ENTSO-E Position Paper

# Project Inertia – Phase II

## Recovering power system resilience in case of system splits for a future-ready decarbonised system

9 January 2025

# ENTSO-E Mission Statement

## Who we are

ENTSO-E, the European Network of Transmission System Operators for Electricity, is the **association for the cooperation of the European transmission system operators (TSOs)**. The 40 member TSOs, representing 36 countries, are responsible for the **secure and coordinated operation** of Europe's electricity system, the largest interconnected electrical grid in the world. In addition to its core, historical role in technical cooperation, ENTSO-E is also the common voice of TSOs.

ENTSO-E **brings together the unique expertise of TSOs for the benefit of European citizens** by keeping the lights on, enabling the energy transition, and promoting the completion and optimal functioning of the internal electricity market, including via the fulfilment of the mandates given to ENTSO-E based on EU legislation.

## Our mission

ENTSO-E and its members, as the European TSO community, fulfil a common mission: Ensuring the **security of the interconnected power system in all time frames at pan-European level** and the **optimal functioning and development of the European interconnected electricity markets**, while enabling the integration of electricity generated from renewable energy sources and of emerging technologies.

## Our vision

ENTSO-E plays a central role in enabling Europe to become the first **climate-neutral continent by 2050** by creating a system that is secure, sustainable and affordable, and that integrates the expected amount of renewable energy, thereby offering an essential contribution to the European Green Deal. This endeavour requires **sector integration** and close cooperation among all actors.

Europe is moving towards a sustainable, digitalised, integrated and electrified energy system with a combination of centralised and distributed resources.

ENTSO-E acts to ensure that this energy system **keeps consumers at its centre** and is operated and developed with **climate objectives** and **social welfare** in mind.

ENTSO-E is committed to using its unique expertise and system-wide view – supported by a responsibility to maintain the system's security – to deliver a comprehensive roadmap of how a climate-neutral Europe looks.

## Our values

ENTSO-E acts in **solidarity** as a community of TSOs united by a shared **responsibility.**

As the professional association of independent and neutral regulated entities acting under a clear legal mandate, ENTSO-E serves the interests of society by **optimising social welfare** in its dimensions of safety, economy, environment, and performance.

ENTSO-E is committed to working with the highest technical rigour as well as developing sustainable and **innovative responses to prepare for the future** and overcoming the challenges of keeping the power system secure in a climate-neutral Europe. In all its activities, ENTSO-E acts with **transparency** and in a trustworthy dialogue with legislative and regulatory decision makers and stakeholders.

## Our contributions

**ENTSO-E supports the cooperation** among its members at European and regional levels. Over the past decades, TSOs have undertaken initiatives to increase their cooperation in network planning, operation and market integration, thereby successfully contributing to meeting EU climate and energy targets.

To carry out its **legally mandated tasks**, ENTSO-E's key responsibilities include the following:

- Development and implementation of standards, network codes, platforms and tools to ensure secure system and market operation as well as integration of renewable energy;
- Assessment of the adequacy of the system in different timeframes;
- Coordination of the planning and development of infrastructures at the European level (Ten-Year Network Development Plans, TYNDPs);
- Coordination of research, development and innovation activities of TSOs;
- Development of platforms to enable the transparent sharing of data with market participants.

ENTSO-E supports its members in the **implementation and monitoring** of the agreed common rules.

**ENTSO-E is the common voice of European TSOs** and provides expert contributions and a constructive view to energy debates to support policymakers in making informed decisions.

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# Background

Through its studies and analysis, ENTSO-E triggers important discussions on various power system stability issues, aiming to engage with stakeholders and establish a common understanding of the challenges and solutions for secure and stable operation of the present and future power system. As part of this commitment, a project was developed to assess and elaborate on the resilience of the Continental European (CE) interconnected transmission system to withstand system splits[1] under future scenarios, given the threat of reduced total system inertia and increased power transfers through the electricity system.

A first report – **"Frequency stability in long-term scenarios and relevant requirements"**[2] – identified the relevant trends and created awareness of the challenge related to the decrease of system resilience in the case of system splits. This report took the first step in enabling a vitally important discussion and establishing the framework for the necessary follow-up studies.

The following report – **"Project Inertia – Phase II: Updated frequency stability analysis in long-term scenarios, relevant solutions and mitigation measures"**[3] – demonstrates the progressive decline of system resilience against system splits in the Continental Europe Synchronous Area (CE SA). System splits potentially leading to a total blackout of both split subsystems, called global severe splits (GSS), are expected to be the most critical situation as there is no healthy energised system to support the restoration of the blacked-out system. The updated results show that the number of theoretical system split cases where both subsystems exceed the operational threshold of rate of change of frequency (RoCoF) of ±1 Hz/s – potentially leading to a total blackout – significantly increases from the 2030 to 2040 scenarios.

The updated report[3] emphasises the urgent need to address the progressive decrease in system resilience. It presents possible solutions and mitigation measures in a structured approach, defining and characterising foundational and enhanced response measures.

Transmission system operators (TSOs) and all relevant stakeholders and institutions agreeing on an acceptable level of grid resilience and accepted risk of blackout is imperative due to its considerable economic and societal impact. Therefore, broad understanding and support for the solution measures in CE SA are necessary at the technical and regulatory/political levels. The conclusions for the public debate focus only on CE SA since other synchronous area challenges and solutions lie beyond the report's scope.

The present position paper and supporting technical report propose decision-making information and a roadmap to the foundational measures as part of a step-by-step, non-regret approach to deliver secure and efficient operation for a future-ready decarbonised system.

1 A system split is a severe disturbance that results in a separation of the interconnected CE transmission system into two or more isolated subsystems. In the context of Project Inertia, two split subsystems were considered.

2 https://eepublicdownloads.azureedge.net/clean-documents/Publications/ENTSO-E%20general%20publications/211203_Long_term_frequency_stability_scenarios_for_publication.pdf?_sm_au_=iHVk1rN4j7K4SZMHfHkkNL6Q61LQ6

3 https://eepublicdownloads.blob.core.windows.net/public-cdn-container/clean-documents/sdc-documents/231108_Project_Inertia_Phase_II_First_Report_FOR_PUBLICATION_clean.pdf

# Recovering the Loss in System Resilience

The transition to a decarbonised energy system is based on the rapid integration of large amounts of renewable energy sources (RES) and the corresponding phase-out of fossil fuel generation. Through the Ten-Year Network Development Plan (TYNDP), ENTSO-E showed that this process is not only feasible but also beneficial for European society.

**The electricity transmission system will have to accommodate the decarbonisation process by adapting not only to the changing demand and generation patterns but also the different impacts of the assets connected to the grid on system resilience.** The reduced system inertia is a natural consequence of the lower number of directly connected rotating masses of synchronous generators to the grid. The stability support traditionally granted by these generators – as the large majority of power generating facilities – will no longer be available in an almost exclusively RES-dominated system. This will expose the electricity system to the risk of being unable to withstand out-of-range events like system splits that were previously manageable.

The discussion on the target resilience level in case of a system split – the capability to survive the split and avoid a potential blackout – focuses on recovering lost system resilience to support the transition to a decarbonised system. The key decisions to be made are based on the target resilience level and the acceptance of risks related to a temporary or permanent loss of resilience compared to the past. In the framework of Project Inertia, the term "resilience" refers to the system's capability to conditionally maintain frequency stability by limiting the speed and magnitude of frequency variations in case of system splits, preventing blackouts and enabling the recovery of the normal state of operation.

In the past, inertia was intrinsically provided by the rotating masses of connected synchronous generators, and the lack of resilience due to inertia was not an issue. System resilience against frequency-related consequences of system splits provided by readily available inertia was free. Today and in the future, maintaining this resilience requires investments in either dedicated network assets or the technical capability of third-party assets, which must be applied in a balanced and efficient manner.

Currently, adding kinetic energy to the system as a foundational measure – via synchronous compensators or inverter-based resources with grid-forming capability and storage – helps achieve the target resilience level.

**Project Inertia Phase II** aims to study and determine the inertia needs to enable RES integration without compromising system resilience. Achieving the target resilience level shall not limit the electricity market services or RES integration through curtailments or re-dispatching. Such options to recover system resilience are excluded.

# Focusing on Necessary Foundational Measures while Retaining the Big Picture

The focus of this analysis is foundational measures[4] to recover lost system resilience, which are essential to ensure the survivability of a subsystem after a split event. Preventive and enhanced response measures[5] also remain as indispensable as ever.

Enhanced response measures will be necessary to mitigate the consequences within the split subsystems. As such, in addition to foundational measures, enhanced response measures and rate of change of frequency (RoCoF) withstand capability should always be further optimised as much as possible. Grid connection requirements and defence plans address these enhanced response measures.

Further to mitigating the consequences of reduced inertia and increasingly large and variable long-distance power flows, learnings from previous events shall be considered from a preventive perspective on reducing the likelihood of system split events.

Measures for avoiding system splits also include enhanced observability and controllability of RES generation by system operators, coordination of system operators to control power flows, implementing dynamic stability assessment in operational planning up to real time, avoid protection schemes that can produce cascading effects (i. e. overcurrent protection) and complement them with robust schemes compatible with system security and asset integrity, etc to accommodate the different fault characteristics in a RES dominated power system.

**Project Inertia Phase II** aims to define a minimum level of inertia, supported by foundational measures, to counter the decline of system resilience and facilitate its recovery. Achieving this minimum resilience target depends on the amount and regional allocation/distribution of additional inertia in CE SA.

4 Foundational measures tackle the root cause, i. e. keeping inertia above a certain level to limit the speed and magnitude of frequency excursions.

5 Enhanced response measures represent improved withstand capabilities for stable grid operation during high-frequency gradients and frequency containment support to limit the nadir/zenith of the frequency.

# Recovering System Resilience is a Common Effort

All CE SA countries must ensure their agreed minimum levels of kinetic energy to recover the resilience up to a certain level and mitigate the occurrence of GSS. The fulfilment of the agreed kinetic energy needs across CE SA in all control areas is a prerequisite to ensure the reliable effectiveness of this foundational measure.

Since system split events cannot be anticipated, kinetic energy should always be well distributed throughout the system. To this end, common support and commitment at the synchronous area (SA) level including all countries and regions is imperative.

ENTSO-E recommends a bottom-up nodal approach to allocate kinetic energy across CE SA. As shown in the supporting technical report, this approach is robust, and its main principles are transparent and easily communicable to stakeholders. Furthermore, the future kinetic energy targets of each node can be easily monitored in operational planning and, if necessary, in real-time or close-to-real-time operations.

It is essential to highlight that it is not possible to avoid all GSS situations or other split situations where one subsystem may experience a blackout. Avoiding a significant number of GSS situations is not a complete solution or definitive metric per se, but rather constitutes a reference of the system's resilience that should be safeguarded. An efficient approach to the challenge posed by reduced inertia levels should aim at recovering system resilience, focusing on reducing the likelihood of GSS occurrence (total blackout of all split subsystems) rather than defining GSS as a design incident to be withstood.

Given that system splits are categorised as out-of-range contingencies, they do not define the maximum load imbalance the system must withstand without deploying defence plans, e. g. load shedding. The load imbalance of 3,000 MW for CE SA remains the reference incident for dimensioning frequency containment reserves.

The most efficient and appropriate way to ensure system security should be the focus of an open debate, considering all technical solutions along with costs, efficiency, and other key factors. ENTSO-E believes this discussion should involve all stakeholders, as the final resilience of the system depends on the contributions of all participants connected to the grid and their agreement on various solutions and targets. An open discussion is required to understand how these out-of-range contingencies are included in the scope of system resilience.

System operators need new tools to monitor inertia and take action. It is necessary to agree on clear targets, methodologies, and operational processes. Moreover, an implementation roadmap coordinated at the SA level is needed.

# Step-by-Step, No-Regret Approach to Recover System Resilience

ENTSO-E proposes a step-by-step approach, aiming at no-regret and realistically achievable steps to gradually and sustainably recover system resilience while continuously reassessing system needs and suitable solutions.

The proposed requirement of ensuring a minimum inertia constant (Hmin) of 2 sMW/MVA at 50 % of the time during the year in each country is a realistic first no-regret step to be reached by 2035. This would serve as a noticeable step in recovering the resilience level in terms of manageable splits and additional kinetic energy. Regular monitoring would be necessary to ensure the actual yearly duration curve of Hmin meets the desired targets.

An ensemble of synchronous condensers (SCs), static synchronous compensators (STATCOMs) with grid-forming capability and storage, and power park modules with grid-forming capability and storage will be necessary to deliver kinetic energy to the system. It will not be possible to meet long-term kinetic energy targets without the contribution of all foundational measures. The decision on the best mix of solutions should be made at the national level, including own assets and exhaustive grid connection requirements for system users' assets to meet their targets.

In addition to SCs which are effective but cannot be considered the single solution to the kinetic energy needs due to limitations resulting from total costs, manufacturing capability, and available building space – inertia can be provided by inverter-based resources, e. g. RES power park modules (PPMs) with grid-forming capability and storage. Generators should still be part of the solution to the challenge of inertia and system resilience, while ensuring increased RoCoF withstand capability, as local RoCoFs can exceed the system design criteria of ±1 Hz/s.

It is essential to gain experience about the actual performance and mutual interaction of large-scale grid-forming technologies with storage. Pilot projects are necessary for this purpose. As grid-forming technology is not yet widely available on the market and no larger related demonstration projects exist, a "trial period" is strongly recommended for the smooth introduction of such devices to gradually increase the capacities installed and collaterally observe the performance of the power system. At the same time, establishing a common SA-level implementation framework to define explicit storage capacities required for certain types of generators to provide kinetic energy could help ensure an even distribution of inertia across the system.

Market incentives and transparency regarding system needs can encourage investments in relevant power park module capabilities. Due to the nature of system split events, markets on inertia would have to be essentially implemented in local control areas, creating risks for market liquidity and prices if not properly designed.

As part of the step-by-step implementation, future reassessments of the methodology should also reconsider the investigated split cases –relevant regional split lines rather than only national borders – to ensure that realistic worst-case splits are captured. Future reassessments should also consider further refinements of the inertia allocation methods by considering additional parameters such as system balance or system load. Such refinements should strive to maintain an efficient and balanced kinetic energy distribution across CE SA.

# An Implementation Framework and Roadmap are Needed

It is necessary to establish a framework to implement the minimum inertia targets and continuously monitor its implementation and effectiveness. This will support the necessary TSO investment decisions in terms of necessary assets (e. g. SCs or STATCOMs), the specification of non-exhaustive grid connection requirements, and the mandatory application of such requirements, e. g. grid-forming convertors (GFCs) with stored energy requirements for generators.

ENTSO-E proposes establishing an ex-post assessment of yearly inertia levels in CE countries. This assessment would not affect operational decisions and is intended to monitor the evolution of the overall resilience level and provide information on the need for additional means. Following the ex-post assessment, each TSO shall take measures to enable the minimum inertia level in its own control area, ensuring the efficient use of system defence plans in case of system splits.

**A feasible and agreed roadmap with policy and regulatory decision-makers and further stakeholders is necessary and urgent. Resilience targets should be defined for the short/medium and long-term. ENTSO-E proposes:**

a. **As soon as possible,** any device that is technically capable of providing inertia – such as PPMs, STATCOMs, and SCs connected for system strength/voltage needs – that will be connected to the CE SA transmission system shall in practice be equipped to provide inertia.

b. **Regarding future connection requirements** to be enforced by the revision of the connection network codes, dedicated implementation guidance documents should support TSOs in defining adequate specifications for non-exhaustive requirements for the identified needs, which should be specific for each SA. This also ensures a level playing field across Europe.

c. **In parallel,** the optimisation and development of enhanced response measures and preventive measures should always be pursued.

d. **By 2035,** a minimum inertia constant of 2 sMW/MVA for 50 % of the year should be reached in CE SA. For the first steps, part of the targets can be largely ensured with technologically available TSO assets.

e. **As a subsequent long-term target,** subject to reassessment based on the return of experience, efficiency of grid forming, progress on foundational measures, and evolution of assets' RoCoF withstand capability, all countries shall ensure a minimum inertia constant of 2 sMW/MVA for 90 % of the year. The total kinetic energy resulting from the long-term target implementation still remains below the total kinetic energy levels available in CE in the past.

Long-term needs and global resilience levels should be reassessed every two years in the regular TYNDP identification of system needs (IoSN) to ensure a focused assessment of the inertia needs leading to feasible mitigation plans implemented at the national level. Country needs – actual coverage of the equivalent inertia year duration curve – should be reassessed every year via ex-post operational monitoring.

It is necessary to monitor and check the fulfilment of minimum inertia needs among all countries on a comparable basis. As such, all CE SA TSOs should develop and agree on a common methodology for "measuring" inertia. This will enable the ex-post operational monitoring of minimum equivalent inertia constant.

# Acronyms

| | |
|---|---|
| **CE** | Continental Europe |
| **GSS** | Global Severe Splits<br>(split scenarios with the initial RoCoF exceeding<br>1 Hz/s in both resulting subsystems) |
| **GFC** | Grid-forming Convertor |
| **IoSN** | Identification of System Needs |
| **PPM** | Power Park Module |
| **RES** | Renewable Energy Source |
| **RoCoF** | Rate of Change of Frequency (also $f$) |
| **SA** | Synchronous Area |
| **SC** | Synchronous Condenser |
| **STATCOM** | Static Synchronous Compensator |
| **TSO** | Transmission System Operator |
| **TYNDP** | Ten-Year Network Development Plan |

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