Workshop

"High Penetration of Power Electronic Interfaced Power Sources and the Potential Contribution of Grid Forming Converters"

Power System Stability Challenges with High Penetration of Power Electronic Interfaced Power Sources

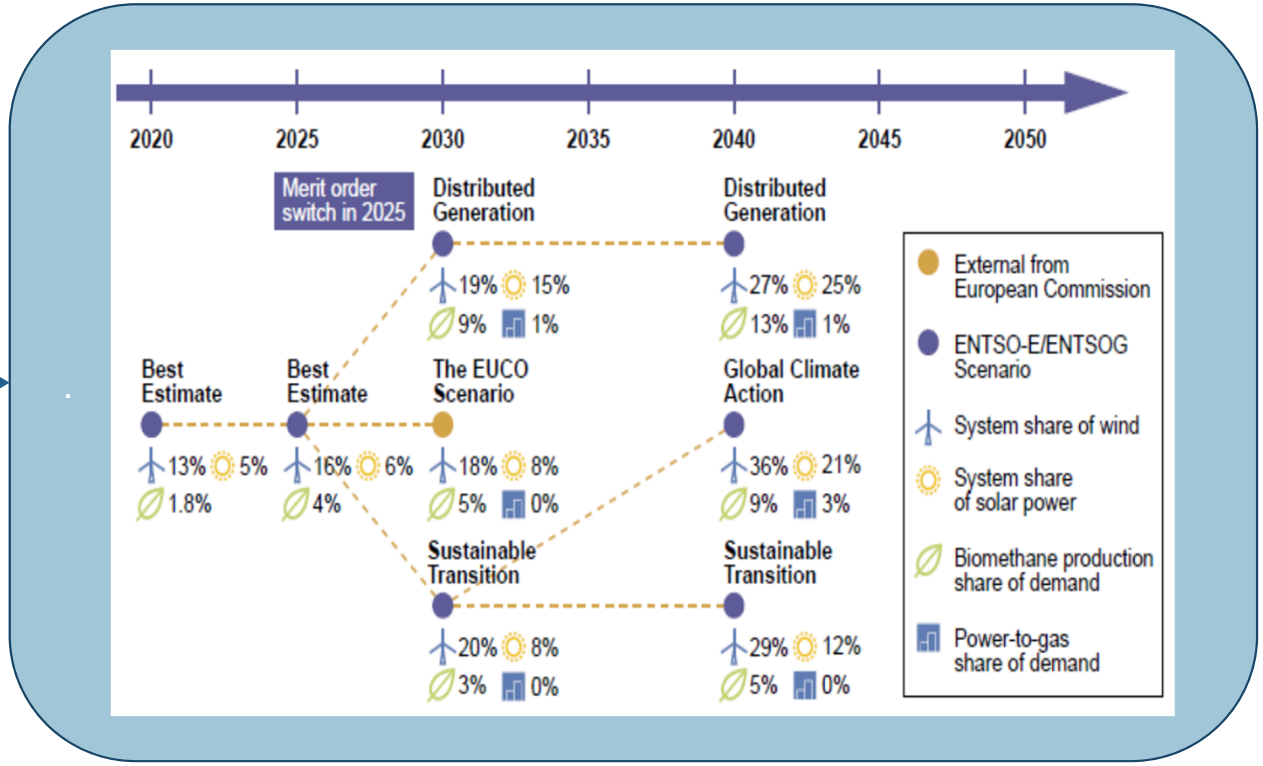
ENTSO-E Technical Group on High Penetration

Brussels, 30th of January 2020

Presented by Mario Ndreko

High Penetration in European Power Systems – Background

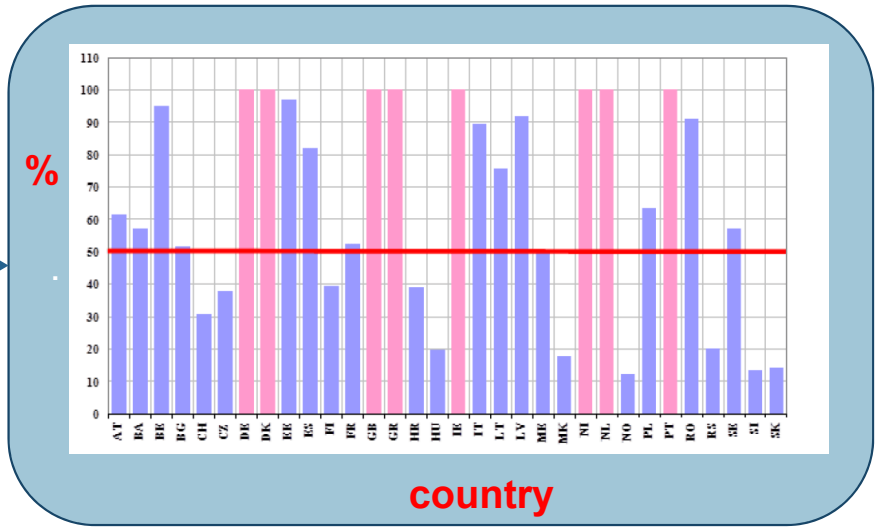
ENTSO-E TYNDP 2018 Scenarios

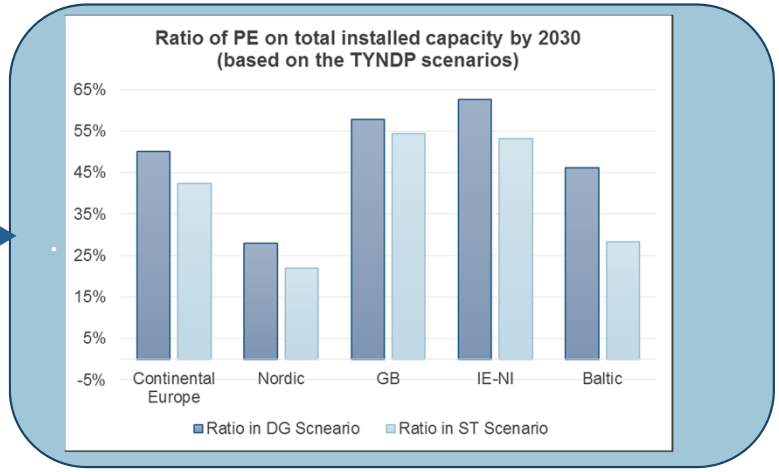


Penetration on RES **energy – averages**
Wind + PV exceed 50% by 2040

High Penetration in European Power Systems – Background

RES Instantaneous penetration (% of demand) **per country in 2025** from TYNDP 2016





- 8 countries reach 100%, 22 reach 50%

High Penetration in European Power Systems – Background

RES is Changing the Power System

the **system is gradually moving from the classical centralised power system** where large synchronous generation units ensure power system stability and robustness, **towards a decentralised power system** where the generation shifts into the distribution level.

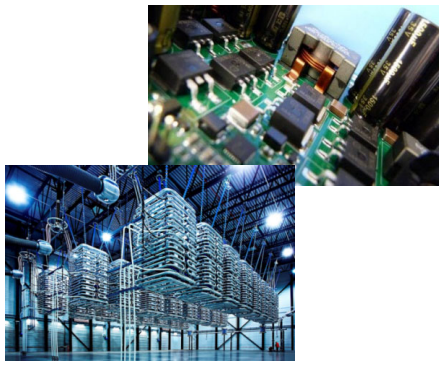
the **observability of the generation fleet** in the medium and low voltage networks becomes **challenging for SOs.**

the **load flow patterns become volatile among transmission and distribution networks**, resulting in increased reverse flows and faster voltage variations

RES variability increases the need for **larger and more variable power transits across the transmission corridors**

High Penetration in European Power Systems – Background

More Power Converters



On generation side, a massive installation of power converters based power sources throughout the **distribution and transmission** system

On the demand side, similar trends are being observed with the load being increasingly interfaced with power converters, e.g. industrial motors or EVs

On the high voltage transmission system, increased HVDC transmission capacity is expected by 2030 (70GW embedded HVDC links)

different power system ***dynamic profiles***

primarily caused by the **displacement of the synchronous generation** fleet

secondarily caused by the **fast time constants introduced by power electronic converters** and actuators

Stability challenges - Ranking

TSOs View on Power System Stability Challenges

The EU-Horizon-2020 funded project **MIGRATE conducted a survey among 21 European TSOs aimed at identifying power system stability challenges** as perceived by the industry under high penetration of PEIPSs.

A recent report from the sub-group **System Protection and Dynamics (SPD) working group of ENTSO-E** has ranked the increase of **RoCoF as a top power system stability challenge** for the CE system

Ranking	Score	Issue
1	17.35	Decrease of inertia
2	10.16	Resonances due to cables and Power electronics
3	9.84	Reduction of transient stability margins
4	8.91	Missing or wrong participation of PE-connected generators and loads in frequency containment
5	8.19	PE Controller interaction with each other and passive AC components
6	7.50	Loss of devices in the context of fault-ride-through capability
7	7.00	Lack of reactive power
8	6.91	Introduction of new power oscillations and/or reduced damping of existing power oscillations
9	6.09	Excess of reactive power
10	4.27	Voltage Dip-Induced Frequency Dip
11	3.87	Altered static and dynamic voltage dependence of loads

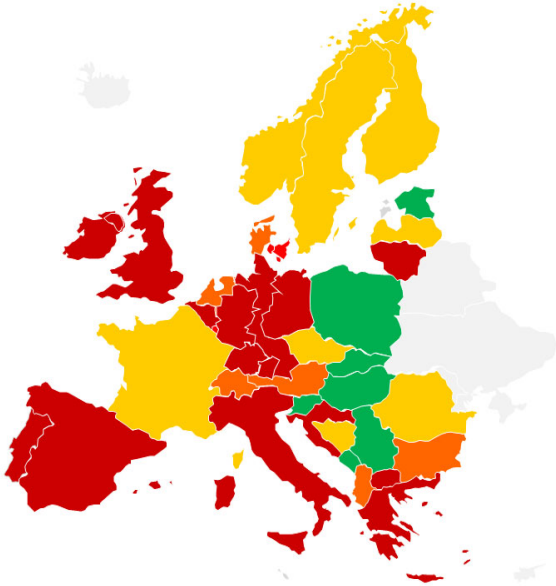
The reduction of total system inertia – Facts and numbers

Total System Inertia

Today: For the **normal interconnected operation** of the CE power system, **the inertia is sufficient considering the normative loss of 3GW**

2030 Scenario:
Figure illustrates the TSOs' view **that a national per unit TSI constant H sometimes falling below 2 s is of concern,** compared with a traditional value of about 5–6 s

At least **two SAs, GB and Ireland, and a number of individual countries' contribution within CE are expected to fall within this category**, highlighting their need to prepare their strategy to cope with such grid conditions



TYNDP 2016: 2030 Scenario

Inertia contribution colouring code:

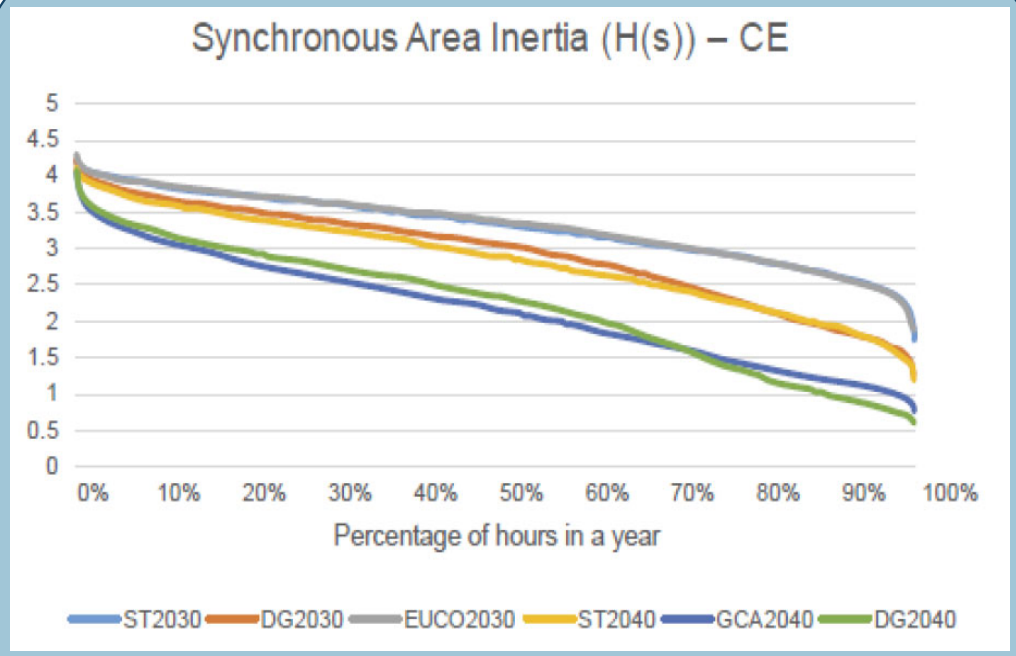
- Green H ≥ 4 s Very good contribution
- Yellow 3 s ≤ H < 4 s Good contribution
- Orange 2 s ≤ H < 3 s Marginal contribution
- Red H < 2 s Limited contribution

The reduction of total system inertia – Facts and numbers

Total System Inertia

progressive decrease in the inertia constant of the CE system when moving towards 2040.

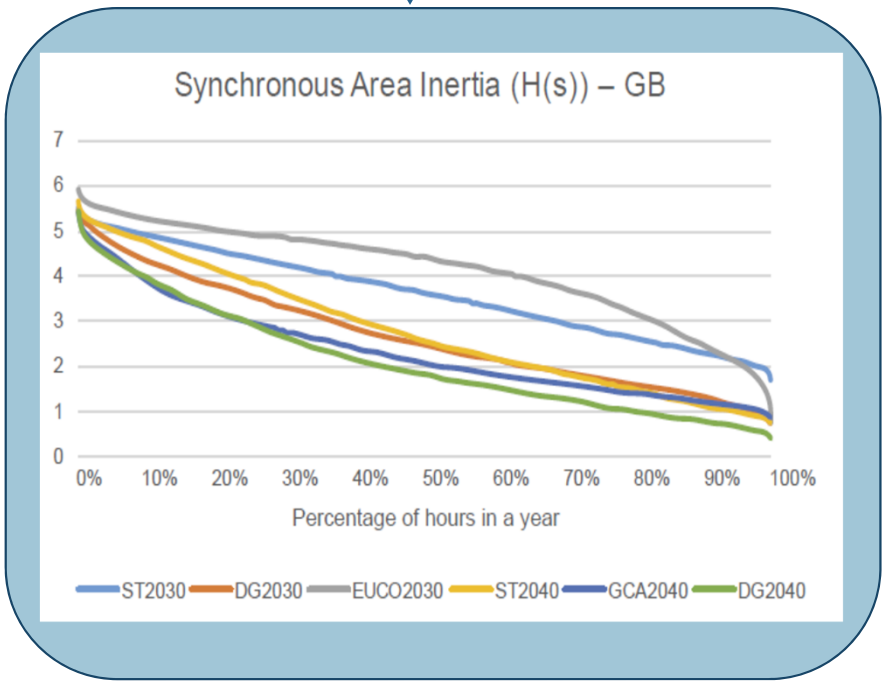
The **decrease** of system inertia is **greater and earlier in the smaller SAs such as GB**, with the inertia constant reaching extremely low values, with **H even below 1 s for about 20% of the year**, compared to a former norm of H of approximately 5–6 s.

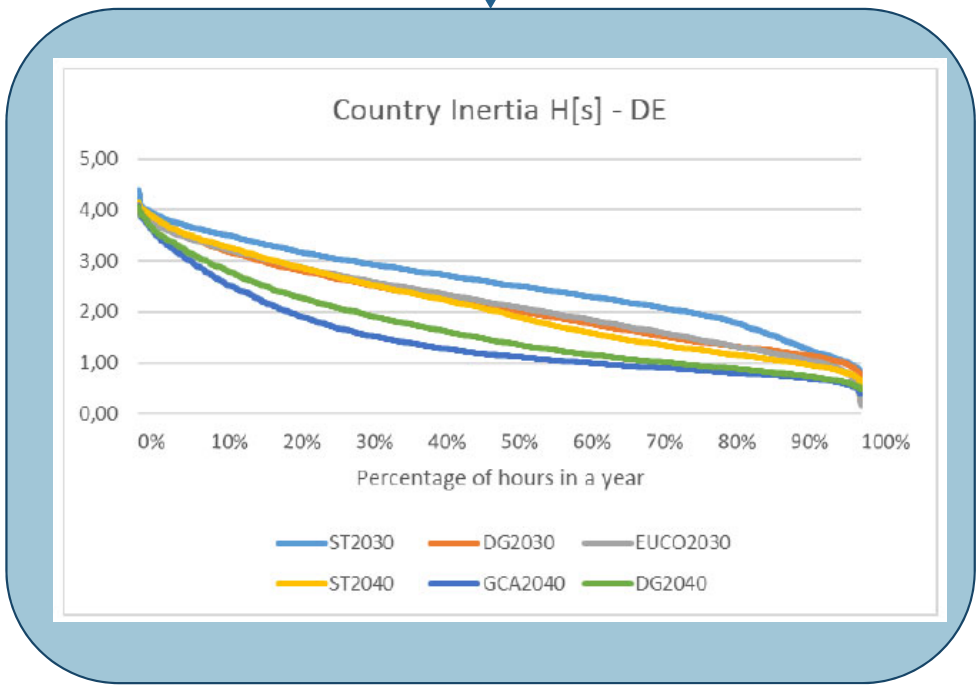


All figures are from TYNDP 2018 report - ENTSOE

The reduction of total system inertia – Facts and numbers

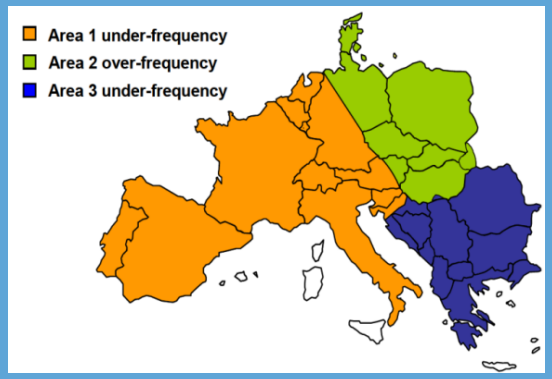
Total System Inertia





All figures are from TYNDP 2018 report - ENTSOE

The Challenge of System Split for CE System



System split is identified as **a grid extreme contingency leading to separation of the system** into asynchronous zones.

Rare events such as **system splits** (currently experienced once in decades), becomes **critical under high penetration levels** of renewable generation sources.

Exports and imports before the system split event become **power imbalances** for the separate islands after the split.

A **system split is more likely** to occur across **highly loaded weak transmission corridors**.

The **potential imbalance after a rare system split which the systems need to survive is expected also to increase**, bringing the system to its **physical limits** in terms of balancing capability.

Developments of the **European Electricity Markets are leading to the transit flows** gradually increasing in magnitude, making system split cases in future more difficult to handle.

System Split for CE System - Studies

ENTSOE System Protection and Dynamics (SPD) working group report

A system split event could lead to a **situation which is outside the pre-defined limits for frequency containment reserves** (3 GW in CE).

The most common **remedial actions are LFDD, LFSM-U and LFSM-O**.

A methodology has been developed for the analysis of system splits from **ENTSO-E** (System Protection & Dynamics working group). Moreover, key conclusions are:

20% imbalance in the CE results in 0.5-1.0 Hz/s RoCof

If frequency deviations exceed 47.5Hz or 51.5Hz, a black out can hardly be avoided

20% imbalance with 1Hz/s is critical and can drive the system to unpredictable states

Market simulations for the future ask for **40% imbalance and 2Hz/s** withstand capability

System Split for CE System - Studies

ENTSOE
Inertia project, Phase I
Drafting Team Planning Standards

❑Input data :

✓market data (market zones)

✓inertia by market zone

❑Task 1 : find credible system splits
❑Task 2 : compute the imbalances and, ROCOFs
❑Task 3 : analyse and find the worst case

Conclusion

Results consistently show that RoCoF values above 2Hz/s are verified across the spectrum of system split cases

It is expected that future reality could be even more challenging than TYNDP scenarios show

Future System Design

The System must **cope with cases of split with imbalances of greater than 40%** leading to RoCof greater than 2Hz/s

- Under-frequency load shedding below 49Hz in the under-frequency island is needed
- power reduction of generation units in the over-frequency island

Normative incident of system split consists of:

- **Maximum imbalance** (as a percentage of the load in the system)
- **Maximum RoCof** or minimum required inertia

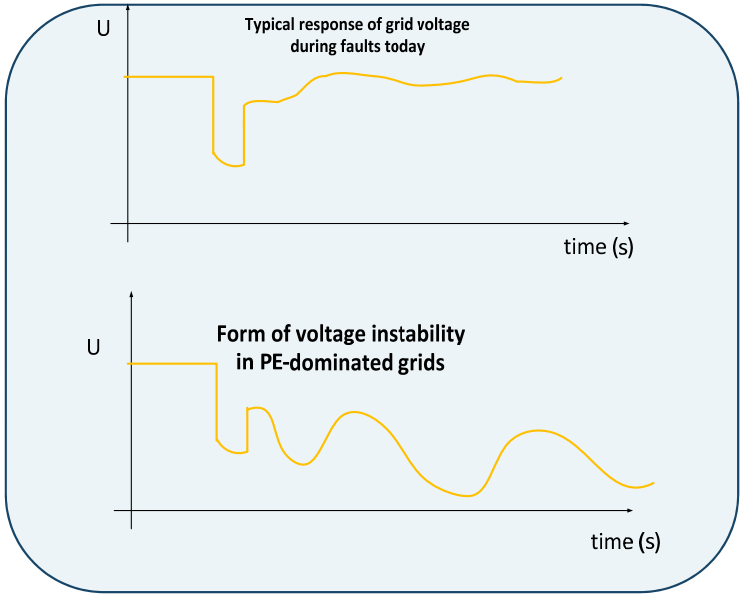
LFDD can be ineffective when inertia is low and power deficit is high

- As an example, in Australia, AEMO has determined that **ROCOF must be less than 3 Hz/s** to allow LFDD to operate effectively
- **inertia should be maintained** to ensure this for all secured events (i.e. excluding system splits).
  - the RoCof observed during the Australian black-out event was 6 Hz/sec

Voltage stability and formation

With regard to voltage stability, concerns as identified by TSOs are summarised as:

- Voltage dip-induced frequency dip
- Lack of reactive power sources
- Excess of reactive power sources
- Altered static and dynamic voltage dependence of loads
- Inadequate support to restore system voltage immediately post fault



Analysis of the **extreme case of 100% PEIPS penetration demonstrates that a response is required in the first quarter cycle** (within 5 ms) to avoid system collapse.

Short Circuit Power Levels - Trends

Already today in **many countries and regions, different levels of short circuit power levels are observed / reported**, mainly between central areas and areas at the system edges.

References from **some TSOs reflect and quantify the expected reduction in the short circuit power levels in the transmission system**.

- In general, the **short circuit power levels trends are regional**, different across different SAs and operating conditions.

The **overall consequence of low system strength** is varied and complex across all categories of system stability (rotor angle, voltage and control interactions).

Short Circuit Power Levels - Effects

Deeper voltage dips (in the medium and low voltage network) **and more widespread (in geographic area)** in the event of severe transmission network faults.

Loss of devices in the context of fault-ride through capability. The main reason is the reduction of the short circuit power levels and the propagation of voltage dips which resulted in trips from under-voltage protection.

Clearly, **outages of such nature would affect the frequency stability** and would have a more global system effect **under high penetration of PEIPS**.

With regard to **PEIPS, it is well known that their stable and robust operation is affected** significantly by the correct operation of the **phase-locked loop (PLL)** modules.

In weak grid connection environment, the stable and robust operation of the **PLL along with the application of vector current control loops (grid following)** could be a potential reason for PEIPS instability.

Other Forms of Stability Issues

- Further concerns include **low synchronising torque between generation sources**, to overcome sudden voltage angle disturbances (at the fundamental frequency).

- The **adverse control interactions between converter controllers** (connected electrically close) is becoming a more significant issue.
  - Such interactions may become **visible as Sub Synchronous Resonances (SSR)** or **Super Synchronous Instability (SSI also called Harmonic Instability).**
  - As PEIPS becomes dominant, these interactions may no longer remain local.

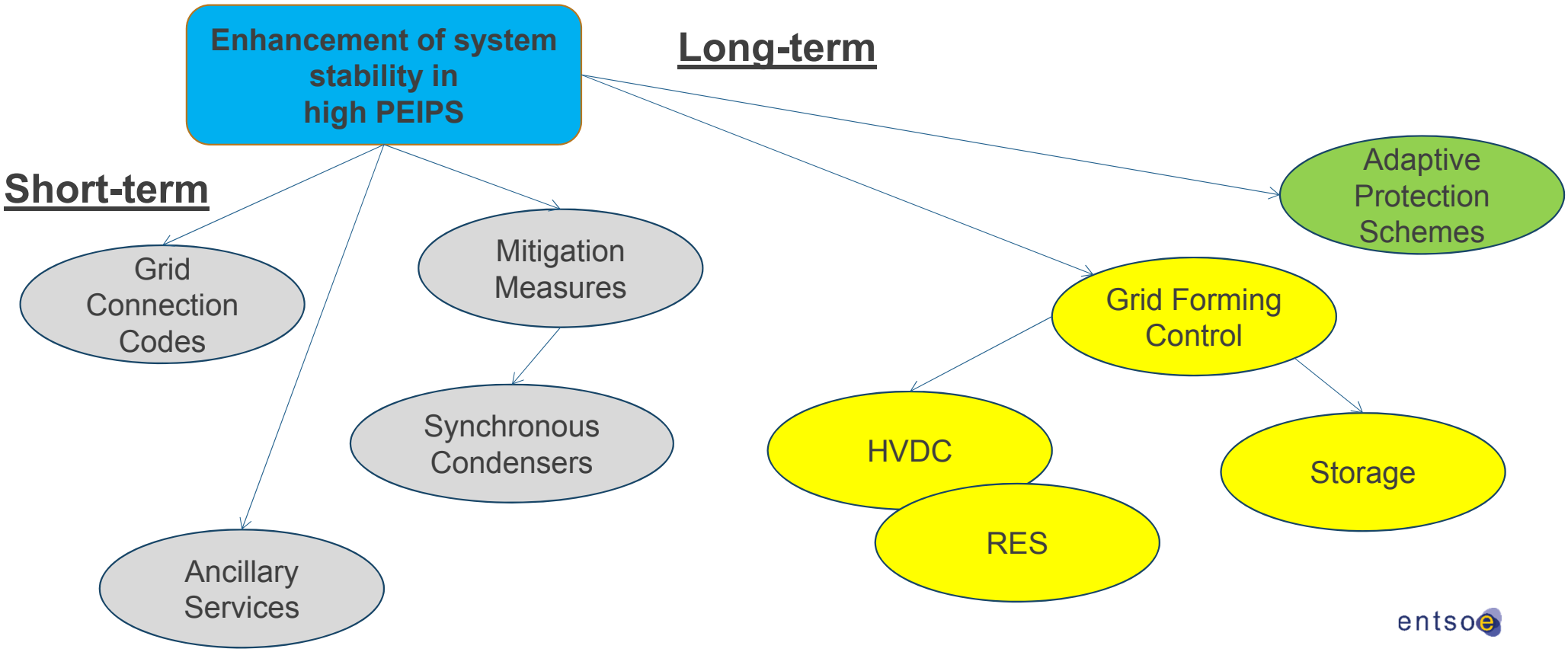
- In the **absence of SGs, the system may lack 'sinks' to correct low order system harmonics** including inter-harmonics as well as lacking 'sinks' to correct phase unbalance.

ENTSOE "One Vision 2030" Roadmap towards Power Converter Dominated Power Systems (incl. HVDC)

Vision on Market Design and System Operation towards 2030

- Enhancement of system stability
- Enhancement of system observability
- Enhancement of flexibility
- Tools and advanced models
- Enhancement of coordination

ENTSOE "One Vision 2030" Roadmap towards PE-Dominated Power Systems (incl. HVDC)



entsoe

Thank you

Presentation prepared by:

Mario Ndreko
(TenneT TSO GmbH)

Based on the work of the authors of the report

„High Penetration of Power Electronic Interfaced Power Sources and the Potential Contribution of Grid Forming Converters"

by the ENTSO-E TG on High Penetration