ENTSO-E Position Paper

Stability Management in Power Electronics Dominated Systems: A Prerequisite to the Success of the Energy Transition

June 2022

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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 39 member TSOs, representing 35 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 use 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.

Table of Contents

Key recommendations

The energy efficiency of the whole energy system, direct electrification and a growing share of renewable generation are the primary tools for decarbonising Europe. The scale of the energy transition and its impacts on the system are beyond compare. The installed capacity of RES must be increased massively to provide the required energy. As a result, power generation will increasingly come from weather dependent and electronic interfaced devices, and the share of synchronous generators providing inertia will be reduced.

Consequently, the system behaviour will change significantly, creating a major challenge for the stability of the system, which relies for the time being largely on those synchronous generators and, therefore, on security of supply.

Responding to this challenge and ensuring system stability during the transition period and in the long term is a condition to making the transition achievable and successful. The challenge is a complex and diverse one. Conventional system development and system operation methods will no longer be sufficient to ensure the system stability of the power electronic (PE) dominated grid. Facing this challenge requires an open discussion, good cooperation with all relevant stakeholders, significant RD&I efforts, and the acceleration of the uptake of new technologies for stability management.

The assessment and control of grid stability require consistent and pan-European methods, especially for system-wide stability challenges and certain new stability phenomena.

To maintain the pace of the energy transition, **network codes shall be updated in a fast and harmonised process**. Amendment of the Connection Network Codes (CNCs) will be crucial to ensure that equipment connected to the grid (on the generation or demand side) provide the stabilising capabilities, e. g. control interactions and resonances, required in the future.

New technical capabilities and system services are making it necessary to define new resilience requirements (e.g. for system splits, wide-meshed offshore grids, sector coupling, etc.). System services contribute to maintaining system stability in daily operation and during incidents such as the disconnection of supply or system splits. Therefore, it is important to develop markets and regulations to ensure sufficient capabilities are available at best cost.

Significant RD&I efforts and stakeholder collaborations are required to accelerate the uptake of new technologies for stability management. Supporting their realisation through **EU financing instruments** – such as Horizon Europe – is essential.

The present paper emphasises that TSOs are already in the process of identifying the growing scope of stability phenomena. TSOs are willing to be the driving force in solving these challenges and provide a list of concrete recommendations for actions. This paper is a key contribution to the larger and upcoming ENTSO-E Vision "A Power System for A Carbon Neutral Europe".

In October 2022, ENTSO-E will present this Vision of a power system, which will be the foundation of a fully carbon-neutral European economy.

The Vision will contribute to the debate on the Green Deal & EU Energy Transition, including TSOs' common intelligence on trends, scenarios, challenges, technology and innovation.

1. Tackling system stability issues: a prerequisite to the success of the energy transition

With the Green Deal, the European Commission adopted a set of proposals to make the EU's climate, energy, transport and taxation policies fit for reducing net greenhouse gas emissions by at least 55 % by 2030 compared to 1990 levels, and achieve net-zero emissions of greenhouse gases by 2050.

A central pillar of this strategy is to drastically accelerate the increase of energy produced from renewable sources (a target of 40% renewable sources in the EU's energy mix by 2030). The spread of renewable energy sources in the existing and future electric grid brings its share of challenges, including those concerning system stability. Power system stability is the ability of an electric system to regain a state of operating equilibrium after being subjected to a physical disturbance, so that practically the entire system remains intact.

The stability of the electricity system is traditionally largely ensured by rotating machines of power generation units connected to the grid (synchronous generation). However, with new renewable energy sources such as wind turbines and solar panels being connected via PEs and networks becoming hybrid AC/DC, a renewed approach to ensuring power stability is required.

Doing nothing is not an option: the risks are huge if the stability issues are not tackled in a timely manner. It is a key precondition for a successful energy transition:

Operational risks:

Insufficient stability management poses multiple challenges that all entail serious risks for the quality and reliability of supply in addition to the risk of serious damage to assets in the high-voltage grid and on the supply and load side. Unmanaged stability challenges would lead to the rise of unforeseen incidents such as islanding events, system splits, cascading faults, blackouts and equipment damage.

Indirect Operational risks:

Insufficient stability management would also force TSOs to implement increased security margins to account for uncertainties in forecasts and models, and to avoid the most severe impact of the instability characteristics of the grid. This would result in increased investment costs, inefficiencies in grid operations, lower transmission capacity available for the markets, and high societal costs.

System Development risks:

If the grid is developed based on incomplete data, tools and models, TSOs risk designing the grid without taking into account the issues and impact of resonances, converter controls or protection interaction. If these characteristics are not properly modelled and verified, it will lead to delays in addressing and solving upcoming challenges with the risk of delaying the energy transition..

Technology risks:

If the needs for new technologies are not communicated properly to research and development institutions, manufacturers and vendors of technical equipment, there is a risk that the technologies will not be ready to be deployed on a large scale when required. This, in turn, may lead to delays in the energy transition and/or to the operational risks (direct and indirect) listed above.

2. Stability phenomena are becoming increasingly concerning and diverse

The share of generation produced by rotating machines providing inertia and other stabilising features to the system has decreased and will continue to decrease drastically in years to come.

This has led to a growth in already known stability phenomena due to the phase out of rotating machines and reduction of inertia. Those well-known phenomena (“Rotor angle”, “Voltage stability” and “Frequency stability”) have increased in recent years and have a timeframe of seconds.

In addition to these well-known issues, recent years have seen the appearance of new stability phenomena. The latter are related to the effects of the fast-acting PEs devices that will dominate the system in the near future.

These new phenomena have been introduced as “Converter-driven stability” and “Resonance stability” and have a much shorter time scale, down to micro and milliseconds.

Power System Stability Phenomena

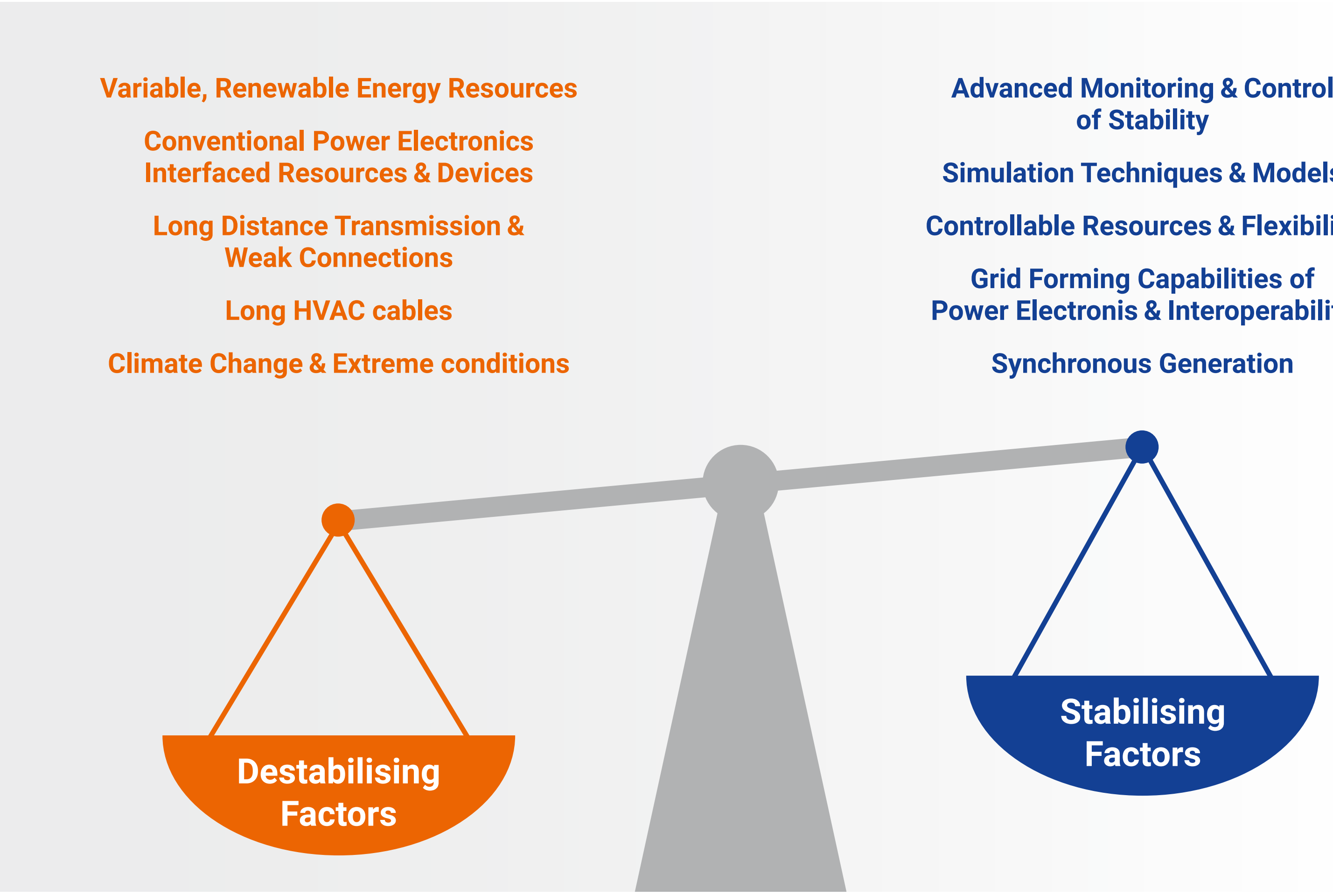
Resonance stability	Converter-driven stability	Rotor angle stability	Voltage stability	Frequency stability
New phenomena TIMEFRAME OF MILLISECONDS		Growing and changing phenomena TIMEFRAME OF SECONDS		

- Resonance stability is the grid’s ability to avoid unwanted oscillation of voltage, current or torque.
- Converter-driven stability is the grid’s ability to avoid undesirable interactions between the controls of different converters or with the controls of conventional generators.
- Rotor angle stability is the ability of the grid to retain synchronisms and avoid unwanted generator disconnection or cascading events and blackouts.
- Voltage stability is the grid’s ability to maintain a steady and acceptable voltage at all buses.
- Frequency stability is the grid’s ability to maintain frequency around a target value (i.e. the nominal frequency).

3. Stabilising technologies must be deployed to counterbalance the increase of factors destabilising the power system

The key factors impacting grid stability can be divided into two opposite groups: either destabilising factors which create greater and more complex stability challenges for grid operators, or stabilising factors that contribute to stable grid operations.

In recent years, new technologies have been developed to manage growing and new stability phenomena as synchronous generation has been reduced. It is crucial for the stability of the future PEs dominated grid that these new technologies are fully deployable on a large scale for them to counterbalance the fast-growing, destabilising factors shown in the figure.



4. Ensuring sufficient stabilising capabilities requires an amendment of the connection codes and TSOs may need to own and operate stabilising capabilities

An amendment to the CNCs will be crucial to ensure that equipment connected to the grid (on the generation or demand side) provide the capabilities required for a power system with high penetration of RES, PEs and DC connection.

Nevertheless, the timeframe for implementing network codes must be considered as the challenges have to be faced with urgency. To do so, and if markets cannot provide the necessary capabilities, TSOs may also acquire, own and operate capabilities within their grid, such as synchronous compensators.

5. All stakeholders have to collaborate and contribute to keeping the system stable

Given the scale and pace of the changes, studies show the urgency of solving the diverse and complex stability phenomena. Solving these challenges requires the coordinated effort of various aspects of European stakeholders to mitigate the risks of new and growing stability phenomena.

ENTSO-E performed an analysis of stakeholders and their relationship to the different stability phenomena, showing how stakeholders can contribute to solving specific phenomena.

Stakeholders / Stability Phenomena	Grid / System operators	Policy-makers	RD&I Institutions	Ancillary Service Market Operators	Generators	DSOs*	Other Sectors	Manufac-turers & Vendors
Resonance stability	■■■	■	■■■		■■■	■		■■■
Converter-driven stability	■■■	■	■■■		■■■	■		■■■
Rotor angle stability	■■■	■	■■	■	■■■	■		
Voltage stability	■■■	■	■■	■■■	■■■	■■■		■■■
Frequency stability	■■■	■■■	■■■	■■■	■■■	■		■■■

■ = relevant ■■ = very relevant ■■■ = extremely relevant

* DSOs including the connected flexibility resources such as demand and storage.

Table 1: Stakeholders and technical stability phenomena

ENTSO-E also analysed how stakeholders can contribute to the different solutions required to manage system stability on all time frames.

Solutions \ Stakeholders	Grid / System operators	Policy-makers	RD&I Institutions	Ancillary Service Market Operators	Generators	DSOs*	Other Sectors	Manufac-turers & Vendors
Modelling and tools	■■■	■	■■■		■■■	■■		■■■
Develop and integrate new stability solutions in system development	■■■	■■■	■■	■■	■■■	■		■
Pan-EU stability management process	■■■	■■■		■■				
Inter-regional real-time data exchange and communication, cyber security	■■■	■■	■■			■■■		
Standards and interoperability	■■■	■■■	■■	■■■	■■■	■■■		■■■
Grid code requirement	■■■	■■■	■■	■■■	■■■	■■■		■■■
Capabilities from flexible resources	■■■	■	■■	■■■	■■■	■■	■■■	■■■
Market development and liquidity	■■■	■■■		■■■		■		
Responsibility (TSO–RCCs, TSO–DSO, cross-sector, market operators, generators) in ensuring the power system stability	■■■	■■■		■■	■■	■■	■■	

■ = relevant ■■ = very relevant ■■■ = extremely relevant

* DSOs including the connected flexibility resources such as demand and storage.

Table 2: Stakeholders and identified issues

6. ENTSO-E actions and detailed recommendations

The stability challenge is a pan-European issue that requires a consistent approach among regions and countries. Several actions must be taken; all require a coordinated effort by the European TSOs.

ENTSO-E and TSOs have a central role to play: As the main technical experts responsible for managing the stability of the interconnected power system, TSOs are indeed in a key position to shed light on all these aspects and prioritise, optimise and standardise the use and application of various technologies. In this fashion, TSOs' role is also to clarify how other actors connected to the grid are impacting the grid stability; they should create a comprehensive action plan including technical, economic, political, legal & regulatory, social and environmental aspects.

Actions for the short term (<1 years)

ENTSO-E and TSOs, in cooperation with policy makers and stakeholders, will:

- **create a common and comprehensive European roadmap** for stability management based on a description of the necessary capabilities of the future power system and grid codes.
- **identify areas for stability assessment and control** where standardisation is necessary and/or beneficial.
- **analyse and identify, for each synchronous area, the point in time when different stability challenges are expected to emerge** based on the speed of the energy transition and the integration rate of Power Electronic interfaced devices.
- **identify a range of new technical capabilities, system services and methodologies** to handle the controllable resources and flexibility necessary to maintain system stability, system security and grid resilience.
- **Continue to insist on the need for significant RD&I efforts.** In this respect, EU financing supports – such as Horizon Europe – will play a key role.

Actions for the medium term (2–3 years)

ENTSO-E and TSOs, in cooperation with policy makers and stakeholders, will:

- **propose methods for the analysis and identification of thresholds** for system inertia and calculation methods that can be applied to identify the optimal socio-economic mix of traditional inertia and inverter-based assets with grid forming capabilities.

- **propose methods to predict and monitor system stability** and handle controllable resources and flexibility, necessary to maintain system stability, system security and grid resilience.

- **identify and specify the required technical capabilities of inverter-based assets** such as grid forming and interoperability and propose grid code amendments for further harmonisation across Europe. The CNCs should evolve to ensure the equipment capabilities needed for a power system with a high penetration of RES. These new capabilities may be new fast frequency reserves or grid forming functionality. The timeframe for implementing network codes must considered as the challenges have to be faced in sufficient time. TSOs may need to acquire and operate some stabilising capabilities if the market is unable to provide them in time or if code amendments cannot be implemented sufficiently quickly.

- **develop high-level specifications of power system models, asset models and simulation tools** capable of analysing new and challenging European stability phenomena in PE-dominated systems with high penetration of RES. This also requires that the current issues regarding confidentiality and intellectual properties of manufacturers models are solved.

- **develop market mechanisms appropriate for ensuring the availability of necessary system services**, the capabilities of controllable resources, and the flexibility to maintain system stability, system security and grid resilience.

- **analyse roles and responsibilities with regards to the stability management of the pan-European grid**, considering the cross-regional aspect of certain stability phenomena and the impact of cross-sector integration.

Actions for the longer term (>3 years)

ENTSO-E and TSOs, in cooperation with policy makers and stakeholders, will:

- **deploy prediction, monitoring and communication systems for stability management** on a pan-European level.

- **ensure that stability issues are considered** in the planning processes of network development.

- **support vendors and manufacturers in the development and deployment of new capabilities** in inverter-based assets through the testing and assessment of new technologies and to ensure interoperability.

- **develop and verify power system models, asset models and simulation tools** capable of analysing new and challenging European stability phenomena.

- **ensure liquidity in markets for new system services**, where applicable.

Glossary

AC	Alternating Current
AVR	Automatic Voltage Regulator
CE	Central Europe
CGMES	Common Grid Model Exchange Standard
CIM	Common Information Model
CNC	Connection Network Codes
DC	Direct Current
DSO	Distribution System Operator
EC	European Commission
EMT	Electromagnetic Transients
ENTSO-E	European Network of Transmission System Operators for Electricity
EU	European Union
FACTS	Flexible Alternating Current Transmission System
HVAC	High-Voltage Alternating Current
HVDC	High-Voltage Direct Current
PE(s)	Power Electronic(s)
PED(s)	Power Electronic Device(s)
PESTLE	Political, Economic, Social, Technological, Legal and Environmental
RCC	Regional Coordination Centres
RD&I	Research Development and Innovation
RoCoF	Rate of Change of Frequency
RES	Renewable Energy Sources
SA	Synchronous Area
SO	System Operation(s)
TSO	Transmission System Operator
TYNDP	Ten-Year Network Development Plan

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8 Rue de Spa | 1000 Brussels | Belgium
www.entsoe.eu | info@entsoe.eu

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