although it is clear that the plant, connected

of the transmission network, is disconnected almost 2.5 seconds later, at

Regarding the disconnection of the wind power connected to , the system operator reports a voltage of 428.2kV based on SCADA data.

On the other hand, the disconnection of in

it occurs, according to SCADA data reported by the system operator, at a voltage of 247.1 kV in the 220kV network.

Both data would point to "early" disconnections.

Event 3: 12:33:17,780: disconnection in (Seville)

According to the system operator, at the instant prior to the trip, the voltage recorded in

it reached 437.91kV and, therefore, less than 440 kV.

On May 14, a request was made to , the joint venture that manages the evacuation of the positions of that substation to provide information on the circumstances of the disconnection.

The owner responded with a report indicating that the disconnection is caused by the activation of the overvoltage function, after overvoltage was detected in the 400kV network. However, in the information provided, the last minute value before the trip is 418kV.

Analyzing the oscillographic data, a distortion is observed around the voltage wave measured a few moments before the shot. With the information received, it is not possible to determine if it is a problem in the measurement, and if this distortion has been decisive when detecting the overvoltage that triggers the trip.

Graph 44 Oscillographic record measured in .

In any case, at this point tensions were close to the maximum admissible levels and, after the shot, they continue to increase.

In conclusion, the system was in a situation with little capacity to control voltage, with tensions escalating in various parts of the system. In this context, any disconnection of renewable generation means an increase in

voltage in at least two ways: reduction in reactive absorption when operating at a power factor, and reduction of the load of the lines with the consequent increase in reactive generation and, with it, a new increase in voltages.

Each of these disconnections, whatever their nature, brings the system closer to a point where, in the absence of systems or tools that absorb sufficient reactive energy, it becomes a "point of no return" by initiating a "chain reaction".

PHASE 3. COLLAPSE TO ZERO VOLTAGE

Continuing with the reference of the previous phase, once the "chain reaction" process has been triggered, any new disconnection is likely to continue increasing the voltage for the reasons already expressed above (reduction of load on the lines, less absorption of reactive energy) and, with this, perpetuating this "cascade effect".

In particular, once the voltages that the generation facilities are obliged to withstand are exceeded in the system, generation disconnection is expected. Although voltage is a variable with a local component, this "cascade effect" contributes to the rapid propagation of overvoltage conditions until, in the system as a whole, the conditions cause the disconnection of the generation that is connected.

Ballast and impossibility of containment of the event

With respect to demand ballasts, their function is to respond to balance problems, i.e. imbalances between generation and demand that have not been solved by any other of the system's tools. In a general case, an untimely generation disconnection of a specific volume causes an imbalance between generation and demand (which must be rebalanced), thereby causing a drop in frequency and, at one extreme, disconnecting demand by activating the ballasts so that the balance is restored.

However, from the analysis of the events of April 28, it can be deduced that we are not facing a balance problem in which a certain amount of generation is lost punctually, but a systemic situation of overvoltage that is what causes the generalized disconnection of generation.

In fact, it is likely that, in this case, the activation of the ballasts (although it is in line with the design, since they are activated automatically when the corresponding voltage thresholds are crossed) may aggravate the situation of overvoltages as a counterpart, by further reducing the load on an already highly meshed network in a context of low demand. thus contributing to a further increase in tensions.

As indicated in the description section of Phase 3, it is not until practically the end of the phase that the lower threshold of subfrequency is crossed, below which the rest of the generation is susceptible to disconnection: in the bulk of the disconnection process, the effect of overvoltage has dominated.

By way of illustration, at the time of 12:33:23, even after the threshold of the last step of ballast has been exceeded, voltages more than 20% higher than the nominal voltages are still being measured: that is, conditions in which generation would continue to be disconnected, in any case.

That is, the "failure mode" in this case was not so much a massive drop in generation, but a systemic condition – in this case, overvoltage – that propagated tending to generate new disconnections.

In other words, once this phase had begun, the way to have contained the system would have been a sufficient absorption of reactive energy to reduce the voltages faster than the "chain reaction" tended to raise them and, with this, recover voltage conditions that were not likely to trigger generation.

As can be seen throughout this document, the system did not have, at that time, sufficient voltage control capacity, thus preventing the collapse from being halted once this phase had begun.

ANALYSIS OF THE ROLE OF INTERCONNECTIONS

As is known, the peninsular electricity system has a low level of interconnection with the European continent, barely 3% of the installed capacity, far from the 15% target established in European regulations.

As explained, the level of interconnection is relevant from the point of view of the stability of the system. The peripheral and poorly connected regions

Electrically with the rest, such as the Iberian Peninsula, they are further away from the center of gravity of the system and are more prone to suffer inter-area oscillatory phenomena such as the one at 12:19 on April 28 and, in addition, because they are at the end of that "oscillating seesaw", they perceive the oscillations with greater amplitude than in the systems more connected to the center.

Therefore, if the Spanish system had been more interconnected, the probability of occurrence of the oscillatory phenomena of April 28 would have been lower and, if they occurred, they would have done so with less virulence.

Beyond their influence on the stability of the system, interconnections are a relevant element for the analysis of the incident, in a fourfold way:

They are a source of variations in energy flows on the peninsula, since, in an internal market such as the European one, flows through interconnections allow generation and demand to respond to the price signals that may occur in the different regional markets. This means that, every 15 minutes, flows with France or Portugal can change sharply if price differences between countries promote it.

They are also an indicator of potential balance problems in a system, as interconnects tend to instantly correct power deficits or surpluses that may occur on one side. As has been seen throughout the analysis, deviations in exchange programs are a very useful tool to identify generation losses and to estimate or contrast their magnitude.

Interconnections can play an important role in the event of an incident, providing instant inertia and primary frequency regulation in the form of active power.

Finally, interconnections were essential for the rapid restoration of supply, since the prompt contribution of voltage and energy from France and Morocco made it possible to build the first islands in Catalonia, the Basque Country and Andalusia, from which to feed the auxiliary services of the combined cycle plants that were providing energy to the grid.

This section chronologically includes the most important aspects of the behavior of the interconnections on the day of the incident, some of which have already been referred to in the previous sections.

Early hours of April 28

At 6:00 a.m., there is a change of program of approximately 1,000 MW in the interconnection with France (going from 2,590 MW export to 1,600 MW export). Shortly before the start of the program change, voltage variations were detected in all the pilot nodes of the 400 kV network.

For its part, the flow through the interconnections reflects the variations in the active power of the peninsular system, responding to the temporary deviations between generation and demand. In the early morning and morning of 28 April, significant deviations were observed in the scheduling of exchanges with France.

In particular, on the morning of 28/4 there were two significant detours (difference between the scheduled flow and the actual flow) in the exchange with France: one at 10:00 and the other at 11:00.

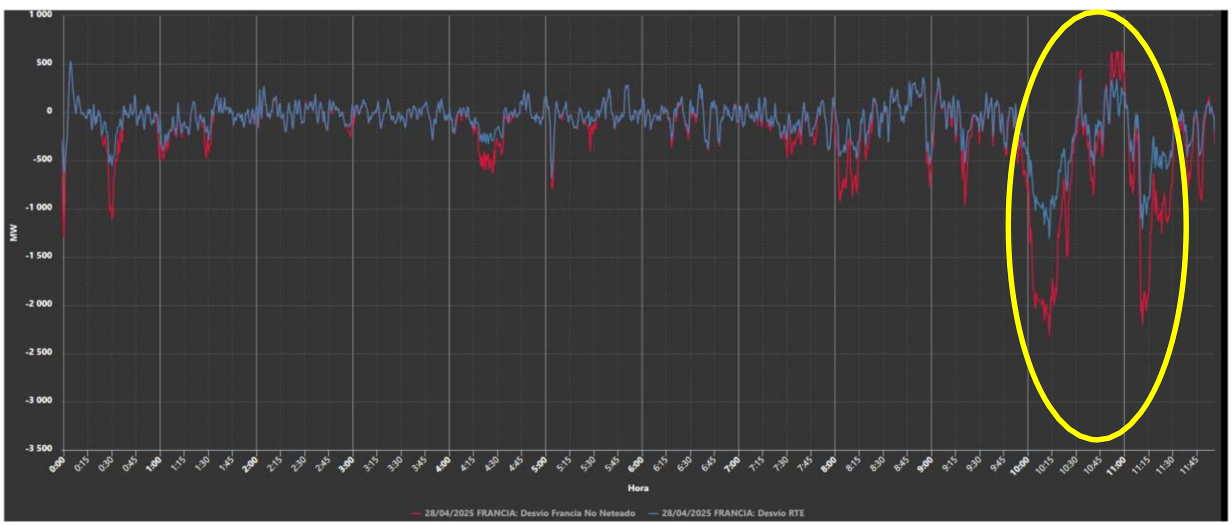


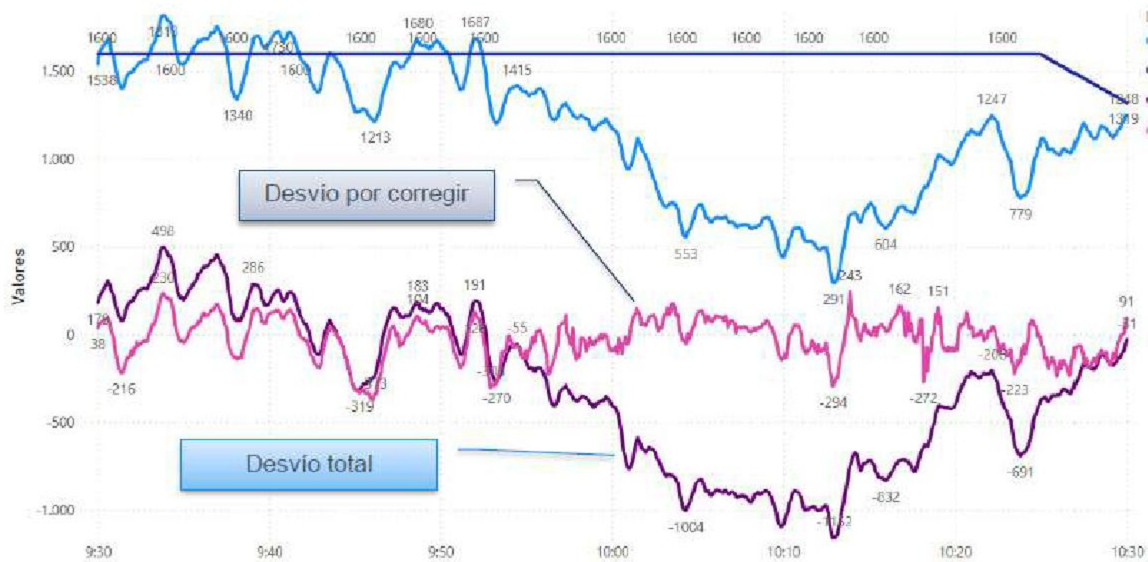
Figure 45 Scheduled (blue) and actual (red) exchanges with France on 28 April. Source: REE

According to this analysis, the deviation at 10:00 would be explained by a deviation in photovoltaic production between 9:55 and 10:05 of around 900 MW (for photovoltaic production an increase of almost 2,000 MW was scheduled at that time) whose most likely cause is the reduction in the marginal price.

Deviations in interconnections are not immediately corrected, as there are internal market rules which, in the interests of coordination and efficiency in the

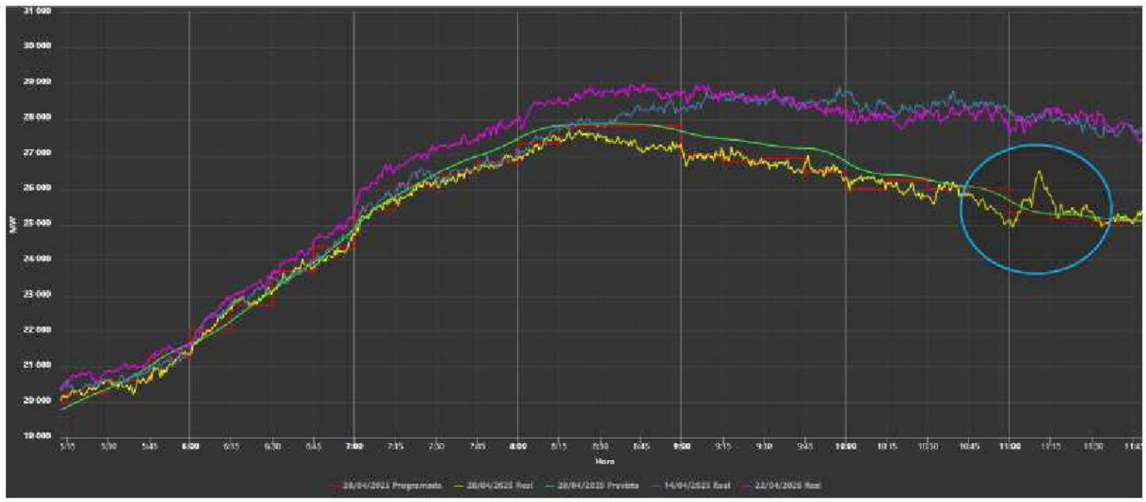
operation, require a prior calculation of what the net deviation is between the two sides of the border, in order to correct only by activating reserves of each TSO the part of the deviation that cannot be netted.

In the case of the 10:00 a.m. deviation, the deviation to be corrected is practically zero at all times and the total duration of the detour is uncertain, as it depends on the secondary activations of all TSOs participating in the European platform and the available exchange capacities.



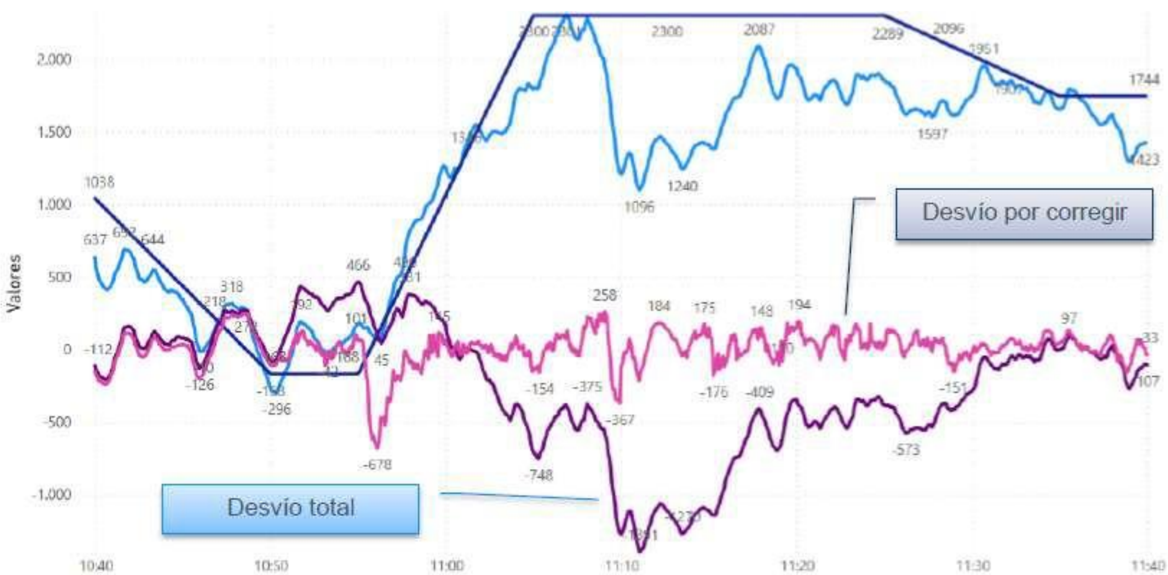
Graph 46 10:00 a.m. deviation: breakdown of net deviation and to be corrected. Source: REE

The 11:00 a.m. deviation, with the information available, cannot be explained by the behavior of generation, but correlates with an unforeseen and sudden deviation in demand, which increases by about 1,200MW without known cause and without bearing any similarity to the next few days. This "anomalous" increase in demand, marked in the graph below, is compatible with a temporary reduction in distributed and small-scale generation (including self-consumption) in lower voltage networks.



Graph 47 11:00 a.m. deviation: "anomalous" increase in demand. Source: REE

As with the 10:00 diversion, the total correction is delayed by a few minutes, in this case until 11:17, once the secondary needs netting has been applied.



Graph 48 11:00 deviation: breakdown of the net deviation and to be corrected. Source: REE

Deviations in interconnections and, in general, variations in flow a, have an effect on voltages as they vary the load on transmission lines, which can cause voltage variations in the system.

First swing (12:03)

Interconnections play an important role not only in the origin of oscillatory phenomena but also in damping them.

As explained, in response to the 12:03 oscillation, REE adopts a series of measures to increase damping related to interconnections:

In accordance with the protocols agreed with the French TSO, RTE, at 12:04 p.m. it is contacted to apply from 12:07 p.m. to 1:00 p.m. a reduction in exchange with France of 800 MW, setting a program of 1,500 MW of export.

Likewise, and also in line with these protocols, at 12:06 a modification of the operating mode of the direct current circuit (HDVC) of the interconnection was agreed with RTE, moving at 12:11 from AC emulation mode (Pmode 310) to DC mode (Pmode 111) with a consignment of 1,000 MW exporter.

At 12:15 p.m., REN is asked to reduce the export exchange to 2,000 MW to reduce the flow of L-400 kV CEDILLO-FALAGUEIRA and to improve the buffering by trying to reduce the load on the lines. REN requests to keep it at 2,500MW at the current time, finally agreeing that the proposed reduction will be applied from 1:00 p.m.

In their contributions, some agent has linked the mode of operation of the HDVC direct current link as a possible cause of the occurrence of oscillations, citing a 2019 ENTSOE technical document in which it would be postulated that the operation of these links emulating AC lines (Pmode 3), with real AC lines operating in parallel, could favor the appearance of oscillations.

The agreement between REE and RTE that establishes the rules of operation of the interconnection in real time contemplates actions to be carried out when there is a risk of inter-area oscillations in certain circumstances. In such cases, the protocol states that measures must be taken including, but not limited to, operating the HVDC interconnection on Pmode 1 (and if it was already operating in this mode, increasing the active power flow setpoint by the link), or shutting down transformers and lines in the system.

10 A mode of operation in which the power activated by the link is defined in a manner similar to that of an alternating current line.

11 Flow at constant power according to the setpoint.

Consequently, and as mentioned, after the first oscillation at 12:03, around 12:1212, the interconnection operating mode was switched to DC, so the subsequent oscillations already occurred with this operating mode activated and therefore these oscillations would not be attributable to the interconnection operating in "AC emulation" mode.

Second Swing (12:19)

As a result of these new oscillations, REE adopted the following buffering measures related to interconnections:

At 12:19 p.m., RTE is contacted to reduce the exchange with France to 1,000 MW from 12:20 p.m. to 2 p.m. During this phase, the previously established Pmode 1 HVDC interconnect operation mode is maintained.

REN is contacted at 12:20 to reduce the exchange with Portugal to 2,000 MW at 12:30. The program goes from 2,545.2 to 2,000 MW and began to be regulated at 12:27 p.m. Subsequently, at 12:26, it is agreed with REN to reduce the program additionally from 12:45 (at which time it was not reached, to produce zero at 12:33).

Interconnection behavior during Phases 2 and 3

At 12:30, after the oscillatory phenomena, the flows through the interconnections have been scheduled to limit them to 1,000 MW with France and 2,000 MW with Portugal.

At 12:32, exports to France are 1,500 MW and begin to fall as voltages begin to rise and generation is lost.

After the disconnection, the exchange with France goes from about 450 MW of exporters to an almost zero or slightly importing exchange. This same trend continues, and after the shots fired by , the increase in the import balance is 895 MW and 1,510 MW, respectively.

12 That is, a few minutes after the oscillation had been muffled, at around 12:07, with the measures adopted earlier.

As explained, with the fall in generation due to cascading surges, the maximum import exchange with France was reached at 12:33:19.620, reaching 3,807 MW in absolute value (4,609 MW were imported through the AC lines and the HVDC in Pmode 1 returned 802 MW to France). At this time, when the flow of energy from France reaches its maximum value, there is a loss of synchronism between the peninsular and continental systems. From then on, although the interconnection lines are still operational, the contribution from France decreases, even reversing the flow of energy from a certain moment and exporting up to 5,587MW, which further aggravates the drop in frequency on the Spanish side.

About 4 s after the trip, the peninsular system was disconnected due to the action of the synchronism loss protections and, another 2 s later, the HDVC cable (which was still exporting about 1,000 MW since the 12:03 oscillation) was disconnected due to the voltage collapse on the Spanish side.

As explained, the interconnections with France worked according to their design parameters and in accordance with the operating modes they had configured.

Link operation at the time of voltage collapse

Regarding the question of how this Pmode 1 mode of operation could have influenced subsequent events, the operation in Pmode 3 mode (emulation of an alternating current line) allows that, in the event of an event of loss of generation in the peninsular electricity system, the power flow of said HVDC is adapted to the needs of the system, increasing its flow of energy to the peninsula, just as an alternating current line would, improving stability conditions. This regulation of the active power in the link is carried out from the angular difference of the voltages on both sides of the boundary, so it is not a regulation by frequency control.13 In turn, after the experience obtained in past oscillatory events, this emulation behavior was configured to have a

slower response and thus improve the behavior of the HVDC from the point of view of oscillatory stability.

Therefore, if the HVDC link had been configured in Pmode 3 at the time of the frequency collapse, the contribution of active power from the European system could have been up to 3,000 MW more than what was reached (since not only would the 1,000 MW set per slogan not have been exported, but up to 2,000 MW could have been imported) so the frequency drop in the peninsular system could have been slower and, therefore, the rate of disconnection of generation by subfrequency could also have been slower. However, it does not seem evident that this greater contribution of active power from the continental system could have prevented the final result of the collapse, since the problem in the peninsular system according to the information sent by the System Operator was not one of active power balance, inertia or primary regulation but of surges: significant overvoltages are found in the 400kV network beyond 12:33:23, practically the end of the collapse phase, which would have continued to lead to the disconnection of generation despite a slowdown in the frequency drop.

OTHER FACTORS ANALYZED

This section analyses other dimensions of security of supply, the conceptual explanation of which is included in Annex X of the report, as well as other circumstances and factors relevant to the understanding of what happened.

Inertia

With regard to inertia, the system operator indicates that before the incident the system had inertia levels of 2.3 s (not counting the contributions through the interconnections), which is a value higher than the 2 s recommended by ENTSOE in its INERTIA project, published last January 2025.

Regarding the availability of inertia in the system, and beyond the 2-second reference set by ENTSO-e, it is found that until at least 12:33:19 a frequency derivation threshold of 1Hz/s was not reached (the one considered to be "a large incident"), while the generation to which the generator requirements regulation applies must support frequency derivative values of 2Hz/s.

On the other hand, as a reference, the generation must be able to stay in operation for an unlimited time above 48.5 Hz, and for a period of 30 minutes between 47.5 and 48.5 Hz. The configuration of the system's "frequency firewalls", i.e. the ballast protections, starts from

49.5Hz for pumping and between 49 and 48Hz for the six levels of ballast in the case of demand

According to the data provided by the system operator, on April 28 it was not until 12:33:20:180 that the first step of deballasting arrived, while until at least 12:33:22 the frequencies were within the limits at which the generators should be able to stay connected. In turn, as indicated above, significant surges are found in the 400kV network beyond 12:33:23, a scenario that would have continued to cause generation disconnections regardless of frequency. Therefore, it is highly likely that, in a scenario of greater inertia and therefore a slowdown in the frequency drop, the "surge wave" would have caused the "cascade effect" in any case, causing a significant part of the generation to fall and thus exceeding the

Responsiveness of underfrequency protections (see section on ballasts).

Reservation

According to the data provided by the system operator, the system also had a comfortable level of reserves. The reserve is the backup power margin that the system has to use at any time in case of excess or lack of power (the reserve is both "up" and "down"). There are different types of booking depending on the time needed for activation. The fastest (immediate) is the primary reserve, which is another dimension of inertia mentioned above, since the instantaneous frequency regulation given by synchronous machines is carried out by regulating the power injected into the grid.

In addition, there is secondary and tertiary reserve, which are activated in seconds or minutes, respectively. The reserve can be provided by generation, demand or storage, although the largest percentage is provided by generation. The type of reserve that each technology can provide depends on its speed of start-up and regulation and also on whether it is already working or is stopped and must start from cold.

In general, operating procedures require that reserves be sufficient to cope with the largest generation pool available in the system. In Spain, this volume corresponds to the largest nuclear group in the system, at around 1,000-1,100 MW. At that time, there was about 3,000MW of pumping consumption, which is the first consumption to be disconnected in the event of a power shortage (drop in frequency). As for the rolling reserve, the one that could be activated in approximately 15 minutes, the levels were also much higher than necessary. Specifically, the tertiary reserve to be raised just before the incident exceeded 7,000 MW and to be lowered it exceeded 5,000 MW.

Technical restrictions for April 28

In the programming of technical restrictions for April 28 carried out the previous day, there were 12 thermal generators coupled for the central hours of the day with a control obligation by setpoint (of which 10 were specifically programmed for dynamic voltage control, another programmed for another motivation and another for market entry). Specifically: 4 nuclear power plants

and 7 gas plants

As explained in the section on the characterisation of the system on 28 April, the programming of the thermal groups at each time of the day obeyed different safety objectives: static and dynamic voltage control, reserve for the ramps for raising and lowering demand, restrictions in the network due to overload in the case of N-1, etc.

After the group's failure on the afternoon of April 27, there was finally one less combined cycle in the southern zone. However, after the oscillation of 12:03, the system operator identified the need to control voltages and reinforce the damping in the southern area, so he requested the connection of a new group in this area, looking for the plant that could be coupled in the shortest possible time. As already indicated, the scheduled group was (which finally did not connect as it did not arrive on time before 12:33).

In order to characterise this circumstance, the system operator has been asked to clarify the reasons why, despite the fact that the group, declared unavailable on the afternoon of 27 April, was initially scheduled in the PDVP for 24 hours on 28 April, the real-time programming of the

that replaced him only covered the aforementioned 4 hours (until 9:00).

The System Operator argues that, in the analysis of April 27, the need to have generation with the capacity to regulate voltage in

, which justified the scheduling of being the group with the most competitive offer of technical restrictions.

After this plant was declared unavailable, the operator argues that the decision not to maintain the schedule due to technical restrictions in real time from 9:00 a.m. was based on the operating situation up to that moment and the forecast for the following hours, with adequate voltage levels and sufficient resources for voltage control in the area. Nor was its programming considered necessary for other needs (coverage of demand).

In response to situations similar to that of April 28 in terms of groups coupled in no problematic situations seem to be identified for the

operation and with correct voltage levels (days 31/03/2025, 01/04/2025 to 07/04/2025 or 27/04/2025). In any case, as a result of the circumstances described and the decisions taken by the system operator, the final number of thermal generators coupled at 12:30, just before the event, was 11, a figure that has not been recorded on any other day this year. Since January 1, 2025, there have been 12 thermal generators coupled in 13 days , exceeding that figure on the rest of the days.

This analysis does not include coupled hydroelectric generation, generally by market, and which can also contribute to tension control depending on its size.

Graph 49 Thermal groups coupled in the final daily programme (P48). Source: own elaboration

Voltage control of power plants obliged to regulate voltage

Specifically, as explained, at 12:30 there were 11 thermal power plants coupled with the obligation to regulate voltage by setpoint: 4 nuclear power plants

, 1 coal-fired power plant

and 6 gas plants

Groups that are programmed by technical constraints to control voltages receive remuneration for this, since the technical constraints are allocated through a competitive procedure based on marginal offers that allow service providers to recover their costs and, depending on the degree of competition in each market, to have a greater or lesser profit.

Based on the information received, there are discrepancies regarding the behaviour of different groups and facilities in relation to voltage management or reactive energy, in relation to the provisions of the applicable regulations14 .

14 P.O. 7.4 "Complementary voltage control service for the transmission network", Royal Decree 413/2014, of 6 June, which regulates the activity of electricity production from renewable energy sources, cogeneration and waste and Circular 3/2020, of 15 January, of the National Commission on Markets and Markets and

In the case of synchronous generation of more than 30MW, which is required to provide voltage control by setpoint in accordance with P.O. 7.4, the operator has reported insufficient absorption of reactive energy by practically all the coupled generators in one or more periods of the morning of April 28. In particular, according to data from the system operator, in the central and southern areas, where voltage increases were detected earlier, the generator sets

they would not have absorbed all the reactive energy necessary for adequate dynamic voltage control.

None of the agents has reported having detected or scheduled on April 28 a behavior of the thermal groups different from previous days or times.

However, it has been found, with the information provided by the generators, that in the minutes and hours prior to zero, with already high voltage levels (above 410-420kV) in the 400kV network, several of the coupled thermal generators did not respond as expected in this context: either they absorbed less reactive energy than expected by the system operator, not providing sufficient tension control or, in some cases, they generated reactive energy instead of absorbing it (thus contributing to worsening the overvoltage).

In particular, it has been found that the group connected in the southern area behaved visibly differently from other plants connected at that time:

What is to be expected, and what has been observed in the rest of the plants connected that day analysed, is that the absorption of reactive energy follows a pattern associated with the voltages in the grid (the higher the voltage, the greater the absorption of reactive energy). This shows, for example, the reactive energy curve with respect to the voltage curve in power plants.

In general, the higher the voltage, the greater the absorption of reactant.

Although, as already indicated, the operator reports that the absorption of reagent was not sufficient.

However, in the case of reactive absorption it does not seem to show any relationship with the tension profile. In other words, this plant shows a

the Competition, which establishes the methodology for the calculation of electricity transmission and distribution tolls

behaviour very different to the of the remainder of central plants analyzed, and inappropriate behavior for tension control.

Contribution to the voltage of other installations

The system operator has analysed the contribution to the voltage of other installations at 12:32, when the voltages begin to increase rapidly.

In the case of renewables, cogeneration and waste installations, in accordance with RD 413/2014, they must maintain a power factor between 0.98 capacitive and 0.98 inductive on an hourly basis. The system operator has analysed the 850 installations with the highest generation at that time. It has been reported that almost 22% of the installations analyzed did not meet the applicable power factor criterion. According to the operator's analysis, in nodes where compliance was not as expected, generation was relatively low (with a median of 11% with respect to installed power). Therefore, this non-compliance could be attributed, at least partially, to the capacitive effect of generation evacuation infrastructures, which are less discharged at times of low generation.

In the case of consumers, out of 141 supply points directly connected to the transmission grid, it has been detected that 20 did not comply with the power factor required by current regulations (P.O. 7.4 for those with more than 15 MW and Circular 3/2020- for the rest) or, where appropriate, by the requirements of the Demand Voltage Regulation (PDR) Demonstration Project.

In the case of the distribution networks, which are subject to the same requirements as the consumers of P.O. 7.4, out of a total of 283 border points between the transmission and distribution networks that must provide the service, the operator reports non-compliance in between 9.4% and 21.4% of the border points between the transmission and distribution networks.

Therefore, with the data of the system operator, it can be concluded that different installations contributed to increasing the voltage or, in any case, did not contribute to improving the situation in the proportion expected by the System Operator.

Common evacuation infrastructures

The deployment of renewable generation in Spain in the last 25 years has favoured the emergence of complex structures for the evacuation of clusters of

generation that are connected to a single point of the transmission network, in most cases.

For economic and environmental efficiency, in order to take advantage of electrical corridors and minimise the impact and costs, private networks of substations and collector lines have been developed in the shape of a "Christmas tree", from which several dozen plants belonging to different owners hang on occasion, which, through private agreements, built and/or use common infrastructures for evacuation (ICE).

Each of the plants may, in turn, be attached to its own generation control centre, while the common part may be managed by one of the generators, by a company owned by several, sometimes by an entity without legal personality (EIA) or even by a third party. The owner of the common evacuation infrastructure usually, in turn, subcontracts the operation and maintenance services of the assets to a third party, with these engineering companies being the ones that maneuver and control the protections and measures.

These complex ownership and governance structures make it difficult to analyse an event such as that of 28 April, as it is not easy to collect all the information (which, on occasions, has required the infrastructure manager to obtain the consent of all the partners), identify the owners of the infrastructure, ensure its coherence and comparability.

On some occasions, these companies have shown and/or acknowledged that they do not have the capacity to collect and analyse the requested data, requiring the hiring of third parties for these tasks and giving long response times.

One of the issues identified as relevant during the analysis is that generators connected "downstream" do not always have visibility or the ability to manage the conditions and operation of evacuation infrastructures. In relation to voltage, which has been a key variable in what happened on April 28, different generators have reported not knowing the data related to the measures and management of the evacuation infrastructures to which they are connected. The existence of transformers in the evacuation infrastructure, with their own transformation and independent management relationships, can generate additional challenges, as developed in the subsequent section on transformation relationships.

On the other hand, the evacuation infrastructures themselves have their own capacitive effects and therefore their own contribution to reactive energy and voltage control, which must be taken into account in their design and operation.

In any case, it is important to remember that the regulation is clear in establishing that the obligations and technical requirements of operation and connection are enforceable at the border point with the network.

Granularity of markets

In the interactions with the different agents, there has been a high level of consensus on the challenge posed by the advance of hourly markets towards quarter-hours / fifteen-minute markets. In this sense, since March 18, 2025, intraday market trading is quarter-hourly. That is, up to 4 different market results can occur in each hour, which can lead to changes in production schedules or links at each of these times.

This project began in 2020 with the aim of responding to the requirement of Regulation (EU) 2019/943 of the Parliament and of the Council, of 5 June 2019, which determines that NEMOs must offer market participants the opportunity to trade at intervals at least as short as the Imbalance Settlement Period (ISP). both in the day-ahead market and in the intraday markets.

This greater granularity of intraday markets, with price signals every 15 minutes, together with the development of an increasingly distributed generation mix that is more responsive to price signals, means that changes in energy flows are increasingly frequent, more abrupt and potentially of greater magnitude. which poses a growing challenge for the stabilization of tensions.

Likewise, the fact that, with the current regulation, part of this generation is subject to a power factor instead of dynamic voltage control, means that the ups and downs of this generation cause, in turn, rises and falls in the absorption of reactive energy, contributing to these voltage variations.

The relevance of sudden changes in the program lies in the almost instantaneous reaction capacity of technologies connected to the network by means of electronics

of power to price signals or slogans, as well as the fact that so far these technologies are subject – by regulation – to a fixed power factor. A sudden upward or downward variation in production (for example, due to price changes) therefore entails a sudden downward or upward contribution to voltages, since the absorption of reactive energy by these installations is configured to be directly linked to energy production. As an additional factor, changes in production in facilities involve changes in the loads of the associated lines (and, with it, changes in their behaviour with respect to reactive energy and therefore in voltages).

As has been pointed out, it is expected that the daily market will soon also be traded on a quarter-hourly basis (matching every 15 minutes, instead of every hour). The start of the daily quarter-hour market was scheduled for June 11, 2025, having recently been delayed to October 1, 2025[15]. When the daily market is fourth hourly, the magnitude of the variations of programs every 15 minutes will potentially be greater, since the daily market is the one that mobilizes the most energy.

Transformation ratio and rate of voltage variation

One of the questions that has arisen during the analysis of the behaviour of voltages is how the speed of voltage changes in the transmission network, and not so much the absolute values reached, can have undesirable effects on other parts of the system: distribution, generation and demand networks.

Because the voltages of the transmission network (400 kV and 220 kV) are higher voltages than those of the operation of the distribution network or those of the injection of generation or connection of consumption, it is necessary to install voltage transformers between one element and the other. These machines not only raise or reduce voltage, but also serve to regulate and maintain adequate voltage levels, absorbing and modulating variations that may occur in the transmission network.

The operating procedures establish maximum and minimum values between which the network must be operated, but does not currently incorporate any quantitative limitation to

15 Decision of the Market Coupling Steering Committee of 14 May 2025, on the grounds that some market operators have not demonstrated that they are technically ready for start-up by the scheduled date of 11 June 2025

the variation/derivative of the voltage beyond a general principle that the non-existence of a condition of voltage instability that could lead to a situation of voltage collapse must be guaranteed, in all cases. This requirement may be more restrictive, in certain cases, than the condition of maintaining tension.

Due to the fact that voltages can fluctuate on one side or the other of the transformer, transformers that reduce the voltage of the energy from the transmission network to the different levels of the distribution network and to the consumers, usually have different "sockets" that allow the voltage relationship between one side and the other to be adjusted around the nominal ratio. Therefore, depending on the configuration at any given time of these transformers, it is possible that a "correct" voltage (within the limits set by the regulations) in the transmission network is perceived as an overvoltage on the distribution side, or for generators connected to an ECI.

In the case of generators, it should be clarified that the obligations refer to the conditions in the transmission network. Therefore, data compatible with an inadequate configuration of the transformation relationship between the grid and generation or distribution are identified, which may be one of the factors that may have contributed to the generation drops, both in distribution and transmission. In turn, this can be contextualized by an excess in the voltage variation rate: starting from correct transformation ratios in a context of low or moderate voltage, a sufficiently fast voltage rise in the transmission network, even if it always remains within parameters, can lead to an overvoltage on the other side of the transformer, if it has not been adjusted quickly enough to the new conditions.

However, as indicated above, it should be noted that the operating procedures do not currently establish limitations on the rate of voltage variation.

Correlation with coupled synchronous power and with photovoltaic generation

A company consulted has studied the correlation between the volatility of voltages in the grid, the probability of observing extreme voltage events and the amount of asynchronous generation (photovoltaic) and synchronous generation (with control

voltage per setpoint) coupled. It has carried out the same analysis for the weeks prior to 28 April and for those after 28 April, in which the system operator has been applying a "reinforced mode of operation", which consists, in essence, of greater programming of generators with voltage control capacity as well as "smoothed" ramps for raising and lowering photovoltaic installations (which, Thanks to the power electronics, they have the ability to switch large amounts of generation on and off in instants).

The results of the analysis show that there is a certain correlation between the stability of the voltages and the amount of solar generation or the amount of synchronous coupled generation, although this correlation is not equally strong in all the observed nodes.

In fact, in most of the grid nodes analysed, there is no correlation between the stability of the voltages and the amount of solar generation or the amount of synchronous generation coupled. For example, there is also a high probability of episodes of unstable voltages with little photovoltaic generation or with a lot of synchronous coupled generation. However, their analyses indicate that there is a much more determining factor in the stability of the tensions: the fact that the analyses are carried out in the system before or after April 28.

Thus, since the application of the reinforced operation mode, the voltages show a clearly more stable behavior, with less variability and probability of occurrence of extreme events for the same level of photovoltaic generation or coupled synchronous generation. In other words, isolating the effect of more or less photovoltaic generation or greater or lesser power with the obligation to control coupled voltage, the fact of whether the data analysed was before or after 28 April was more decisive.

Therefore, it follows that there is a different behavior in the system since April 28 that is not explained exclusively by a greater or lesser coupled synchronous power.

In the absence of unidentified changes in other variables that could affect tension control, this greater stability observed after the incident would be compatible with smoother ramps, and/or with a change in the behavior of the

generation, demand and distribution in terms of their contribution to voltage control and therefore with the thesis that, on the day of the incident, it was inadequate or insufficient.

Episodes prior to April 28

Some agents have referred to previous episodes of instability in tensions this year, citing January 31, March 19 and April 22 and 24 and related the previous situation of the 28th with that of these precedents, particularly with that of April 22.

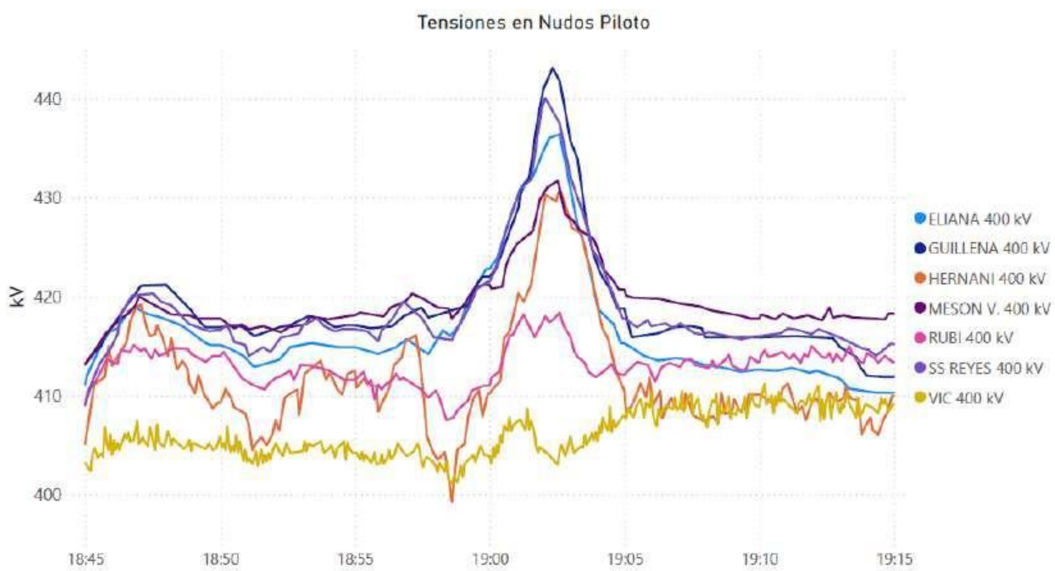
In both incidents, on 22 and 24 April, the system was able to correct the voltage deviation with the resources available in the system, with no major repercussions other than those indicated. However, given the relevance that has been given to the events of April 22 and 24 in several of the contributions received, we proceed to analyze these situations below, in order to extract similarities and differences with respect to April 28.

April 22, 2025 Episode

On April 22, at 7:00 p.m., there was an episode of surges in the transmission network that caused the disconnection of more than one

some generation evacuation substations

and large industrial consumption



Graph 50 400kV grid voltages during the April 22 incident. Source: REE

After noticing the impacts of this event, the Ministry for the Ecological Transition and the Demographic Challenge asked the System Operator to report on what happened. This report is received on April 28 shortly before 11 a.m.

The explanation given by REE about the episode is that a combination of causes that, although in isolation, are relatively frequent in the operation, in the situation of April 22, coincided simultaneously:

The change of the 1,650 MW exchange program with Portugal, which has a very important impact on flows throughout the peninsula.

The gradient of the decrease in photovoltaic production by solar radiation, which is typically 500 MW/min at those moments. This reduction was accelerated by the fact that 750 MW were assigned in the balancing services to be lowered for that quarter of an hour.

Significant network outages in the central area. This causes the transport to focus on a few lines that go from being highly loaded consuming reactive, to being discharged in just one minute, behaving like capacitors.

The state of the interconnection with France, with an unavailable line and with the maximum export program. Transport was centralised from Portugal to France through a weakened central area.

The reduced conventional generation, thermal and hydraulic, coupled in the system. Currently, this is the only technology that provides continuous voltage regulation. Most of these generators had been coupled by technical constraints for continuous voltage control.

Wind and photovoltaic generation accounted for 59.21% of the generation connected to the system and, since their participation in voltage control is currently based on power factor monitoring, they did not help to hold the voltage profile.

REE also states that the situation on the 22nd would have been different if this renewable generation (photovoltaic and wind) controlled the voltage, thus helping to keep the voltage stable in real time and avoiding the coupling of thermal groups due to restrictions.

In a public communication, REE indicated that the 22nd could not be correlated as an isolated and exceptional event with the energy zero that occurred on April 28.

The GTOSE has made a request to report on the behaviour of its demand facilities connected to the transmission grid on 22 April. Confirms that surges compatible with the disconnection of the equipment were recorded according to the configuration of the protections.

Regarding the behaviour of thermal generation on 22 April, and according to the information provided by the plant owners, all the groups analysed reacted in such a way that, as the voltages rose around 7 pm, their reactive absorption increased.

In fact, in the case of the plant, it came to absorb almost   of reactive energy, more than 3 times more than the maximum absorbed at minute 12:32 on April 28, so it is concluded that this plant does have the technical capacity to reach levels of reactive absorption higher than those it showed at the key moments of April 28.

April 24, 2025 Episode

The case of April 24 was the opposite: REE has reported that it was a phenomenon of a drop in voltages in the system between 6:00 p.m. and 6:03 p.m., which had no consequences either in generation facilities or in consumption.

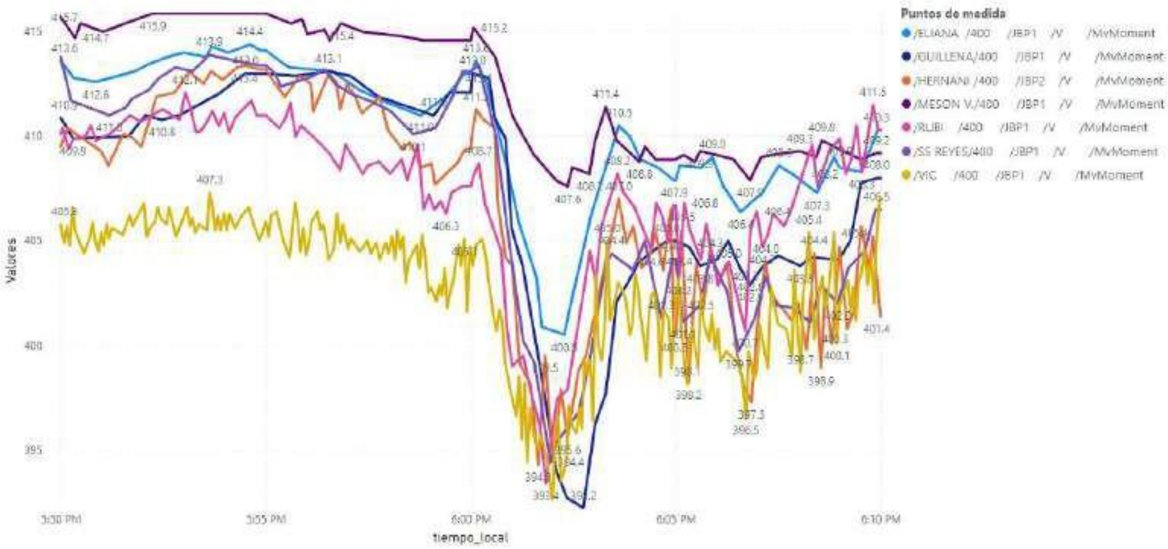


Figure 51 400kV grid voltages during the April 24 incident. Source: REE

In relation to this episode and as can be seen from the data analysed, REE has reported that it was a phenomenon of a drop in voltages in the system between 18:00 and 18:03, which had no consequences either in generation facilities or in consumption and that it was caused by two factors:

An increase in the export exchange to France of 1,220 MW, coinciding with a change of exchange program at 18:00 for a further 1,675 MW of exports.

An increase in measured solar PV generation of approximately 900 MW, although the schedule change at 18:00 was only 340 MW.

Both causes (increase in exports to France and increase in photovoltaic production), as well as a moderate increase in demand (approximately 300 MW) imply an increase in flows through the transmission lines from southwest to northeast that causes a greater consumption of reactive energy and a sudden drop in voltage throughout the Spanish peninsular electricity system. as reflected in the values measured at the main pilot nodes of the transmission network.

Analysing again the behaviour of different coupled thermal generators, it is generally verified that at the moment of undervoltage at around 6 p.m., most of the generators analysed respond by reducing their absorption of reactive energy (or by generating reactive energy), as would be expected (again, the analysis has focused on the qualitative behaviour, therefore, no conclusions are made here about the level of compliance with OP 7.4). However, in this case it is seen in a "flat" reactive energy behavior, that is, from which no clear response to the evolution of tensions is perceived.

The GTOSE has made a specific request to REE to analyse the similarities and differences between the events of the 22nd and 24th and the 28th. In its response, REE analyses the following parameters:

Time of the incidents: the incidents of the 22nd and 24th occurred around minute 00 coinciding with a time change, which is compatible with a change in the schedules by market. The incident on the 28th occurred in the 33rd minute not coinciding with a change in the programming period.

Changes in international exchange programs: the events of the 22nd and 24th were related to changes in international programs in minute 00 with values greater than 1,400 MW of change in the set of all interconnections. On the 28th, the program changes at minute 12:30 were less than 700 MW in the set of all interconnections.

Changes in renewable generation (RCR) programmes: the incidents on the 22nd and 28th implied downward changes in the RCR energy programme between the fourth-hour programming periods, although the events occur at times other than the fourth-hour period: minute 1 on the 22nd and minute 3 on the day

28. The event of the 24th was related to an increase in the RCR program in the change of programming period due in part to the change from zero or negative prices to positive prices in the daily, intraday and balance markets.

Generation disconnections: Generation disconnections occur on the 22nd and 28th. On the 24th, no disconnections were recorded.

Profile of peninsular tensions: on the 22nd and 28th there were profiles of rising tensions. Geographically, the highest tensions were located in the areas

Center and Southwest. On the 24th, a profile of downward tensions was recorded during the event.

PHASE 4. REPLENISHMENT OF SUPPLY

The process of replacing the system has been recognized nationally and internationally for its agility.

However, elements have been identified that could have contributed to an even faster replacement, thus reducing the impact of the peninsular zero of last April 28.

Incidents detected in the start-up of the equipment

Firstly, there is information consistent with the fact that several installations with an autonomous start-up obligation were finally unable to provide this service in a stable way, joining the system only once voltage had arrived from the outside (from another of the "islands", normally anchored in one of the interconnections). This slowed down the start-up of the "skeleton" of the electricity system that would later allow supply to be restored to demand.

Incidents identified in distribution

Secondly, several distribution companies have reported the impossibility of acting by remote control in several of their substations, even once they had recovered voltage and had authorisation to supply new load. This forced the displacement of equipment to the substations, increasing the time until full replacement

According to the information received, it is found that the process and pace of replacement varied according to geographical location. As indicated above, in order to restore supply, it is necessary not only that the corresponding location in the transmission network recovers voltage, but that sufficient generation is available to balance the demand in the "steps" in which it is going to be incorporated.

In this sense, divergences have been found depending on the characteristics of the network and the territory: areas with greater geographical dispersion have a greater number of substations, more separated from each other, to be recovered, for the same demand.

On the other hand, differences have been found in the operation of the systems in the distribution networks.

Remote control systems. Under normal conditions, high-voltage substations are operable by remote control (i.e. actions can be carried out remotely from the corresponding control centres). However, several distribution companies have reported the impossibility of replenishing the load remotely in some cases, forcing manual actions (moving personnel to the substations to carry out the actions in situ) and thus slowing down the recovery of supply.

Telecommunications difficulty. In addition to the above, the agents have identified difficulties in telecommunications, both between the control centers and the displaced teams, and, in some cases, between the control center of the System Operator and the distribution control centers. These difficulties, which could eventually be remedied, contributed to delays in the replacement.

ANALYSIS OF DIGITAL SYSTEMS

The primary objective is cybersecurity supervision to obtain and analyse context information and that recorded in the entity's systems in order to identify possible indications and evidence that could point to a cyberattack or cyberincident as the cause of the event that affected the Spanish electricity system on 28 April 2025.

The analysis refers to the aforementioned date and the previous days, with a time frame limit of 7 previous days, taking as a reference 12:33 on April 28, 2025. For prioritization, the following temporal parameters are established for criticality for the analysis:

Priority 1. Events, performances, or evaluations dated April 28, 2025 at 12:33 p.m. and the previous 15 minutes.

Priority 2. The hours prior to April 28 not contemplated in priority point 1.

Priority 3. On April 27.

Priority 4. The previous days.

Focusing the analysis on determining whether a cyberattack is the potential cause of the event that affected the electricity system on the aforementioned date, the following specific objectives are established:

Analysis of possible unauthorized access to control centers.

Evaluation of indications such as lateral movements, compatible with unauthorized third-party activity.

Evaluation of potential harmful code existing in the system or indications of them.

Identification of unauthorized alterations.

System outages caused by actions related to denials of service or that cannot be explained by the entity responsible for the service.

Exploitation or attempted exploitation of vulnerability, whether successful or not.

Uncontrolled sending of digital signals or commands that may affect the functionality of other systems.

Others that may be related to indications of activity not controlled by the entity or outside its security operating procedures.

The secondary objective is the identification of potential security risks, which represents an opportunity for improvement by the entity, to provide systems and processes with better resilience and/or capacity to identify possible cyber incidents.

In relation to the primary objective, on cybersecurity supervision to obtain and analyze context information and that recorded in the systems of the

In order to identify possible indications and evidence that could point to a cyberattack as the cause of the event that affected the Iberian electricity system on April 28, 2025, it is indicated that:

After analysing the reports, events, documentation, information and data both provided and extracted from the entities' systems, as well as interviews with the entities' staff, no incidents, indications or evidence have been detected that suggest a cybersecurity event that could be directly related to the energy crisis of 28 April. Nor have any patterns been detected, nor have any known TTPs, nor relevant actors or threats been detected.

No lateral movements have been detected between IT and OT networks.

Other types of events such as unauthorized access to systems and networks or privilege escalations have also not been detected.

In relation to the secondary objective aimed at identifying potential security risks, which represents an opportunity for improvement by the entity, to provide systems and processes with better resilience and/or capacity to identify possible cyber incidents, it is noted that the analyses carried out have made it possible to identify other risks such as vulnerabilities, deficiencies or misconfiguration of security measures, which expose networks and systems to potential risks for which controls and security measures should be applied, in order to eliminate them, mitigate them and bring them to acceptable levels of risk.

It should be noted that this is relatively common in networks and information systems in any other sector.

The following are the potential general security risks identified during the analyses carried out:

There are assets within the analyzed systems of some of the entities that present vulnerabilities of different kinds, but with the information analyzed, there are no indications or evidence that indicate that these vulnerabilities have been exploited.

There are some systems in which authentication should be strengthened. However, after analyzing the logs of the systems, no unauthorized access has been detected.

In some cases there is no system for centralizing activity records (logs). In other cases, the system does not have the ingestion of all the records that would be desirable.

Some of the infrastructures analysed do not have sufficiently segregated IT and OT infrastructures and networks.

It has been detected that in some systems the security policies applied to users must be reinforced.

In some entities, it has been observed that vulnerability management does not carry out continuous cycles or assessments. This fact is more critical the higher the level of exposure of the assets, especially those exposed directly to the Internet, which require frequent analysis and updating processes.

Conclusions

Conclusions from the digital sphere

Based on the analyses carried out and the findings found, and taking into account the scope and scope of this analysis, as well as the limitations set out in this document, it can be determined that no indications or evidence have been found that point to a cyberattack or cyberincident, in the entities analysed, that could be the cause of the energy crisis of 28 April 2025.

No indications or evidence of harmful activity have been found in any of the activity logs.

No signs of harmful code activity or hacking tools have been found in the protection systems of the Control Centers analyzed.

Systems that have network traffic evaluation probes have not observed records that are compatible with unauthorized activity, such as

lateral movements, network crawls or file movements for the exploitation of vulnerabilities or the escalation of privileges, among others.

However, and as is common in networks and information systems in any sector, other risks have been identified, such as vulnerabilities, shortcomings or inadequate configurations of security measures, which can expose networks and systems to potential risks, for which a series of measures are proposed.

The following are the potential general security risks identified during the analyses carried out:

There are assets within the analyzed systems of some of the entities that present vulnerabilities of different kinds, but with the information analyzed, there are no indications or evidence that indicate that these vulnerabilities have been exploited.

There are some systems in which authentication should be strengthened. However, after analyzing the logs of the systems, no unauthorized access has been detected.

In some cases there is no system for centralizing activity records (logs). In other cases, the system does not have the ingestion of all the records that would be desirable.

Some of the infrastructures analysed do not have sufficiently segregated IT and OT infrastructures and networks.

It has been detected that in some systems the security policies applied to users must be reinforced.

In some entities, it has been observed that vulnerability management does not carry out continuous cycles or assessments. This fact is more critical the higher the level of exposure of the assets, especially those exposed directly to the Internet, which require frequent analysis and updating processes.

Conclusions from the electricity sector

The information analyzed, as well as the contrast of this with the contributions and iterations maintained with the different agents, allow us to conclude that the electricity zero of April 28 had a multifactorial origin.

The ultimate cause of the peninsular electricity zero on April 28 was a phenomenon of overvoltages in the form of a "chain reaction" in which high voltages cause generation disconnections, which in turn causes new increases in voltage and with it new disconnections, and so on. This phenomenon was preceded by variations in voltage of great amplitude in short periods of time throughout the morning. Several factors contributed to this phenomenon:

The system showed insufficient dynamic voltage control capabilities sufficient to keep the voltage stable. The data compatible with this factor are:

The number of coupled generators with voltage control capacity was lower than those programmed by the system operator in previous weeks and months, and lower than that programmed the day before as one of the planned generators had failed on the afternoon of 27 April and had not been replaced by the system operator.

Specifically, taking into account the zonal nature of the tension, the group

declared unavailable the previous afternoon it was located in the southern area of the peninsula, having registered in this area the phenomenon of overvoltages with greater intensity. In this area, there was a group with coupled voltage control which, in addition, corresponds to the one that showed a different behavior in terms of voltage control than the other coupled groups and than the same group on previous occasions.

After the oscillations suffered, the system operator programmed an additional group in the area for voltage control, which did not arrive in time to couple before the system collapsed as it needed 1h30 to start.

The generation that was connected with the ability to control voltage – and specifically rewarded for it by being programmed by technical constraints – may not have adjusted to the set parameters.

The totality of the generation connected with the capacity to regulate voltage would not have provided all the contribution expected by the system operator, absorbing less reactive than it expected in times of high voltage.

In particular, the group connected in the southern area stands out for having acted, in terms of voltage control, in a visibly different way from the rest of the connected groups, and even differently from the behaviour of that same group in the episode of overvoltage of

when he did respond as expected.

In addition, a proportion of distribution networks (at the border point with the transmission network), consumers connected to the transmission grid and generators subject to the power factor may not have responded according to the power factor, which, in turn, could have contributed to the context of overvoltages.

A series of rhythmic oscillations significantly conditioned the system, modifying its configuration and increasing the difficulties for tension stabilization.

The characteristics of the first great oscillation (12:03) indicate that it is a phenomenon generated within the Iberian Peninsula. It is an atypical oscillation, with a frequency of 0.6 Hz, and its origin has been correlated with the operation of an installation. In addition, the system operator has identified atypical behaviour in a park installation

The second oscillation (12:19) has more common characteristics and a lower frequency (0.2 Hz). On both occasions, it was detected that shortly after an oscillation appears at 0.6 Hz, the oscillation mode appears or is magnified at 0.2 Hz.

Some of the measures necessary to cushion and protect the system against oscillations, provided for in the protocols between system operators (increasing grid meshing, reducing exports in the interconnection) contribute to the rise in voltages and involved a different configuration of the system than expected at the beginning of the day.

Generation disconnections occurred that led to a system already weakened with respect to voltage control to a situation of generalized overvoltage.

Some of these disconnections may not have been adjusted (ahead of time or at a voltage level at which installations should not be disconnected).

The disconnection of generation contributed to an increase in voltages, propagating overvoltage conditions and helping to start the "chain reaction" by disconnecting, in turn, new generation due to overvoltage.

The disconnection of large-scale generation due to overvoltage led to a drop in the frequency of the system, which in turn subsequently caused the disconnection of some sub-frequency generation groups.

Once the "chain reaction" of overvoltage disconnections has begun, the so-called phase 2, its containment or arrest would have required the ability to regulate downward voltages of a magnitude greater than the upward effect on the voltages of this chain reaction. Something that, as has already been indicated, was missing from the system.

The instruments available to the system to respond automatically to the loss of generation were not effective not because they were insufficient, but because they did not correspond to the current phenomenon:

The inertia available in the system allows the frequency drop to be slowed down in the event of generation drops. However, on the one hand, the information indicates that neither underfrequency levels nor derivatives of frequency drop were reached on 28A until very late in the generation disconnection due to overvoltages. In fact, significant surges are found beyond 12:33:23, near the end of the event, which would have continued to cause generation disconnections regardless of frequency. Therefore, even in a scenario of greater inertia and therefore of slowing down the frequency drop, the conditions of overvoltage in cascade effect would have caused generation disconnections in any case.

The disconnection of demand (deballasts) that aim to balance generation and demand after the disconnection of generation, in a context of low demand, could even contribute to the phenomenon of overvoltage by discharging the power lines even more, increasing the contribution of reactive energy.

Once the chain reaction and the fall in generation began, the interconnection with France went from export to import, providing active power to compensate for the loss of generation, up to the maximum of its physical capacity. The contribution of the interconnection was less than it could have been since the HVDC link was programmed in the export direction as a buffer measure against oscillations. However, due to the nature of the phenomenon and the technical and operational characteristics, and in a similar sense to the reference on inertia, if this had not been the case, the fall in generation due to subfrequency would have been slowed down, so it is not likely that it would have avoided the total collapse and disconnection of the continental system due to loss of synchronism in a context in which voltages were in ranges Compatible with mass generation disconnection.

Proposed measures

1. Measures proposed by the GTCSD

A series of recommendations are then sent, which would make it possible to strengthen the security of the energy sector, electricity subsector. These recommendations are both general and more specific depending on the type of entity.

It should be noted that the risks detected are common in all types of sectors, being more frequent in small or medium-sized entities that, as a general rule, have a lower degree of maturity in cybersecurity and can dedicate fewer resources to this purpose.

One of the particularities of the energy sector, electricity subsector, is the number of small and medium-sized enterprises that make it up (such as control centres and, above all, generation centres), so it is advisable to extend the current scope of cybersecurity regulations to smaller entities, in line with the provisions of Directive (EU) 2022/2555 on measures to ensure a high common level of cybersecurity in the whole of the Union (NIS 2), which, precisely, has under its scope of application entities of equal or greater size than medium-sized companies and even allows the Member State to identify and declare them under its umbrella, based on risk, small companies.

In order to have a legislative framework that covers a greater number of entities and that allows them to strengthen cybersecurity and their resilience, it is recommended:

Accelerate the transposition of the NIS 2 and CER Directives.

On the other hand, at the sectoral level, last year the Implementation of Commission Delegated Regulation (EU) 2024/1366 of 11 March 2024 supplementing Regulation (EU) 2019/943 of the European Parliament and of the Council by establishing a network code on sectoral rules specific to the cybersecurity aspects of cross-border electricity flows was approved. including rules on common minimum requirements, planning, monitoring, reporting and crisis management.

Delegated Regulation (EU) 2024/1366 obliges each country to catalogue infrastructures whose unavailability would compromise international trade, distinguishing between high impact (≥ 1 000 MW) and critical impact (≥ 3 000 MW).

The entities that make up the list have 24 months to implement a cybersecurity management system and the minimum or advanced controls set by the EU, compatible with standards such as ISO 27001 or IEC 62443.

In addition, they must immediately report any cyber incident to the national authority and, if there is a cross-border impact, coordinate the notification with operators and regulators in the affected countries, thus ensuring that a local attack does not trigger cascading blackouts.

To strengthen their cybersecurity, it is recommended that entities under the framework of this Delegated Regulation (EU) 2024/1366 adopt the measures and aspects contained therein.

With regard to the private sector in general, INCIBE, through INCIBE - CERT as the national CSIRT of Reference in Spain for citizens and private law entities, works to strengthen the cybersecurity capacities of companies and professionals, including strategic operators in this electricity sector.

To this end, the following initiatives or services are made available to these entities that allow them to increase the cyber resilience that is so necessary in this sector.

Support for cybersecurity incidents or crises, where help and technical support is offered to these entities to help in the resolution of their cybersecurity incidents within their scope of action.

In the event of incidents, they can notify and request support through incidencias@incibe-cert.es or if it is an essential operator or critical infrastructure

Digital surveillance services in cybersecurity focused on the detection of any cybersecurity event related to digital threats, cyberrisks or cyberattacks that it analyzes and, if necessary, notifies the different bodies or entities affected so that they can be prevented and protected with the corresponding security measures that should be applied.

Cyber threat information sharing services: through which information on cyberthreats of interest is shared (analysis, indicators of compromise (IOCs), other detection mechanisms and rules, etc.), so that the use of such information allows for the expansion of the detection and protection capabilities of entities

Early warning services: where warnings and notifications are prepared with the aim of quickly informing about the latest cybersecurity threats and anticipating the application of measures.

Carrying out cyber exercises in cybersecurity (CyberEx Spain): which allow these entities to train and evaluate in a practical way their capacity to respond to circumstances that could arise when suffering a cybersecurity incident, and thus increase their defense and resilience capabilities against attacks or situations of imminent risk.

Measurement and improvement of cyber resilience to help these companies in the sector diagnose and measure their capacity to withstand and overcome disasters and disruptions from the digital sphere and to know their level of cyber resilience and its evolution with respect to their sector.

Knowledge and awareness. Recognising the role of disclosure as a basis for the generation of a culture of cybersecurity, INCIBE-CERT's experience in threat investigation and incident management is the optimal ecosystem for the analysis and development of specific advanced information and content to improve the protection of organisations. This content facilitates prevention and reaction to risk situations and takes the form of awareness kits, security advisories, guides, blogs and best practices, among others, which aim to raise awareness of cybersecurity and thus help to respond to and prevent cyberattacks.

Free of charge and confidentially, INCIBE offers advice, support and help in the event of any questions or incidents that may arise through the 017 cybersecurity helpline, available every day of the year from 8 a.m. to 11 p.m.

Proposals for entities and companies

In general, the risks identified could be mitigated by applying a series of measures detailed below, taking as a reference those indicated in the National Security Scheme (RD 311/2022, of 3 May), the ISO 27001 standard and the Directive of the European Parliament and of the Council 2022/2555 NIS 2.

Risk management and continuity:

Carry out periodic risk analyses and implement controls proportional to the identified threats, reviewing them after incidents or technological changes. Have business continuity and disaster recovery plans that cover both corporate IT systems and OT (operational) systems.

- With regard to industrial control systems, it would be advisable to apply the updates according to what has been established by the manufacturers and to deploy solutions with current support. Taking into account the National Security Scheme, maintenance measures and security updates should be applied. Where a series of measures and reinforcement are established to meet the specifications of the manufacturers and the continuous monitoring of defect announcements.

The NIS 2 directive also includes the need for cyber-hygiene practices such as zero trust principles, software updates, device configuration, network segmentation, identity and access management or user awareness, and training for its staff and raising awareness of cyber threats, the illegitimate capture of confidential data or social engineering techniques. In addition, those entities should assess their own cybersecurity capabilities and, where appropriate, ensure the integration of cybersecurity enhancement technologies, such as artificial intelligence or machine learning systems, to strengthen their capabilities and the security of network and information systems.

Strengthen access control

Apply the principle of least possible privilege. Strictly control accounts with privileges over SCADA/OT systems, implementing audit logs of their activities.

It is highly recommended to use a second authentication factor in all remote accesses, both to corporate and third-party services provided through cloud solutions. The National Security Scheme in the measures on authentication mechanisms for both external users and the entity, establishes the need to use another authentication factor in addition to the password in those exposure scenarios.

Article 21 of NIS 2 on measures for the management of cybersecurity risks explicitly includes the use of multi-factor authentication or continuous authentication solutions, secure voice, video and text communications, and secure emergency communications systems in the entity, where appropriate.

Two-factor authentication elements such as certificates, OTP (One-Time Password) elements or others based on biometrics may be applied, taking into account the additional security measures that these systems must have in place.

It's important to set strict access policies and review who has admin permissions.

Default credentials must be changed. Enforce multi-factor authentication.

Use strong, unique passwords per device. Disable unnecessary services.

Close unused ports. Activate access logs and audits. Active monitoring

Strengthen detection, prevention and response systems.

It is recommended to use SIEM (Security Information and Event Management) with SCADA log integration.

The collection and centralization of activity and/or security logs/events in SIEM-type solutions is recommended to allow their correlation and analysis in bulk.

Similarly, a sufficiently long retention period is recommended (2 years would be ideal) to allow for investigations with sufficient depth in the event of a cybersecurity incident.

The National Security Scheme includes the activity register as an essential element to guarantee adequate compliance with the traceability dimension. Only through consolidated systems of records management and their correlation will the organization be able to identify and react early to a harmful action.

Likewise, the NIS 2 Directive, international standards and schemes include traceability and event management as one of the fundamental elements to guarantee the ability of an entity to identify and react appropriately to cyberattacks.

It is advisable to implement global solutions with the ingestion of those activity records that are most significant for the purpose of the entity: protection solutions against harmful code, authentication, perimeter protection or SCADA system events, among others, are important logs to consolidate.

Segregation of environments and networks

Given the importance of network segregation, in order to prevent impacts of one system from causing repercussions on the other (mainly from the IT to OT environment), the segregation of the environments is recommended.

The risk assessment through an analysis of these will probably determine that the risks, more common in IT environments and the lower ability to apply security measures in OT environments, will require the application of compensatory measures.

The segregation of environments or the establishment of devices such as diodes or gateways and the use of appropriate operational safety procedures will ensure isolation and safety of the environments, each of them taking into account the risks according to its nature.

In cases where communication between the two worlds is necessary, industrial firewalls and demilitarized zones (DMZs) must be used to filter and control that traffic.

Strengthen perimeter security and network segmentation (IT/OT). Use DMZ for Human-Machine Interfaces or data servers.

It uses secure, efficient, and interoperable communication standards between devices, systems, and applications in industrial environments, with TLS encryption and mutual authentication.

Isolate protocols in dedicated virtual private networks (VLANs) or encrypted VPN tunnels.

Protection and detection:

Implement a "lines of defense in depth" strategy with perimeter protection solutions, up-to-date antivirus/EDR, intrusion detection systems (IDS/IPS) specialized in industrial environments, and continuous monitoring of critical networks to detect anomalous activity in real time. Keep all systems up to date on security updates, prioritizing those that fix actively exploited vulnerabilities or that affect legacy industrial equipment.

Incident Response Capabilities:

Have a Cyber Incident Response Plan (involving operations and physical security). This plan should include procedures for rapid isolation of compromised systems, internal and external communication (e.g., how to notify authorities and customers in the event of outages), and staggered service recovery.

Conduct periodic drills and exercises (e.g. network team exercises) to train staff and polish coordination between IT, OT and crisis management teams.

Ensure the availability of the organization's key personnel; Identify the means to provide emergency support to respond to an incident.

Awareness and training:

It is advisable to facilitate that employees receive training in secure practices (e.g., recognize targeted phishing attempts, protocol for alerts in systems of

control, etc.). Foster a culture where anomalies or errors are immediately reported, so they can be investigated before they escalate.

Admin Users

Strengthen the security measures applicable to these administrator users.

In this sense, the CCN-STIC guides of the National Cryptologic Center or the good practices of the manufacturers, establish additional measures for application in privileged users. Tightening the credential policy, limiting the use of credentials by preventing Internet browsing or increasing the processes of warning privileged use of rights are some of the measures that can be implemented. Likewise, create differentiated accounts according to roles, so that a privileged user also has a standard account, to differentiate operations.

Do regular security reviews

In general, it is recommended that entities carry out periodic vulnerability assessments in order to determine possible risks in infrastructures, as well as management of the corrections carried out to the vulnerabilities identified.

Article 8 of the National Security Scheme itself includes as a fundamental principle the actions related to the aspects of prevention, detection and response, in order to minimize the vulnerabilities of a system and ensure that threats to it do not materialize or, in the event of doing so, do not seriously affect the information it handles or the services it provides.

Also in its article 10 on continuous surveillance and periodic re-evaluation will allow the permanent evaluation of the state of the security of assets and measure their evolution, detecting vulnerabilities and identifying configuration deficiencies.

Article 21 of the European NIS 2 Directive includes in point e) security in the acquisition, development and maintenance of network and information systems, including the management and disclosure of vulnerabilities.

The implementation of an automated solution for vulnerability analysis in a white box and the performance of Pentest or Red Team exercises from time to time, will allow the entity to have a greater capacity to understand its weaknesses and apply direct protection measures, such as the application of updates, or when

it is not feasible due to uncontrollable issues, such as the lack of functionality in an OT-type system, to use appropriate compensatory measures.

It is essential to apply the security patches published by manufacturers.

The people who operate the systems need to be aware of good security practices, know how to identify suspicious behavior, and understand how to act in the event of an incident.

Perform SCADA pentesting in controlled environments

Train staff in social engineering, phishing and OT best practices. Backing up and restoring systems

Perform regular backups, as well as restore and recovery tests. Ideally, these backups should be physically disconnected and protected.

Actively participate in public-private collaborations specialized in cybersecurity.

NIS 2 (consolidating 55), like its predecessor, has reiterated to Member States the importance of promoting policies that support the creation of specific public-private partnerships in cybersecurity. ENISA has been promoting this type of entity since 2009.

An example would be participation in ISACs (Information Sharing and Analysis Centers) in strategic sectors. ISACs are public-private partnerships that facilitate the sharing of cyber threat intelligence and collaboration among their members to improve cybersecurity.

FOR CRITICAL INFRASTRUCTURES/OPERATORS OF ESSENTIAL SERVICES

Electricity companies declared Critical Operators (Law 8/2011) are also automatically classified as Essential Services Operators (OSE) for the purposes of RDL 12/2018; which are subject to a double regime of compliance with obligations:

AS CRITICAL OPERATORS

Under the supervision of the Secretary of State for Security, as the competent authority exercising through the National Centre for Critical Infrastructures (CNPIC):

Develop an Operator Security Plan and, for each critical infrastructure, a Specific Protection Plan with a continuous risk-adjusted information security management system.

Appoint a person responsible for Security and Liaison with the CNPIC.

Appoint Safety Delegates at each critical facility and facilitate inspections.

The technical and organisational measures implemented are reviewed by means of external audits, at least every two years.

Promptly report relevant incidents.

Communicate without delay the incidents that disturb or may disturb the security of critical infrastructures or the essential services that are provided to the public through them, adopting at this time the specific measures contained in the Specific Protection Plans, for each of the critical infrastructures.

ESSENTIAL SERVICES OPERATOR

Under the supervision of the Secretary of State for Security, as the competent authority exercising through the Cybersecurity Coordination Office (OCC), at least:

Designate and communicate an information security officer (IHR) as a point of contact and technical coordination.

Resolve and report cybersecurity incidents to the competent authority through the national CSIRT as set out in RD-l 12/2018 on the security of networks and information systems. The established hazard and impact thresholds can be consulted in the annex to RD 43/21 "NATIONAL INSTRUCTION ON THE NOTIFICATION AND MANAGEMENT OF CYBER INCIDENTS".

Adopt appropriate and proportionate technical and organisational measures to manage the risks posed to the security of the networks and information systems used in the provision of services. These measures must be

reflected in the Declaration of Applicability of security measures that is sent to the OCC.

Collaborate with the competent authority. In particular, to provide the necessary information to identify the causes, nature and effects of the possible incidents they have suffered.

The following recommendations can be made from both areas:

Inter-institutional coordination between critical operators and the Secretary of State for Security is a key element in incident response. Therefore, it is essential that critical operators carry out continuous and periodic risk assessments (of all kinds), and business continuity exercises, updating the operator's security plans and specific protection plans, including depth data in these plans, which would facilitate the identification of possible failures in the systems or operating procedures.

An analysis could also be proposed to help decision-making on the integration of IT/OT systems in secure, segmented networks, as well as the implementation of state-of-the-art industrial firewall systems, based on AI.

On the other hand, traffic monitoring is essential by means of specific intrusion detection systems (IDS) for industrial environments, since these systems can be the source of incidents that cause the lack of provision of essential services of vital importance.

It is also considered appropriate to introduce the obligation, for critical operators/OSE, to have backup communication systems, for example, satellite phones, which help to guarantee the connectivity of these entities in situations such as the one experienced on April 28.

In addition, it is recommended to explain the deployment of certain technologies in critical infrastructure. Each critical infrastructure is unique, which means that there is technology specifically designed so that they can fulfill their purpose. This means that it is necessary to be especially specific in the explanation that is transferred in the Specific Protection Plan in the case of infrastructures of this nature, in order to facilitate its understanding.

In the same way, it seems appropriate to specify where in the architecture of networks and systems the logical security measures operate, specifying on which part the system is intended to be protected.

It is also considered of interest to exhaustively identify the interdependencies of the infrastructure with third parties. This is because no infrastructure operates in isolation. Their operation and security are intrinsically linked to the stability of other infrastructures, services and providers.

Finally, and notwithstanding the above, it should be noted that, in general and in terms of cybersecurity, OSEs, including those analysed by this working group, have robust policies and a high level of maturity.

INCIDENT MANAGEMENT AND NOTIFICATION CHANNELS

Agile and coordinated incident management is needed. The following is a summary of the key instructions and channels available for reporting and managing cybersecurity incidents in the electricity sector:

Who notifies and to whom

OC/OSE operators: CNPIC, and the competent authority in the field of incident response, through the reference CSIRT:

Public sector → CCN-CERT (24/7 channels): Private sector → INCIBE-CERT (web form and telephone).

High/critical impact entities (Reg. 2024/1366): in addition, formal part of the CNMC and INCIBE-CERT.

Content and reporting cycle

Initial file with type of attack, affected systems and impact; intermediate updates and closure with measures applied, as described in RD 43/2021.

Post-Alert Technical Support

CCN-CERT or INCIBE-CERT provide malware analysis, IOCs and guide eradication; authorities may require additional information and lay down specific obligations for SBIs in terms of both network and information system security and notification.

Additional resources

Line 017 (INCIBE) for queries 8-23 h, portals with forms and legal FAQs; Include emergency telephone numbers in the internal plan.

Reference Guides

National Instruction on the Notification and Management of Cyber Incidents (RDL 12/2018). CCN-STIC Series; the CCN-STIC-817 Guide addresses industrial environments.

Measures proposed by GTOSE

In compliance with the mandate of the National Security Council, proposals for measures to address the factors that led to the electricity zero of April 28 are developed below, as well as, additionally, measures aimed at strengthening the electricity system in different aspects.

Analysis of compliance with the applicable regulations by the competent bodies in inspection, instruction and, where appropriate, sanction, not only of what happened on April 28, but more broadly.

To regulate the legal regime of common evacuation infrastructures, as a critical point identified in the operation of the system, with a view to the requirement of technical solvency criteria and other requirements, their obligations towards the system, as well as the co-responsibility of the agents connected to these infrastructures with their proper operation.

Accelerate the constitution and adequate staffing of the National Energy Commission as a specialized regulatory and supervisory body focused exclusively on the energy sector, in view of the high complexity and specificity of the sector, the growing abundance and specificity of applicable technical regulations, the need for greater supervision and transparency, and the criticality of the sector for society as a whole, of the economy and national security.

Urgent approval and implementation of the new regulated voltage control service in operation procedure 7.4. With this update:

o This service may be provided not only by synchronous generation, but by any generation facility, including asynchronous generation installed in recent years16, depending on who provides this function at a more competitive cost.

This change will mean that installations distributed throughout the country will be able to contribute to voltage control, thus reinforcing the tools available with a wide territorial distribution. As it is an open service, it reinforces technological neutrality, allowing the objectives sought to be achieved at the lowest cost for consumers, even foreseeing savings with respect to the starting point.

In addition, penalties are established for non-compliance with voltage control obligations that continue to be applicable to synchronous groups.

Once approved by the CNMC, it is up to the operator and all the agents of the system to apply this new framework in an agile manner.

Urgent incorporation of additional tools for voltage monitoring and oscillation management into the power grids

It is proposed to urgently incorporate technologies into transmission grid planning that allow for greater voltage control, in addition to continuous (rather than staggered) control. Analysing the cost-benefit of different technologies, the incorporation of the following is proposed:

16 It is estimated that, in the peninsular electricity system, 19 GW of installed photovoltaic capacity (almost half of the total) and 5 GW of wind power (16% of the total) currently comply with the European RfG grid code and, therefore, have the capacity to regulate voltage.

Synchronous compensators distributed throughout the peninsular territory. This technology allows continuous voltage control, in addition to providing short-circuit power, and inertia.

Updating of the FACTS17 system, to provide tension stability and damping against oscillations.

Installation of new ballasts

In the regulation relating to the levels of investment in distribution networks, it is proposed to include the obligation to specifically incorporate tools for voltage control and monitoring in the investment plans of distributors. It is also proposed to incorporate measures associated with telecommunications and remote control, as well as the resilience of the facilities to unforeseen events.

It is proposed to incorporate regulatory measures to speed up the incorporation of these actions into the plans of the transmission network and distribution networks, as well as to speed up their processing.

Installation plan and correct configuration of PSS and POD stabilization systems (in synchronous and asynchronous generation respectively) to reinforce the robustness and damping of the system against oscillations. It is proposed that the system operator and owners of generation facilities carry out analyses and actions that allow the system to be provided with greater protection against oscillations.

These measures, in addition to reinforcing voltage control in the system, will reduce the programming needs of thermal generators due to technical constraints (these generators will also be able to participate in the voltage control markets, competing with the rest of the technologies), with a fourfold benefit: lower cost of adjustment services, lower CO2 emissions, etc. lower renewable discharges18 and the possibility that different technologies (different generation technologies,

17 Flexible AC Transmission system

18 When a generator set is programmed for voltage control, it is usually programmed at the "technical minimum", that is, the minimum generation required to be coupled, since the system does not "need" that energy, but is the result of having the generator set coupled for voltage control. To guarantee the balance between generation and demand, this "surplus" generation of the generators connected by voltage control means limiting another generation that would have matched in the market, increasing generation discharges.

storage systems, etc.) have new revenue streams, as long as they are more competitive than the other technologies they compete with to offer this service.

Request for an exception to delay, at least until January 1, 2029, the reduction to 30 minutes before the actual closing time of the intraday interzonal market, so that the system operator has enough time for the analysis and programming of the operation in real time without jeopardizing security of supply.

The reinforcement of the interconnection will make it possible to electrically bring the peninsula closer to the "centre of gravity" of the interconnected electricity system, improve competitiveness on both sides of the interconnection thanks to the increased energy flow capacity and, in the event of incidents, increase the support capacities available on both sides of the border.

As a result of the electricity zero, adjustment services have acquired greater importance, in view of the fact that some groups programmed and remunerated in this framework seem not to have adequately fulfilled their purpose in the case of voltage control, as well as from the role that these services have acquired in the "reinforced operation" by the system operator.

An adjustment services plan is proposed aimed at strengthening the system, while minimising costs for consumers:

Analysis of the current operation and behavior of the facilities

Review the regulation of the programming of technical restrictions to incorporate the new situations of the system and solutions to solve the most innovative ones, from a perspective of technological neutrality. By way of illustration, the substitution or incorporation of criteria such as

entry and exit ramps, opening of new markets so that the services or technical requirements that the system may need are offered by the most competitive technologies at all times, investments in the system that can avoid the need to program certain services...

Analysis of the costs associated with adjustment services

As detailed, the restoration of supply after the electricity zero of April 28 was considered exemplary by experts at the national and international level. However, it is proposed to update and modernize this operating procedure in order to:

Incorporate penalties for non-compliance

Enabling the entry of new technologies to facilitate autonomous start-up

Incorporate lessons learned during the process

In view of the lessons learned from what happened on April 28, it is proposed to analyze and review the operating procedures in relation to:

Complement the existing requirements relating to voltage levels with new regulation of response to the rate of increase in voltage, a phenomenon that has been key in what happened on 28 April but which is not sufficiently specifically reflected in the procedures.

Grid power injection requirements by production facilities, including aspects such as the quality of the active power wave.

General criteria for the protection of the electricity system, through the processing of new P.O. 11.1 and 11.2, based on the system operator's proposal at the end of January 2025.

As described above, a low electrical demand in a poorly meshed system contributes to overvoltage through the capacitive effect of the lines. One

The promotion of electrification allows a better use of the electricity system and with it a lower effect of overvoltage on the lines and lower unit costs. In addition, it is the best opportunity to take advantage of the potential of the competitive advantage of the competitive costs of renewable energies in Spain. To this end, it is proposed:

Industrial electrification

Launch of the next planning of the electricity transmission grid horizon 2030 with prioritization for industrial consumption

Approval of an investment plan under the RTRP (€931 million) to finance actions in the transmission network that minimise the impact of these investments on consumers' final bills.

Activation of tenders for access to demand for this type of installation

Expiry of unused demand access permits to avoid artificial blockage of electricity grids and allow them to be used by mature and solvent projects

Revision of the regulations on investment limits in networks, associating this revision with the obligation for distribution network owners to incorporate specific actions for the electrification of industry into their investment plans, as well as open and transparent processes that allow industry to set out its demand needs.

Electrification of other energy uses, such as mobility and thermal demands

As can be seen from the information gathered and the analysis carried out, the event of April 28 was not due to a lack of capacity or firmness of the system. However, in compliance with the mandate of the National Security Council and in the context of a more comprehensive analysis of the security and flexibility of the electricity system, it is proposed:

Boosting electrical storage

Recognition of storage facilities and their evacuation infrastructures as being of public utility already applicable to generation facilities, as well as the consideration of general interest applicable to other types of infrastructure.

Administrative and processing improvements associated with storage facilities and their hybridisation in renewable projects.

Promotion of specific flexibility regulations

Incorporation of flexibility objectives into national sectoral regulations

Approval of the regulation of the independent aggregator, in order to maximize the possible agents to participate in flexibility systems

Approval of the capacity market regulations, following the mandatory authorisation from the European Commission, with the aim of increasing the firmness of the system, thereby increasing the levels of security of supply.

Plan to promote the repowering of renewable projects, facilitating the replacement of old renewable equipment with modern ones that therefore incorporate the most recent requirements of control, management and robustness before the system.

Reflections at the European level

After analysing the factors that contributed to the zero tension of 28 April, relevant elements have been identified in the regulatory, governance or technical field at the European level, which are summarised below, and which are proposed to be transferred to the corresponding EU bodies.

Interconnections. The peninsular electricity system has a low level of interconnection with the European continent, barely 3% of installed capacity, far from the 15% target established in European regulations. It is necessary to continue advancing in the increase of the electricity interconnection of the Iberian Peninsula with the rest of the European system in order to strengthen the internal market and take advantage of the corresponding opportunities both for the Iberian Peninsula and the rest of the European system.

Quarter-hour market. In the interactions with the different agents, there has been a high level of consensus on the challenge posed by the advance of hourly markets towards quarter-hours / fifteen-minute markets. In this sense, since March 18, 2025, intraday market trading is quarter-hourly, and it is expected to also apply to the day-ahead market from October 1. It is proposed to convey to the European Commission and the Agency for the Cooperation of Energy Regulators (ACER) the need to analyse and reassess the cost-benefit of this measure and with it, its entry into force. Any modifications to market and operating rules that reduce tools for managing electricity systems should be carefully analyzed.

Interzonal closing time. Related to the above, the latest reform of the Internal Electricity Market Regulation established that, as of 1 January 2026, the closing time of the intraday interzonal market will not precede the actual time by more than 30 minutes. The aim of this measure is to bring markets closer to real-time so that agents can maximise their transaction opportunities, especially those, such as renewable generation, which are subject to greater uncertainty and variability. Without prejudice to the fact that the Regulation allows system operators to request an extension to delay this obligation when there is a risk to security of supply (which the Committee proposes for REE in the Recommendations section), the analysis of the incident shows that the measures aimed at bringing the closure of the system closer to real time

Markets limit the capacities for analysis and programming of the system's operation, especially in poorly interconnected systems such as the Iberian one, where there are fewer market resources available from neighbouring systems.

Capacity mechanisms. Although the electricity zero on April 28 was not due to a lack of firmness or capacity (as it occurred at a time of relatively low demand and with more than enough firm generation available), it highlights the importance of all the tools linked to security of supply having the highest priority and agility. In this sense, it is necessary for the capacity mechanisms to have an agile processing that allows the member states to have them available according to their needs.

Annex I. Control Centres

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Annex II. Critical and high-impact generation companies

This classification by business group corresponds to that given by the CNMC.

Annex III. – connected facilities

Annex IV. - Connected facilities

Annex V. Connected Facilities

Annex VI. Supply replenishment: evolution of the replenished load

Annex VII. Actions carried out by the GTOSE

The GTOSE has held the following working meetings:

04/30/2025: working meeting after the constituent session of Committee 28-A, at the headquarters of MITERD.

01/05/2025: working meeting with the REE system operation directorate (DOS), at REDEIA's headquarters.

03/05/2025: working meeting after the second ordinary session of Committee 28-A at the headquarters of REDEIA.

05/05/2025: working meeting after the third ordinary session of Committee 28-A, at the headquarters of MITERD.

06/05/2025: working meeting with the REE System Operation Directorate (DOS), at the headquarters of the SEE.

08/05/205: Working meeting with the REE System Operation Directorate (DOS), at the headquarters of the DGPEYM.

08/05/205: working meeting after the fourth ordinary session of Committee 28-A with the management of Iberdrola España and its energy and networks subsidiaries, at Iberdrola's headquarters.

10/05/205: working meeting by VC.

12/05/2025: working meeting after the fifth ordinary session of Committee 28-A with the management of Endesa and its energy and networks subsidiaries, at Endesa's headquarters.

05/13/2025: working meeting with the REE System Operation Directorate (DOS), at the headquarters of the DGPEYM.

16/05/2025: working meeting by VC.

05/26/2025: working meeting with the REE System Operation Directorate (DOS), at the SEE headquarters.

28/05/2025: Working meeting with the management of and its subsidiaries of Energy and Networks, at the headquarters of

28/05/2025: Working meeting with the management of and its subsidiaries of Energy and Networks, at the headquarters of

04/06/2025: Work meeting with the company management.

at the headquarters of this

10/06/2025: working meeting with the REE System Operation Directorate (DOS), at the SEE headquarters.

For reasons of work organisation and the time available, other invitations could not be attended, although fluid interaction with all agents has been ensured.

In turn, requests for information and data have been made to the main operators in the electricity system:

The system operator (OS), Red Eléctrica de España, S.A.

The operators of the generation control centres attached to the managed grid (Annex I)

Generation companies with an installed capacity of more than 1,000MW (Annex II)

Distribution system operators

To the companies responsible for the common infrastructures for the evacuation of generation plants in the substation positions, in which the first generation disconnections have been detected on 28 April, as well as disconnections on 22 April:

To companies owning generation facilities in which the data received showed the possibility that they were between

The first disconnections:

Inverter manufacturers representing a significant part of the renewable generation market in Spain

Annex VIII. Actions carried out by the GTCSD

To carry out the set of planned actions of Analysis/Review of systems in situ, this Group constituted six RRT (Rapid Reaction Team) teams, plus a team for technical coordination, with the function of compiling context information and that recorded in the systems of different entities, identifying indications and obtaining evidence that could point to an event of a cybernetic nature related to or possible cause of the incident that affected the system electricity in Spain on April 28, 2025.

The RRTs are composed of and led by the three reference Computer Security Incident Response Teams in Spain, included in Royal Decree-Law 12/2018, of 7 September, on the security of networks and information systems: the INCIBE-CERT (2), CCN-CERT (2) and ESPDEFCERT of the Joint Cyberspace Command (2). The national coordination of the technical response is carried out by the CCN by virtue of the provisions of the aforementioned Royal Decree-Law in its article 11.3.

Each Team included personnel from the State Security Forces and Corps, assigned to the National Centre for the Protection of Critical Infrastructures or the Cybersecurity Coordination Office of the Ministry of the Interior.

Finally, staff from MITECO and the Ministry for Digital Transformation and the Civil Service (Secretary of State for Telecommunications and Digital Infrastructures - Sub-Directorate General for Digital Security) were also integrated into some of these Teams.

The minimum composition per Team is:

1 Team Leader

1 Cyber Threat Analyst

2 IT Network Analyst

2 OT Network Analysts

1 documentalist (2nd chief)

1 minimum member of the OCC/CNPIC (Civil Guard or National Police).

1 member of the MTDyFP (SETELECO -SGSD-) optional.

1 optional MITECO member.

Alternates

At least 60 people have been mobilised, in addition to another 15 working on the analysis of information and data that the RRTs have collected. In total, more than 75 people have made up the 6 teams.

The main activities carried out in the deployment are:

OT Network Analysis

IT Network Analysis

Analysis of interconnections and cybersecurity systems

The prioritisation of which centres should be analysed or reviewed is established by MITECO based on the knowledge of the electricity grid and the analysis that the network operation WG is carrying out, and it is essential, in order to maximise the efficiency of the RRTs, to permanently update them based on this analysis.

The teams have carried out analyses in the following entities:

RRT-1 (CCN-CERT) in the entities Company 1, 7 in the facilities of the Control Centers that they have in Spain.

RRT-2 (CCN-CERT) in the entities Empresa 2, 8 and 13 in the facilities of the Control Centers that they have in Spain.

RRT-3 (MCCE-ESPDEFCERT) in the entities Company 3 and 9 in the facilities of the Control Centers they have in Spain.

RRT-4 (MCCE-ESPDEFCERT) in the entities Companies 4, 10 and 14 in the facilities of the Control Centers that they have in Spain.

RRT-5 (INCIBE-CERT) in the entities Companies 5 and 11 in the facilities of the Control Centers that they have in Spain.

RRT-6 (INCIBE-CERT) in the entities Empresa 6 and 12 in the facilities of the Control Centres they have in Spain.

Also part of each RRT were a minimum member of the OCC / CNPIC (Civil Guard or National Police) and, optionally, a member of the MTDyFP (SETELECO -SGSD-) and MITECO.

Annex IX. List of Petitions

Annex X. Brief Fundamentals of the Electrical System

Electrical systems are highly complex, as they have millions of "synchronously" interconnected elements that are injecting and consuming energy in quantities that vary instantaneously.

As set out in the Electricity Sector Law, the electricity system is made up of different agents or subjects, with specific responsibilities and rights essential for the proper functioning of the system. In this sense, there is technical regulation that specifies the conditions that must be met by the different subjects: from the system operator and the transporter (owner and operator of the transmission networks, those of "highest voltage" that constitute the main "arteries" of the system), the distributors (owners and managers of the networks at lower voltage, which generally carry the energy to consumers), but also consumers and generators themselves (who must comply with certain obligations in terms of the "quality" of energy and the way they interact with the system).

Consumers and generators can be connected to both transmission and distribution networks. In the case of generation, there are shared evacuation infrastructures (also known as "collection facilities" or common evacuation infrastructures, ICEs) between the different generators that wish to connect to a specific point in the grid. These infrastructures are not transmission or distribution networks, but constitute a private network owned by the generators, up to the "border point" where they are connected to the grid. These facilities are usually managed by companies that are, in turn, made up of the owners of the generation facilities that use these facilities to evacuate their energy to the grid.

The peninsular electricity system is part of the European synchronous interconnected system, which includes Turkey in the southeast, Moldova and Ukraine in the east, the Baltic countries in the northeast, the Nordic countries in the north, Ireland in the west and Morocco in the southwest.

Figure 2 Map of the ENTSO-e interconnected network

The fundamental variables in the operation and functioning of electrical systems are frequency (Hz) and voltage (V).

Frequency has to do with the electromagnetic nature of electricity in alternating current (AC) and measures the number of oscillations per second of the waves (voltage, intensity, power). 50 Hz means that the electrical waves repeat 50 times per second (one full cycle every 20 ms). This frequency of electricity is determined by the rotational speed of the rotor of alternators (also called synchronous generators). In the event that the generators are not rotary (as in the case of photovoltaic generation), the electricity is initially generated as a constant variable (direct current, DC) and by means of equipment called inverters it is converted to alternating current (AC) with the desired frequency so that it can be injected into the grid.

Voltage, also called voltage or potential difference, determines the ability of each point in the network to transfer energy. The higher the voltage, the lower the intensities of electric current will be necessary to inject or consume a certain amount of energy. There are many voltage levels in the grid: from 220V in our homes to 220kV and 400kV in REE's transmission network.

Both variables are related to the energy that circulates through the network and, in a way, serve to measure the health and stability of the system. Electrical energy in alternating current always has two components: a term of "active energy", which is the energy useful to perform work (moving motors, pumps, lighting...) and a term of "reactive energy", which is non-useful energy, but whose presence in the network is inevitable due to the natural existence of certain elements that either generate reactive (capacitors) or consume reactive (reactances).

The frequency measures whether the active energy available at a given time is "sufficient", i.e. if there is no generation deficit or surplus and, therefore, there is a balance between generation and consumption. When generation is missing, the frequency drops below 50Hz; when there is excess, the frequency goes up.

"Inertia" is the system's ability to automatically and instantaneously correct deviations in frequency caused by generation-demand imbalances. At present, only synchronous generators that rotate with large masses of energy (hydro and thermal generators: nuclear, coal, gas, solar thermal, biomass, cogeneration and waste) provide inertia. With the development of power electronics and grid forming technologies, the technologies

asynchronous (wind and photovoltaic) and storage will be able to provide synthetic inertia in the future. There is also equipment that can be integrated into the network and that provides inertia, such as synchronous compensators or flywheels.

Voltage, on the other hand, measures the "quality" of the energy flowing through the grid, i.e. whether the levels of reactive energy are limited. When there is a lot of reactive energy generation that is not consumed or counteracted, voltages rise and surges. When the excess is reactive consumption, then tensions fall.

In an electrical system, reactive energy can typically come from certain types of consumption, such as from the power lines themselves. Specifically, underground cables are more likely to generate reactive energy; Similarly, in general, highly meshed electricity grids at times of low consumption (and therefore low energy flows in these networks) tend to generate more reactive energy, contributing, if not properly managed, to voltage increases.

Operating Procedures of the electricity system 1.1 and 1.3 establish that the voltages in the transmission network in a stable situation must be between 380 and 435 kV in the 400 network, and between 205 and 245 kV in the 220 network. However, it is not advisable for the system to operate close to these limits, for which in 2021 agreements were established between REE and the distribution network operators for voltage control at certain reference nodes. In this area, which, although it is not part of the regulations, but is a reference for the operation of the system, the "normal situation" ranges of 380-420 kV and 204.6-234.96 kV in the 400 and 220 kV networks respectively were defined. These agreements also provide for the adoption of "coordination measures" in the ranges 234.96-245.96 kV and 420-435 kV, and "exceptional measures" above the upper values, which already coincide with the upper limits provided for in the operating procedures referred to above.

For voltage control, the regulations oblige all agents to adopt certain measures. Thus, Operating Procedure 1.1 must be applied

by the system operator (OS), both in the programming studies of the operation, and in the real-time operation, and affects all the installations of the network managed by the OS in the peninsular electricity system and all the production facilities directly connected to this network.

The system operator has different tools to act on the voltages. On the one hand, equipment integrated into the network itself: currently the main tool that REE has are reactances, whose connection absorbs reactive (low voltage at the node), and vice versa. However, ballasts do not, in general, allow a gradual adjustment of voltages, but only the possibility of their connection or disconnection ("all or nothing"), which limits the ability of the system operator to laminate voltage variations in the network using this technology. For this reason, there are also other types of equipment (such as synchronous compensators, FACTS and STATCOM), which have already begun to be incorporated into Spanish electricity systems, which reinforce the inherent capacity for voltage control in the network.

On the other hand, the operator resorts to the so-called Technical Restrictions (see next section on market operation) in which it schedules the connection of certain generation infrastructures, based on its capacities and voltage regulation obligations (see previous points), to ensure that there is sufficient active voltage control capacity in the system at any given time.

Likewise, the regulations, in particular Operation Procedure 7.4, oblige generators and consumers to operate within specific parameters, participating in voltage control. As for generation, it can be subject to voltage control by setpoint ("they observe" the voltage of the network and modify its power factor to contain voltage deviations) or to a fixed power factor (in which the active and reactive output power values must maintain a specific relationship). Currently, the aforementioned regulation operation procedure sets obligations for conventional generation to regulate voltage by setpoint, i.e. to actively contribute to voltage control, while renewables, within the framework of Royal Decree 413/2014, of 6

of June, are subject to a power factor, although for years the latter have already had the technological capacity to operate by setpoint, although the regulations do not require it.

For its part, the aforementioned operating procedure imposes on both distribution network operators and consumers with contracted power greater than or equal to 15MW to be subject to a power factor to prevent them from generating or consuming reactive energy in excess.

When the values of the frequency and voltage exceed or fall below certain levels, risks appear for the equipment, so there are protection elements that disconnect them to avoid damage to the equipment or people. In the case of electricity generation, the voltage and frequency criteria that electricity producers must be able to withstand are regulated by standardised technical regulations at European level (Commission Regulation (EU) 2016/631 of 14 April 2016 establishing a grid code on requirements for connecting generators to the grid). incorporated into the Spanish legal system in Royal Decree 647/2020, of 7 July, and Order TED/749/2020, of 16 July. The function of these limits is, on the one hand, to allow the protection of equipment in situations outside the usual parameters while, on the other hand, it is mandatory to maintain the connection in certain margins, to prevent these disconnections from contributing to aggravating problems or situations that occur in the network.

This standard establishes that generation connected to 220 kV must remain connected unlimited at voltages between 198 and 245.96 kV, and for 60 minutes until 253 kV19. In the case of installations connected to 400 kV, they must remain connected unlimited in voltage situations up to 435 kV, and for 60 minutes up to 440 kV.

In the case of distribution networks, Royal Decree 1955/2000, of 1 December, establishes, among other issues, the indices of quality of supply,

19 Unlimited operating time period in the range 0.90 pu – 1.118 pu and 60-minute operation in the range 1.118pu – 1.15pu

including the voltage levels at which these networks must operate. In particular, limits of +/- 7% on the nominal voltage value are established.

For these reasons, the operators of the electrical systems continuously monitor the values of these variables in the network in order to keep them within the tolerable operating ranges. To do this, they use two control systems: "frequency/power regulation" and "voltage/reactive" regulation. Given that many of the changes in the electrical system occur in a matter of seconds, an important part of this management is automatic, based on pre-set instructions or parameters, since there would be no reaction time for manual intervention for certain events.

In addition to frequency and voltage control, system operators have been paying special attention in recent years to stability and oscillatory phenomena.

Electricity systems live in a permanent "unstable balance" between supply and demand, which means that their main variables are changing continuously, suffering ups and downs and returning to previous values after a so-called transitory period.

However, sometimes "oscillations" appear, phenomena in which the electrical variables (voltage, frequency) do not suffer a sudden increase or fall and then remain in a new state or return to values similar to the previous ones, but a wave-like variation that follows a fixed pattern of frequency and amplitude, as a "swing".

Figure: Frequency Oscillation

In electrical systems, oscillations can occur between different areas of the interconnected system and where they are most noticeable is in the most peripheral areas or electrically distant from the "center of gravity" of the system, such as the Iberian Peninsula (which is far away due to its weak interconnection with the continent).

These oscillations are called inter-area or "natural" oscillations, they are known, they are explained by the structure and dimension of the system and they are cataloged, having determined what the concrete movement is and between which zones they occur. They usually have low oscillation frequencies, between 0.1Hz and 1Hz. The fact that it is at one end of the European synchronous system, with a weak interconnection as is the case of the Iberian Peninsula, may cause oscillations in the European electricity system to be felt more strongly in the peninsula, and in particular in the areas that are electrically furthest from the rest of the continent. It could be described as a "bullwhip effect," in which a small movement or oscillation near the center generates a large movement at the end.

Oscillations may also appear between a few elements within a more local zone of the system. They have higher oscillation frequencies than inter-area frequencies (up to more than 1Hz), although this will depend on the origin (mechanical, electromechanical or electronic/control) and the type of generator or demand involved.

Oscillations are very dangerous because, if they are not dampened, amplified and continue to grow, they can cause the disconnection of the different parts of the system and a total collapse. On 1 December 2016, an inter-area East-Central-West oscillation in the European interconnected system caused the disconnection of several areas of the system.

The European electricity system is constantly evolving, which can have implications for the oscillatory modes that can affect the system. As an example, in March 2022 the electricity systems of Ukraine and Moldova were synchronized with the European mainland grid, thus expanding and modifying the electricity system on the continent. More recently, in February 2025, synchronisation with the European system of the Baltic countries (Estonia, Latvia, Lithuania) has been completed.

The ability of an electrical system to neutralize any oscillation that may occur in its fundamental variables and to quickly return the system to its equilibrium state is called damping. It is about

A parameter that can be measured at any time, is specific to each node of the network and different for each mode and frequency of oscillation.

Electrical system operators have protocols to reinforce the damping of the system when they observe that it is reduced and is not able to neutralize an oscillation. Thus, the operators of the Spanish and French system have agreements not to carry out certain topological manoeuvres near the border with a negative impact on the stability of the system's small signal, and have agreed procedures for action in the event of undamped oscillations. In addition, the system operator has a real-time monitoring system for the oscillatory behavior of the system.

In general, damping is increased by increasing the meshing of the network (connecting circuits that were open), reducing export flows from the periphery or reinforcing the interconnection with the system's center of gravity. In addition, so that generation, demand or the grid itself can help to dampen fluctuations, special equipment (power electronics) can be installed in them. In the case of synchronous generation, these are the "power stabilizers" or PSS (Power System Stabilisers) that must be correctly adjusted to the specific oscillation frequencies that may appear in the system.20 Specifically, in Spain in 2016, a review and adjustment of the PSS in the system's combined cycle plants was carried out to help dampen the oscillations. Likewise, the system operator and the companies owning the nuclear power plants analysed the feasibility of installing PSS equipment in these facilities, with the conclusion that it was not feasible to equip them with these systems

20 For asynchronous generation and HDVC links, with power electronics, there are similar solutions called POD (Power Oscillation Damping) systems.

Annex XI. Market functioning and operation of the electricity system

As for the operation of the electricity market, every day of the year at 12:00 CET, the daily market session is held in which electricity prices and energies are set throughout Europe for the twenty-four hours of the following day. The price and volume of energy at a given time are set by the crossover between supply and demand. In accordance with current regulations, production facilities are obliged to make offers on the market for their available power.

It is expected that the daily market will be traded on a quarter-hourly basis (matching every 15 minutes, instead of every hour). The start of the daily quarter-hour market was scheduled for June 11, 2025, having recently been delayed to October 1, 2025222.

The results of the day-ahead market matching process are sent to the System Operator, which prepares the Daily Base Operating Programme (PDBF) incorporating the programming into the interconnections and physical bilateral contracts.

In accordance with Operating Procedure 3.2, the System Operator validates the PDBF from the point of view of technical feasibility. This process is called management of the technical constraints of the system and ensures that market outcomes are technically feasible in the transmission network, based on the declared generation available at any given time. Specifically, operating procedure 3.2 defines a technical restriction as "any circumstance or incident arising from the situation of the electricity system that, by affecting the conditions of safety, quality and reliability of the supply established by regulation and through the corresponding procedures of

21 Decision of the Market Coupling Steering Committee of 14 May 2025, on the grounds that some market operators have not demonstrated that they are technically ready for start-up by the scheduled date of 11 June 2025.

operation". For technical restrictions, the system operator can count on the installations that have not been declared as "unavailable".

Therefore, the results of the day-ahead market may suffer small variations as a result of the analysis of restrictions carried out by the System Operator, giving rise to what is known as the provisional viable daily program (PDVP).

Subsequently, through the intraday market, market agents can adjust, through the submission of offers for the sale and purchase of energy, their resulting program from the day-ahead market according to the needs they expect in real time, giving rise to the Final Program (PHF).

The intraday markets are currently structured in three auction sessions at European level and a continuous European cross-border market. Since March 18, 2025, intraday market trading is quarter-hourly. That is, up to 4 different market results can occur every hour, which can lead to changes in production or links at each of these times.

In addition to these organised markets, there are unorganised markets, based on bilateral contracts between agents. Although these agreements are not made in a centralised market, physical bilateral contracts must be mandatorily nominated before the System Operator and OMIE, in order to guarantee their integration into the electricity system.

As with the day-ahead market, once these markets have been carried out, the results are evaluated by the system operators so that they can program their balancing processes and technical constraints in real time. The final programme, which includes the final result of all these processes, is called the Operational Programme (P48).

Annex XII. Brief Fundamentals of Cybersecurity and Digital Systems

Within a context of cybersecurity, and in general terms, when we talk about the IT (Information Technology) world, we are referring to those information and communication systems that mainly handle information and data, while when we talk about the OT (Operational Technology) world, we are referring rather to systems dedicated to the real-time control and supervision of industrial processes.

In the following diagram, you can see how the main IT and OT components are usually structured in an organization, grouped by levels, so that the lower level, we will always see the OT systems located, and as we go up the level, the IT systems appear.

Figure 3: Example of the location of IT and OT systems in an organization (source: own elaboration)

Convergencia IT/OT

It could be said that the digitalization of the energy sector has been the result of converging IT systems with OT systems. In fact, this sector is experiencing an unprecedented revolution where its systems are increasingly interconnected in search of greater efficiency and productivity. A clear example of digitalisation in the energy sector has been the massive deployment of smart meters. These meters allow utilities to monitor energy consumption in real-time, making it easier to optimize supply and optimize energy flow/consumption. Inverters are another example of systems

digital networks that can communicate through IT or OT networks and communicate both, allowing the operation of network flows.

Cybersecurity challenges

Digitalization is causing extraordinary benefits that the sector demanded, but it also faces significant technical and regulatory challenges. As the network becomes more digitalized, it requires greater attention to vulnerabilities, which are likely to be a possible entry into a cyberattack or trigger a systems failure. Given the level of digital connection of all systems, energy infrastructures are considered critical for States within the scope of the European Union.

In summary, the new challenges of cybersecurity, a field in constant evolution that requires a continuous and adaptable response, has led to the need to become more and more familiar with a series of more technical concepts, which have begun to be in common use, and which are necessary to understand in order to, for example, correctly understand the scope of this document.

Some concepts to take into account:

Cyber incidents. A cybersecurity event that has been determined to have an impact on the organization that causes the need for response and recovery, which can affect the availability of systems and data, their integrity, confidentiality and the security of protocols that are based on authentication and non-repudiation.

Threats. Any circumstance or event with the potential to negatively impact the organization's operations or the organization's digital assets through unauthorized access, destruction, disclosure, modification of information, and/or denial of service.

Cyber Threat: Any potential situation, fact, or action that may damage, disrupt, or otherwise adversely affect networks and information systems, users of such systems, and other persons.

Cyberattack: materialization of a cyberthreat.

Vulnerabilities. Weakness in an information system, communication networks, system security procedures, internal controls, or implementation that could be exploited or triggered by a threat source.

Cybersecurity measures: They are a set of actions, technologies, and policies that are implemented in an organization to protect its systems, networks, and data against cyberthreats and cyberattacks. These measures aim to guarantee the confidentiality, integrity and availability of information. Cybersecurity in critical infrastructures in the energy sector requires a comprehensive approach that combines compliance with specific regulations, such as the NIS2 directive, with the implementation of recognized national and international standards and certifications that strengthen the security of systems. Standards such as the NIST Cybersecurity Framework or certifications such as ISO/IEC 27001 and ISA/IEC 62443, among others, provide practical and universal guidelines for managing risks, protecting systems and ensuring continuity of operations.

Reference regulations: in Spain, energy operators that are designated as critical infrastructure, by virtue of Law 8/2011, have models of Operator Security Plan (PSO) and Specific Protection Plan (PPE), which indicate recommendations on control systems and security measures to be applied for adequate cybersecurity governance. There are also international standards, such as IEC 62443, that offer good practices in this regard. In the cyber field, Essential Services Operators are subject to the obligations contained in RDL 12/2018 and RD 43/2021 that develops it.

For the public sector, the reference regulation on cybersecurity is the National Security Scheme, developed in Royal Decree 311/2022 and the CCN-STIC guides of the 800 series.