SUMMER 26 STUDY

A summer without nuclear
Final report – March 2026

National Control Center

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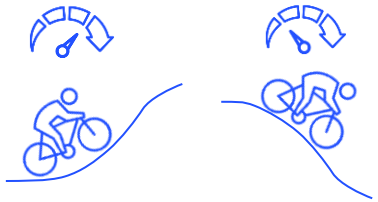
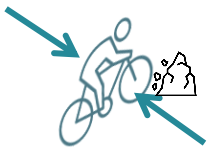
0. Introduction
1. Oscillations
2. Voltage
3. Dynamic

Secure system operation

Scope

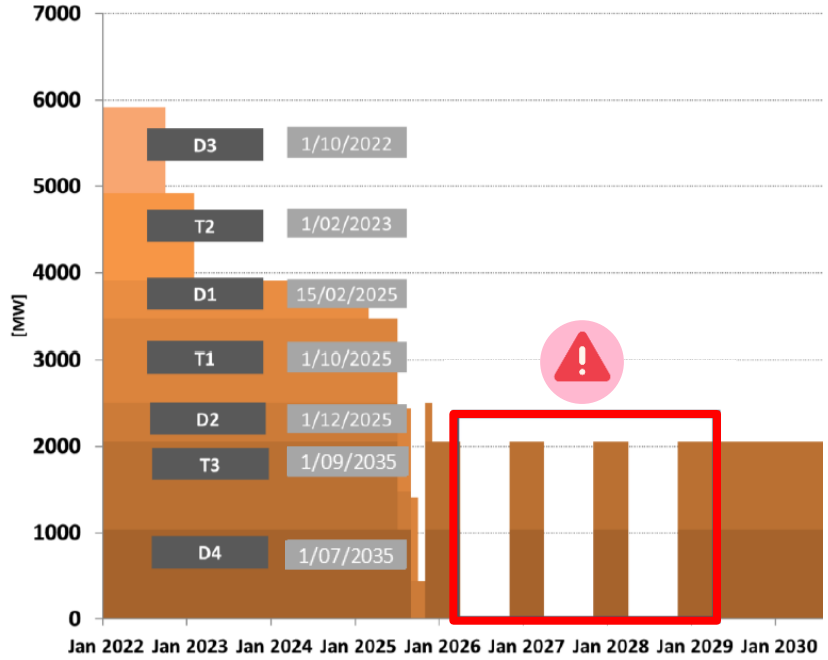
	Adequacy	Flexibility	Grid stability
Goal	**Do we have enough electricity available to meet demand?**	**Can the system handle rapid ups and downs in production and consumption?**	**Is the grid robust enough to face unexpected electrical shocks or phenomena?**
Example	How many power plants / renewable sources do we have?	How fast can we adjust when wind or solar vary?	Can the grid survive a short circuit ?
Analogy			
	Enough muscles to reach the destination	**Enough muscles or brake capability to face local variations**	**Ability to keep the bike balanced and avoid falling when it encounters a sudden obstacle.**

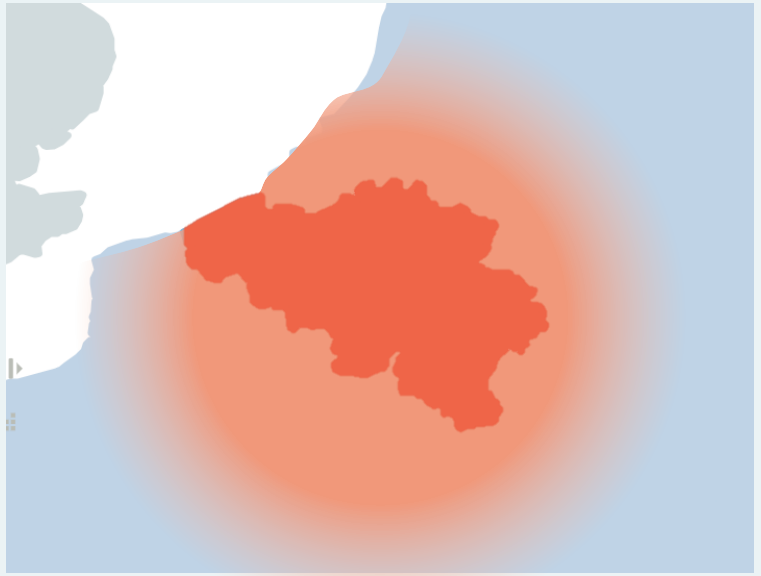
Becoming more critical in the past years because of the increasing penetration of IBR

CONTEXT

As Belgium experiences a growing penetration of renewable energy, the country is facing unprecedented period of three consecutive summers without nuclear power as from 2026, leading to reduced system strength. This unprecedent situation requires a detailed study.

Refurbishments of D4 and T3 are needed to prepare them for running until 2035. Both nuclear units will therefore be out during 3 consecutive summers (1/4 till 1/11) in 2026, 2027 and 2028.
Belgium will face unprecedented periods without nuclear, while renewable energy keeps growing.
Elia conducted a dedicated grid security assessment for these periods of reduced system strength.





Due to the replacement of synchronous machines with power converters, a similar reduction in system strength is being observed in the south of the Netherlands and the west of Germany. Grid stability has thus become a broad challenge that requires analysis and cooperation beyond national borders.

Executive summary

METHODOLOGY

This report summarizes the findings of studies initiated by the unprecedent absence of nuclear in Belgium over the next 3 summers.
While Elia conducts daily system security assessments, dedicated analyses are carried out in specific cases such as this one. The findings concerns summer 26 but the study will last 3 years, corresponding to the duration of summers without nuclear.

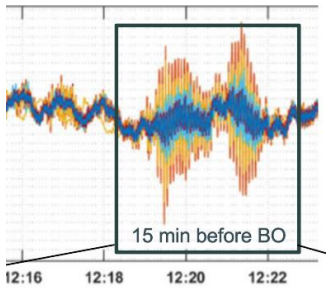
The study's structure is tailored in 3 streams, addressing the Belgium's specific situation while also covering the main issues identified during the Iberian blackout

OSCILLATIONS

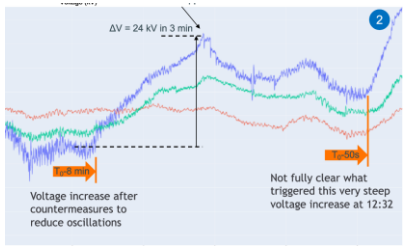
VOLTAGE

DYNAMIC STABILITY

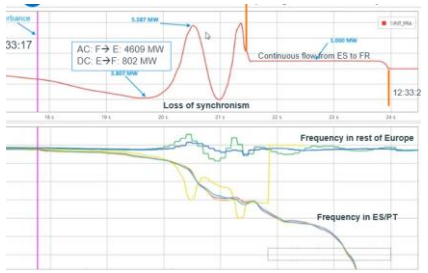
Relation with similar events of Iberic Blackout



Oscillations observed during the last half hour before the event



Fast and important voltage variations leading to GU disconnections and equipment damages



Weak system facing loss of synchronism

Each of the streams went through 3 steps

1. Internal simulation
2. Results exchange & discussion with neighboring TSOs
3. Recommendation assessment

Executive summary

KEY MESSAGES

1. Thanks to its strong interconnections with neighboring countries—especially France—the absence of nuclear power does not pose a risk to grid stability.

From the perspective of oscillations, voltage, and dynamic stability, the absence of nuclear power does not imply an additional risk for the grid. However, our dependency on France increases, making it crucial to address stability disturbances. Close monitoring of stability phenomena during periods without nuclear power is foreseen, requiring the timely deployment of sophisticated measurement devices in Belgium[1].

BE FR

3. Although stability margins are decreasing, the Belgian energy mix and robust interconnections enable the grid to face unexpected shocks.

Dynamic indicators reveal a higher dependency on France and a reduction in stability margins. However, these remain above the steady state security limits and therefore do not indicate additional risk.

2. Despite the temporary increase in voltage pressure, the NCC implemented appropriate measures to remain within operational limits and retains the option to start up additional units as a backup if needed.

The absence of nuclear units, combined with outages and reduced voltage support from neighboring grids, will bring steady-state voltage close to its limits, increasing operational stress. Adapted measures are planned, including more frequent short-term assessments and additional focus on the high-urgency VSP tender[2]. If these measures are not sufficient, the startup of a limited number of units may be necessary. This period of stress is expected to end in early 2027 with the commissioning of shunt reactors, confirming the value of investing in such assets.

4. The overall reduction of stability margins will require close operational attention at the NCC in collaboration with neighboring TSO and grid users.

The National Control Center will take the upcoming operational pressures into account. In addition, close collaboration with neighboring TSOs is planned to improve coordination on outages and exchange methodologies. This will also include raising awareness among power plant owners and grid users.

1: The sophisticated measurement devices are called Phasor Measurement Units (PMUs), and when combined into a network for system-wide monitoring, they form a Wide Area Measurement System (WAMS).

2: High urgency VSP Tender: A fast track “tender” for Voltage Service Provider has been put in place to ensure the MVAR support of coming BESS on the grid.

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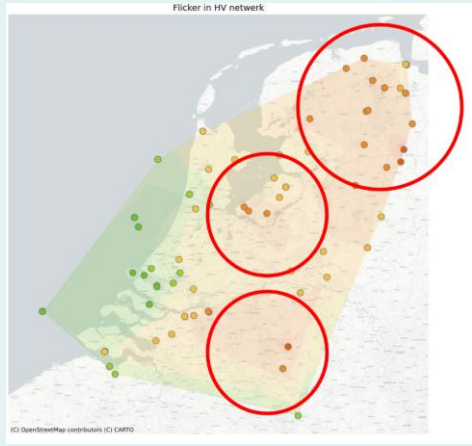
METHODOLOGY TO ASSESS OSCILLATIONS

Two type of oscillations under observation

Low frequency range < 1 Hz

It typically involves interactions between distant regions of the European grid and is referred to as Interarea Oscillations (IAO). ELIA is at the center of this these oscillations and has limited observability and controllability.

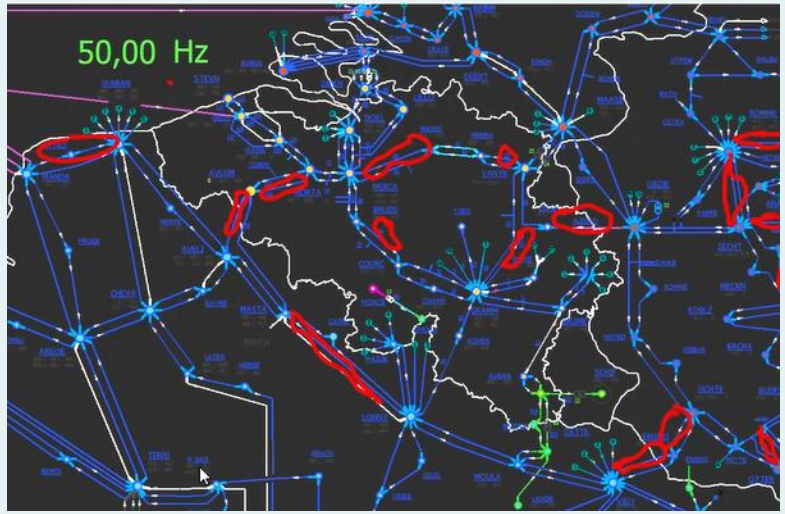
High frequency range > 3 Hz



These oscillations originate from one or a group of assets and are visible within a specific area of the grid, rather than system-wide.

In this study, we focused on the 3.5 Hz oscillation from the TenneT NL grid, which is sometimes noticeable in Dutch household lightbulbs and is visible as frequency and voltage oscillation also in ELIA network.

Simulations across a wide area

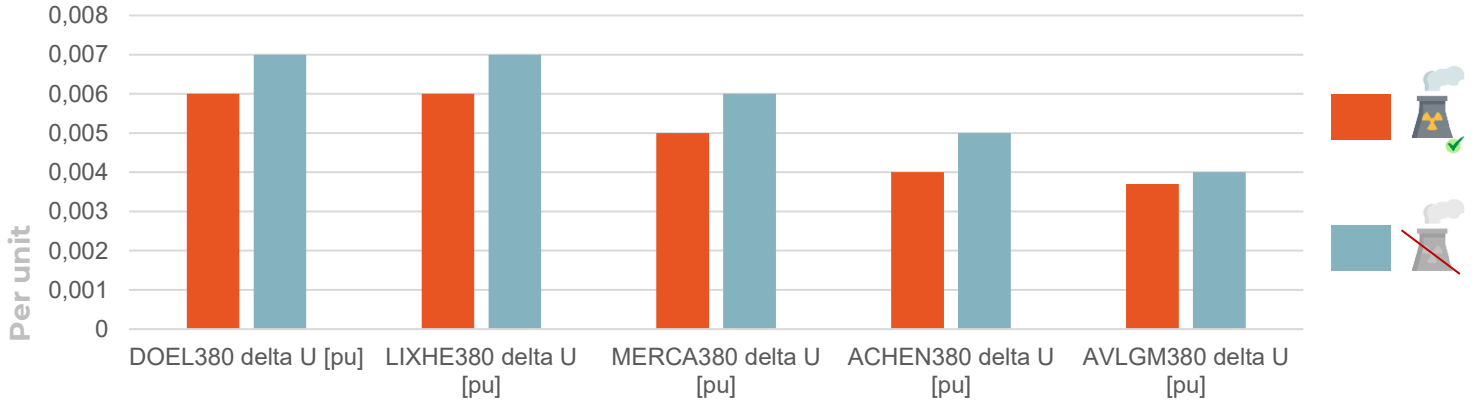


Root Main Square (RMS) simulations are performed with a model area **broader** than Belgium as shown on the picture (BE, North FR, South NL and West DE).

- Simulations involves the injection of a forced oscillation in TenneT NL to reproduce the same magnitudes observed in the past in ELIA.
- Oscillations phenomena are then observed with, and without nuclear.
- Several scenarios performed using different topologies, different models of ALEGrO HVDC and different combination of maintenances.

MINIMAL IMPACT FROM THE ABSENCE OF NUCLEAR ON OSCILLATIONS, EXCEPT IN ONE SPECIFIC CASE THAT HIGHLIGHTS THE IMPORTANCE OF OUR CONNECTION TO FRANCE.

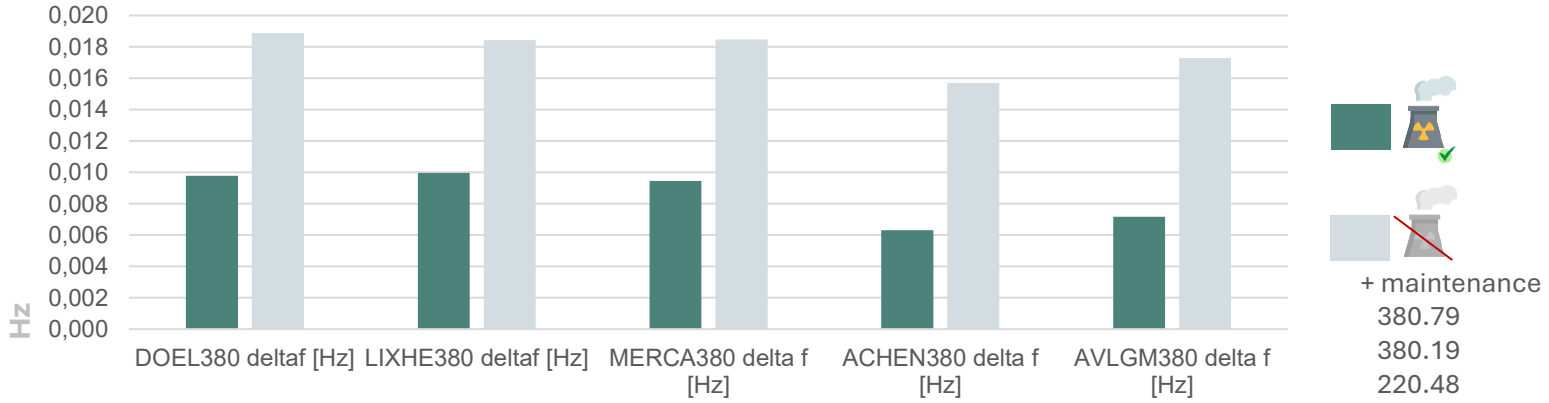
Voltage Amplitudes Oscillation with-without NPP



WHAT DOES THIS GRAPH DEMONSTRATE

The graph shows that on voltage amplitude, there is limited impact of the absence of nuclear for the 3.5 Hz oscillation simulated during the analysis.

Frequency Amplitude Oscillations without NPP, with maximum maintenances in BE/NL/FR/DE and additional disconnections on different elements



The same conclusions can be outlined for frequency, except in one particular case: If we consider the worst case of maintenance without Nuclear Power Plant during the summer 26 and disconnection of critical BE-FR lines. In this case we observe a significant increase in the oscillation amplitude of the frequency.

Oscillations conclusions

NEIGHBORING TSO CONSIDERATIONS

TenneT NL

Very concerned in general with the oscillation problems as already in 2024 and 2025 very high amplitude observed in NL network. Strongly appreciate the work performed by ELIA.

Several actions ongoing with the NL DSOs to look for the cause of the oscillations.

If effectively high number of maintenances or higher observed oscillations are measured, coordination will be needed to assess and implement potential mitigation means.

amprion verbindet

Limited concern as (like ELIA) limited impacted by high frequency oscillations.

Considering the novelty of the issue and of the analysis, methodology confirmation of the study against real data in summer 2026 is recommended.

RTE

Mostly concerned on the potential mitigation actions that have to be coordinated in general to avoid unforeseen consequences (e.g. what happened in the Iberic Blackout with oscillation mitigation).

As no mitigation actions are foreseen, the risk should be low.

No additional concerns relative to the result of the study.

CONCLUSIONS

1. **The absence of nuclear doesn't bring additional risk regarding the oscillations**
2. Except in the worst scenario combining absence of nuclear and disconnection of critical lines with France. This highlights the importance of our connection to France
3. The increase in amplitude of frequency oscillation highlights the importance to keep minimal 380 kV between France and Belgium during absence of Nuclear
4. The source of the TENNET NL Oscillation is not yet clear and all these simulations are based on new methodologies. We will validate the results against real measurement data and potentially simulations during summer 26

NEXT STEPS

1. The monitoring of such phenomena is crucial to avoid incidents, and the PMU/WAMS deployment plan of Elia will be necessary to do so.
2. Exchange of critical measurement with neighboring TSO will be automated

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METHODOLOGY TO ASSESS STEADY STATE VOLTAGE STABILITY

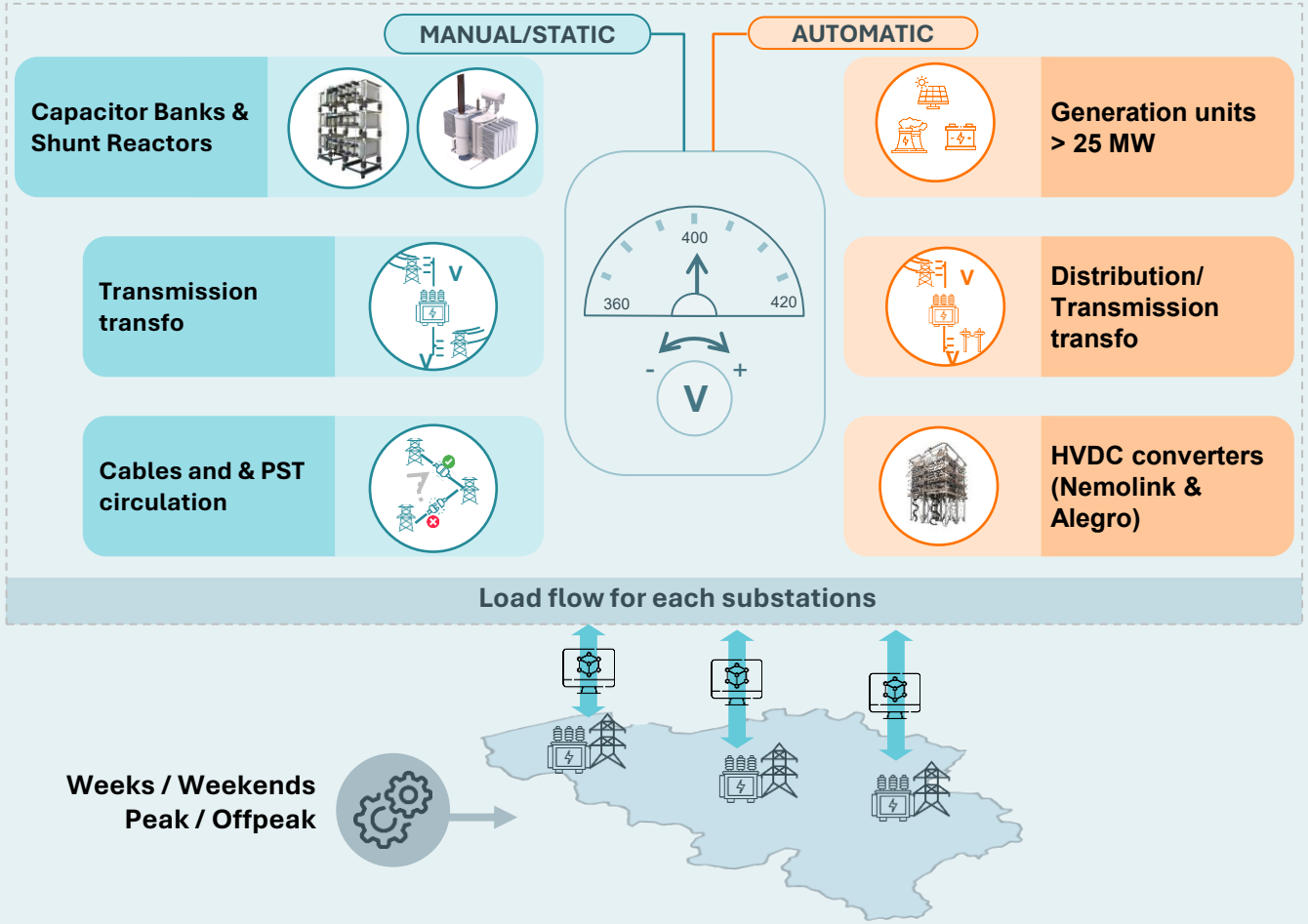
Volt control study from 2023

The voltcontrol study, performed every 2 years is a calculation of system needs

For the summer 2026 study, in addition to incorporating the results of the voltage control study, simulations were performed using modified EMS snapshots

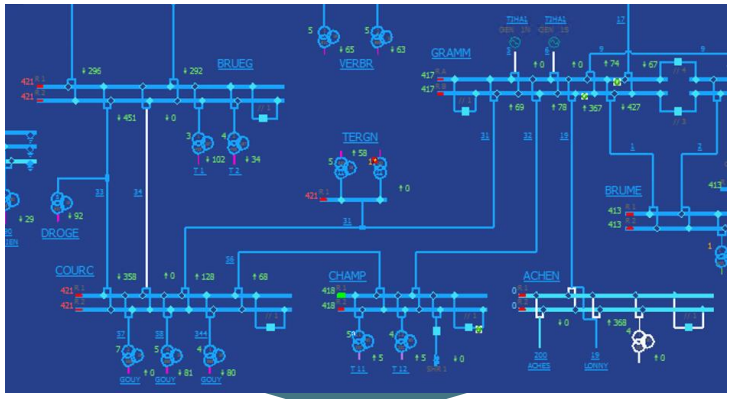
These simulations assessed the expected steady-state voltages in a few conservative scenario's for the period without nuclear availability

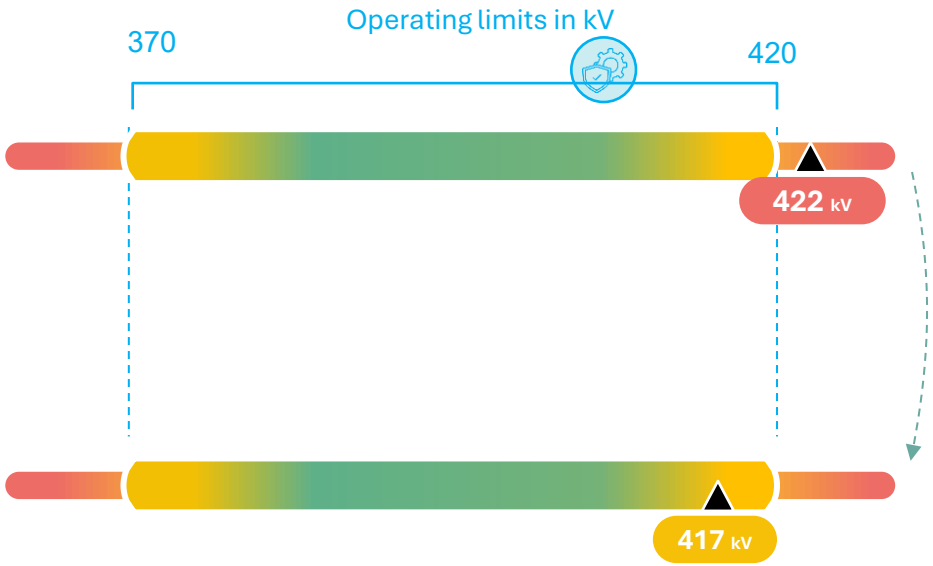
Voltage means support assessment



Study results

Need to de-energise a large volume of cables!





OFFPEAK SCENARIOS: For voltage management, the worst scenarios are offpeak scenarios. This where the voltage is the closest to the high limits and most challenging. Offpeak scenarios involve usually low proportion of synchronous machines and either a low load or a high production of PV:

- Challenging period starts from the 3rd of April
- 3 am at night where the load is low or 2 pm when PV production is at its peak
- Weekend nights and afternoons

WHAT DO THE RESULTS DEMONSTRATE

1. The results indicate that, during off-peak scenarios, voltages could exceed 420 kV, which is above the operational upper limit. Although, 422 kV this is still far from the voltages observed during the Iberian blackout, voltage levels should be kept within operational limits to potential avoid equipment damage.

2. With the right measures, such as de-energizing a large volume of cables and lines and maximizing the use of VSP[1], voltages can be brought within operational limits. However, these actions may conflict with congestion and outage management, necessitating very careful planning. Note that these measures are familiar to operators and will require careful planning since it may conflict with congestion and outage management

3. The study shows it's possible to decrease the voltages to 417 kV. It means that voltage is close to, but still within, the operational limits

Unlike during the Iberic blackout, no self excitation leading to overvoltage instability has been identified in Belgium.

1: Voltage Service Provider

NEIGHBORING TSO CONSIDERATIONS

TenneT NL

TenneT is targeting to have as much as possible generators with automatic voltage control.

TenneT ensure that at least one generator is running in MAASB380, close to Belgium.

amprion verbindet

In comparison to other TSO, Amprion faces a less critical situation regarding lack of shunt reactors.
This strong neighbor is providing Elia with much needed voltage support capability to the region. In the whole Southern and Eastern areas, the only true potential for alleviating voltage issues in the following 3 years is contracting of reactive power by the DSOs from their own customers. There is a lot of unused potential from solar PV plants in the DSO grids.

Rte

A summer 2026 study was performed that concluded that as long as voltage is within operational limit in Elia grid, no impact has been identified on RTE grid. For voltage management in the north of France, 4 units of Gravelines are needed. 5 units minimum are scheduled.The worst case for France is 2 or 3 only units available, in such case, some units shall be started.

CONCLUSIONS

1. Due to the absence of nuclear power plants, combined with still an inadequate amount of shunt reactors in service, voltage management will be very challenging for a period of time.
2. This will bring the voltages close to, but within, the operational limits if required measures are applied
3. On the short term:
    1. Acceleration of high urgency VSP tender
    2. An important amount of cables need to be deenergized in off-peak, for a total amount of 400 Mvar. A planning exercise is underway to ensure this volume is available
    3. Because of being close to the limit, short term studies (day ahead) shall be more frequent, and will be performed to identify the need to start must runs.
    4. The optimization of PST circulation will be assessed in real time
4. On the long term:
    1. Sufficient shunt capacity is expected to be available by Q1 2027 and close the period of risk

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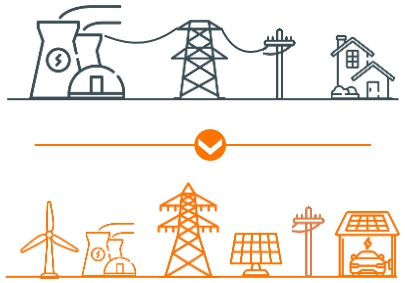
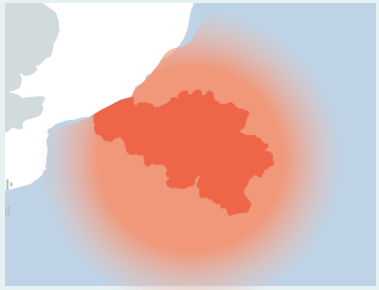
METHODOLOGY TO ASSESS DYNAMIC STABILITY

Classical methods to identify risks for dynamic security are looking at transient stability of synchronous machines. However, power systems are evolving with the integration of inverter-based resources and the decommissioning of large synchronous power plants. As a consequence, new methods need to be developed to properly assess dynamic security.



This study relies on classical and recent methods to identify risks for the dynamic security of the Belgian grid but also developed new indices to better capture risks for system stability with less and less synchronous generators.

1 Generation of different grid models based on scenarios



NUCLEAR; With and without Belgian nuclear

TOPOLOGY; Several maintenances options

GENERATION MIX

High synchronous machines, low RES

Low synchronous machines, high RES

2 Dynamic security assessment through indicators

- Short circuit level (SCL)
- Aggregate SCR
- MW at risk
- Maximum flow exchange

LOW → **2 bis**

If aggregate SCR is below a threshold, more detailed dynamic simulations are performed to assess the risk of converters instability

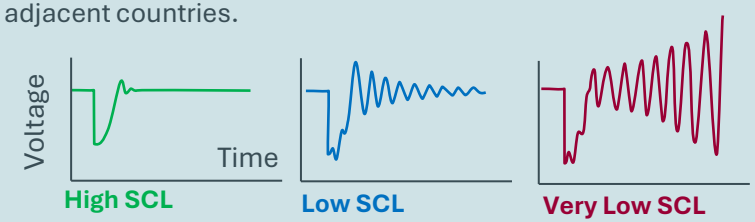
CONCEPT BOX

CONCEPT CLARIFICATION: The indicators

Short circuit level (SCL)

Short-circuit level computed at one of 400 kV substation, MERCATOR, during a fault. It gives an estimation of the grid strength and its ability to maintain stable voltage during and after a grid disturbance (fault, loss of generator/load,....).

It also gives a view on the contribution from Belgium compared to adjacent countries.



Aggregate SCR

Aggregate SCR is the short-circuit power at an electrical node divided by the capacity of the inverter-based injectors around that node weighted by their voltage sensitivity. It estimates the system strength in areas **with high penetration of inverter-based resources.**

LIMITS:

1. Aggregate SCR → 2.5 → Dynamic studies
2. Dynamic studies → 1.5 → **Stability limit reached**

MW at risk

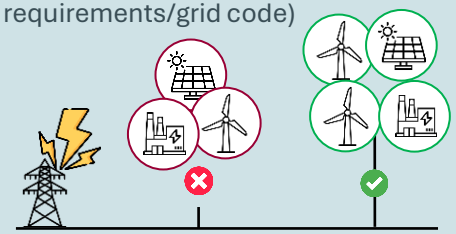
The index monitors the **loss of injected power after a short-circuit** event. It is based on RMS simulations.

Direct indicator

- MW of synchronous generators at risk after a short-circuit
- Based on **accurate protection schemes.**

Indirect indicator

- MW of PPMs[1] type B,C,D, and SPGMs type B, C, D at risk after a short-circuit
- Based on **assumed protection schemes** (following Belgian technical requirements/grid code)

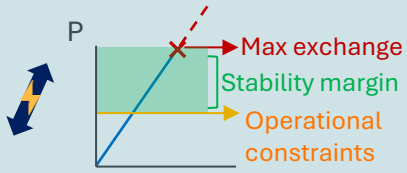


LIMITS:

1. **1000 MW =** warning for balancing of BE control areal
2. **3000 MW** = Continental Europe dimensioning incident

Maximum flow exchange

1. **Active power transfer** between BE-NL and continental EU is increased **until dynamic instability** occurs
2. The **maximum exchange** is determined in both directions, BE-NL ⇔ continental EU and **compared with static flow** based on flow based limits domain
3. Provide a **stability margin** relative to **operational constraints**



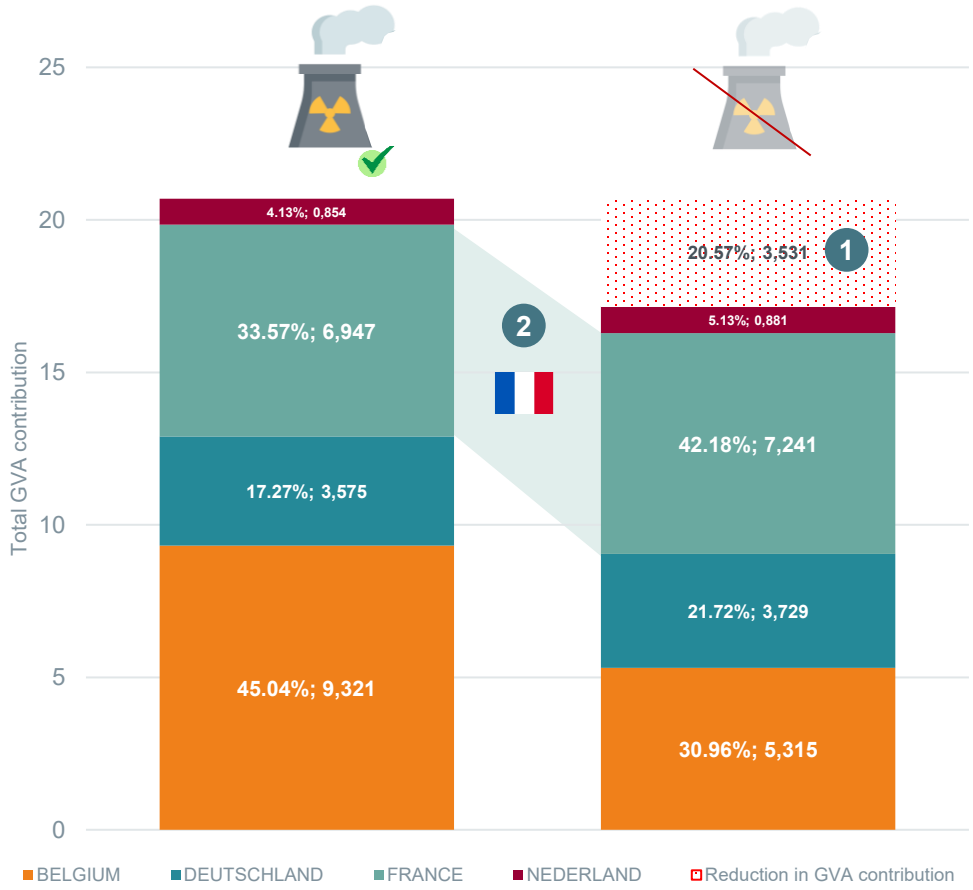
1: PPM = Power Park modules

2: SPGM = Synchronous Power-Generating Module

ABSENCE OF NUCLEAR INCREASING DEPENDENCY TO FRANCE

Short circuit level (SCL)

Short circuit level for a fault at one of most important Belgian substation, MERCATOR and contribution of other TSOs



WHAT DOES THIS GRAPH DEMONSTRATE

1. Without nuclear the total short circuit power is decreased by about 20%
2. With 42 %, France becomes the major contributor of short-circuit power

Without nuclear, the short circuit decreases, highlighting a weaker system strength.
It also shows a higher reliance on France for system stability.

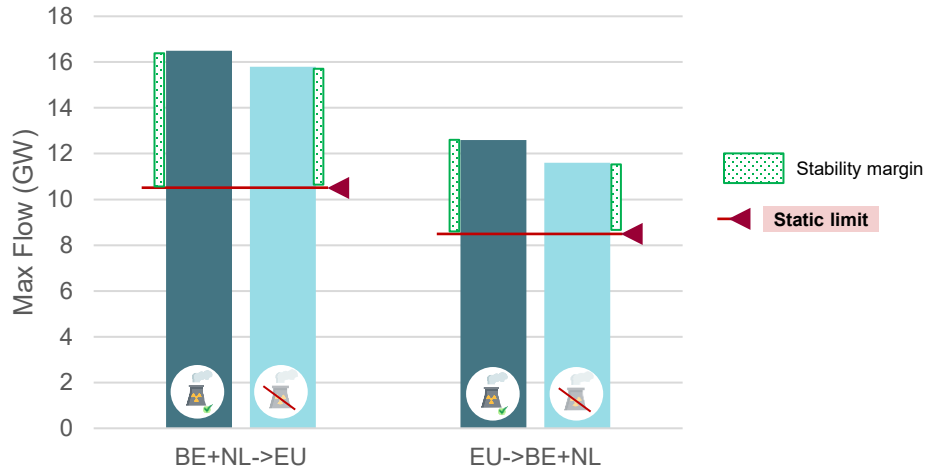
REDUCED STABILITY MARGINS IN NO NUCLEAR SCENARIO

With nuclear

Without nuclear

Maximum flow exchange

Stability margin analysis trough maximum flow exchange in a context of high PV production

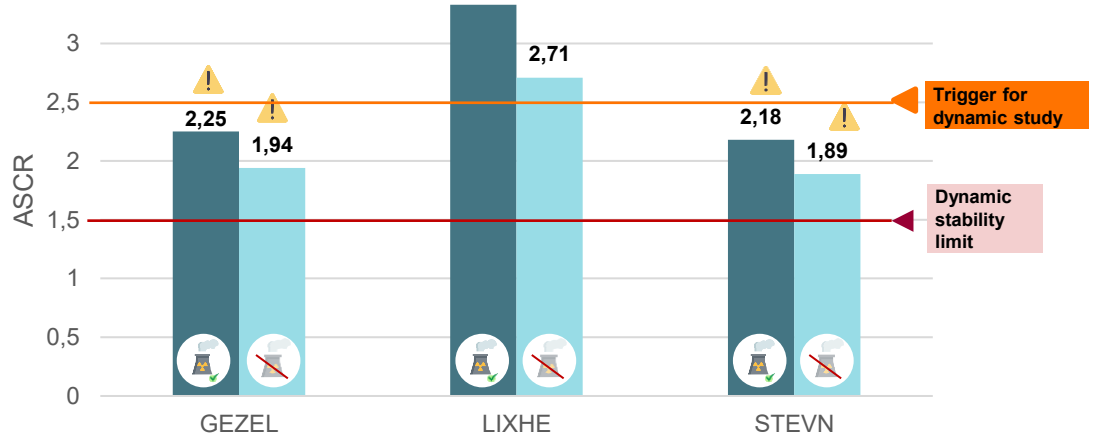


WHAT DOES THIS GRAPH DEMONSTRATE

- Without nuclear, the stability margins are reduced
- However, we do not reach a point where the dynamic security is a limiting factor for the maximum exchange among neighboring countries

Aggregate SCR

Stability margin analysis through aggregate SCR



WHAT DOES THIS GRAPH DEMONSTRATE

ASCR shows the risk of converters instability

- The indicator goes below the threshold at which we trigger dynamic studies at STEVIN and GEZEL without **and** with nuclear
- Additional dynamic studies have been performed and didn't indicate risk of instabilities
- In general, we see that without nuclear, the indicator value is reduced yet remains above the dynamic stability limit

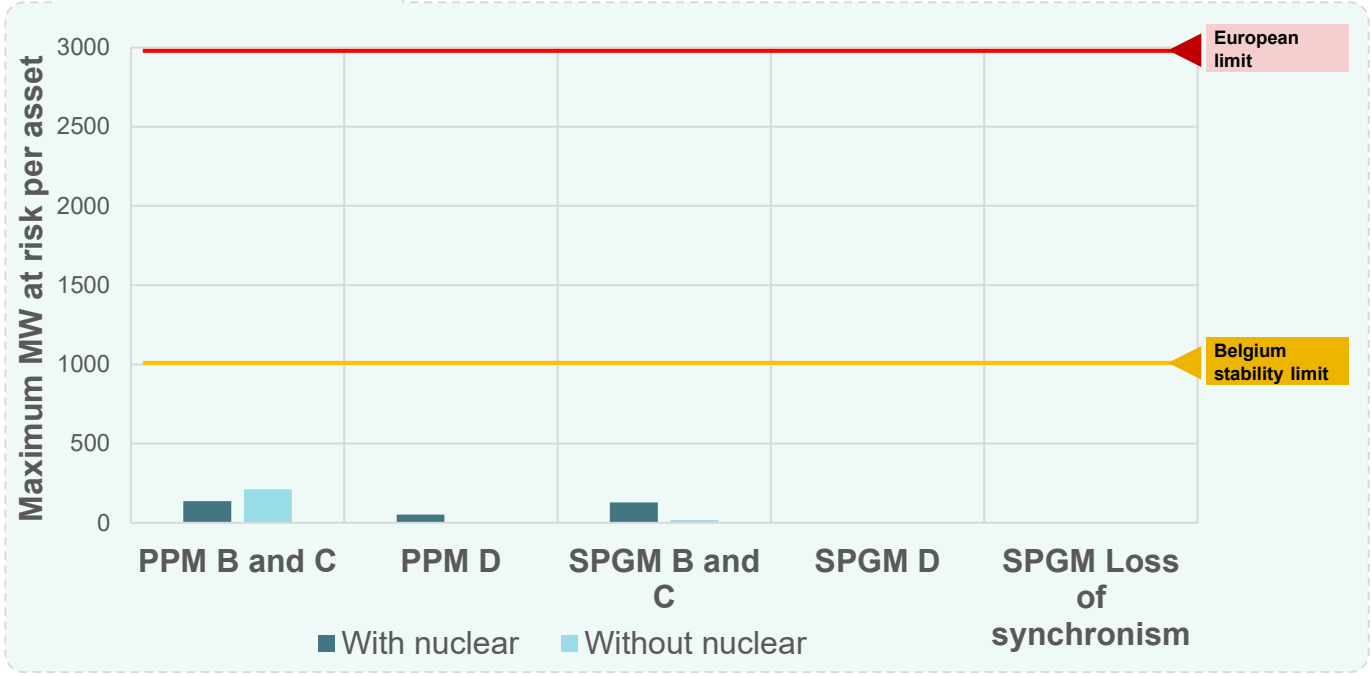
Although no risks have been identified, the system without nuclear is operated closer to its stability limits.

ALTHOUGH INDICATORS SHOW SOME IMPACT FROM THE ABSENCE OF NUCLEAR, THIS IS NOT IDENTIFIED AS A RISK TO DYNAMIC STABILITY.

MW at risk | Maximum flow exchange | Aggregate SCR

All indicators are within stability limits

Graphs on previous slide



WHAT DOES THIS GRAPH DEMONSTRATE

- Results of RMS simulations show that there is no significant difference in terms of potential loss of MW between with and without nuclear.
- This means that there is no risk implied by the absence of nuclear for grid stability

Although we are operating closer to stability limits, the study did not demonstrate any risks to grid stability.

1: PPM = Power Park modules 2: SPGM = Synchronous Power-Generating Module

NEIGHBORING TSO CONSIDERATIONS

- The grid in northern France is robust, supported by a significant number of nuclear units.
- However, critical power plants outage can't be anticipated but timely notification and corrective operation measures are foreseen by RTE
- These 2 information shall be communicated to close to real time engineer
- RTE is assessing transient stability risk and remedial actions assessment hourly

- TenneT is currently migrating its dynamic model from PSS/E to PowerFactory
- Detailed RMS analysis will be possible as from end of 2026.
- Preliminary short-circuit results are more optimistic than those presented by Elia, mainly due to conservative assumptions in Elia's analysis.

- The grid in western Germany is robust, with a highly meshed structure and large generators running most of the time.
- Static short-circuit analysis indicates that the impact of Belgian nuclear unavailability is very limited.

1. Each TSOs confirms that **dynamic phenomena are becoming increasingly important and challenging**. These phenomena now **require greater attention during operational activities**.
2. All TSOs are working towards implementing Dynamic Security Assessment in the near future.
3. TSOs acknowledge that, new dynamic phenomena must be assessed. However, for evaluating these emerging phenomena, methods, indicators, and acceptable thresholds are still primarily topics within research and development.

CONCLUSIONS

1. The absence of nuclear increase Belgian's dependency to France.
2. The indicators also show a reduction of stability margins
3. Although we are operating closer to stability limits, the study did not demonstrate any risks to grid stability.

RECOMMANDATIONS

- It is recommended to avoid having 2 FR-BE 380kV lines in maintenance at the same time during the no nuclear period
- New methodology and indicators to assess dynamic security have been developed during this study. These indicators will be implemented during the no nuclear period and integrated into operational processes.
- An expert will be dedicated to analyse the indicators

NEIGHBORING TSO COMMON RECOMMANDATIONS

1. Increase the frequency of exchange regarding
    1. **Planning:** unavailability about generators and grid elements
    2. **Methodology:** Quartely meeting for stability assessment and monitoring
2. Improve cross-border models
3. Monitor relevant indicators
4. Provide clear operational measures towards operators