EVALUATION OF STRATEGIC DEVELOPMENT IN THE RENEWABLES SECTOR IN ROMANIA

Analysis of the Romanian transmission grid development

Romanian Wind Energy Association (RWEA)

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Customer contact:	Kees Stiggelbout	
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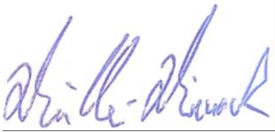
DNV Energy
DNV Energy Systems Germany GmbH
Gostritzer Str. 67
01217 Dresden
Germany

Tel: + 49 30 600 866 80
Registered Hamburg HRB 149659

Prepared by:
Arvid Björemark
Gabriela Cretu
Dr. Konstantin Petrov
Christian Hewicker

Verified by:



Dr. Matthias Müller-Mienack
Managing Consultant

Approved by:

Dr. Matthias Müller-Mienack
Managing Consultant

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1 BACKGROUND

DNV Energy Systems Germany GmbH operates as part of the DNV Group under the name "DNV – Energy Systems" (herein after referred to as "DNV") and has been commissioned by the Romanian Wind Energy Association (RWEA) to conduct a study identifying Romania's technical and regulatory needs for the integration of more renewable energy in context of the energy transition process. In this context, initially a review of the latest Ten-Year Network Development Plan (TYNDP 2020-2029) for Romania should be conducted. But as agreed with Transelectrica after the project kick-off, the focus of the project shall be on the analysis of the Romanian transmission grid development in preparation of the TYNDP 2022-2031.

The project shall comprise the comparison of the RES scenarios implemented in the Romanian TYNDP with the official renewable energy sources (RES) scenarios documented by the National Energy and Climate Plan (NECP) [4], the evaluation of the adequacy of the transmission grid measures incl. flexibility measures identified in the TYNDP and proposal of optimized or additional measures if required. Finally, financial options and the regulatory policy shall be proposed in order to facilitate the realization of required grid and flexibility related measures.

2 RELEVANT CHANGES AGREED IN INCEPTION PHASE

Although the principal approach and methodology for execution of this project have largely remained unchanged compared to the original DNV proposal, like documented in Inception Report [1] the following changes with relevance to this Report "Comparison of RES scenarios NECP vs. TYNDP" have been agreed:

- Instead of analyzing the latest published release "Planul de Dezvoltare a RET perioada 2020 – 2029" [2], the scenarios of the ongoing TYNDP "Planul de Dezvoltare a RET perioada 2022 – 2031" [3] shall be subject of DNV's investigation.
- In consequence, the time horizons to be reviewed are the following ones: 2022 (reference case), 2026 and 2031 time horizon.
- Since the 2026 scenarios reflect a significant number of transmission projects already finally decided, the main focus of the DNV review shall be on the year 2031.

2.1 Provision of required updated data

As underlined in Chapter 2.1, the project was launched by RWEA by mid 2020 requiring the consultant to compare the RES scenarios in NECP with TYNDP 2020-2029. At that time, TYNDP 2020-2029 was the latest bi-annually revision adopted by Transelectrica[1] and the Romanian Regulator ANRE. On 8 December 2021, during the project kick-off meeting with RWEA and Transelectrica, a comparison of the RES scenarios NECP versus TYNDP 2022-2031, currently drafted by Transelectrica, was agreed to be conducted.

Based on a DNV data request letter to the Transelectrica management and the subsequent NDA agreed between Transelectrica and DNV, Transelectrica provided all relevant data required for the comparison of the RES scenarios NECP vs. TYNDP as well as for evaluation for network scenarios and conducting of network simulations.

[1] https://www.transelectrica.ro/ro/web/tel/planului-de-dezvoltare-ret-2020-2029

3 COMPARISON OF RES SCENARIOS NECP VS. TYNDP (TASK 1)

Task 1 is dedicated to the comparison of RES scenarios. In the framework of this first task, the RES development pathway of the current NECP scenario was evaluated technology wise. And it was analysed to which extent the RES scenarios of NECP & Energy Strategy should be reflected in the ongoing TYNDP looking at 2022 - 2031.

3.1 Clean Energy for all Europeans Package

In 2019 the EU overhauled its energy policy framework to help us move away from fossil fuels towards cleaner energy - and, more specifically, to deliver on the EU’s Paris Agreement commitments for reducing greenhouse gas emissions. The agreement on this new energy rulebook – called the **Clean energy for all Europeans package** – marked a significant step towards implementing the energy union strategy, published in 2015.

Based on Commission proposals published in 2016, the package consists of 8 new laws. Following political agreement by the EU Council and the European Parliament finalized in May 2019 and the entry into force of the different EU rules, EU countries have 1-2 years to convert the new directives into national law.

The new rules will bring considerable benefits for consumers, the environment, and for the economy. By coordinating these changes at EU level, the legislation also underlines EU leadership in tackling global warming and makes an important contribution to the EU’s long-term strategy of achieving carbon neutrality (net-zero emissions) by 2050.

To show global leadership on renewables, the EU has set an ambitious, binding target of 32% for renewable energy sources in the EU’s energy mix by 2030. The revised Renewable Energy Directive (2018/2001/EU), which contains this commitment, entered into force in December 2018. The EU countries shall commonly contribute towards reaching the EU binding target of 32% without a binding target for renewable energy sources set at national level.

The package includes also a robust governance system for the energy union, the EU's plan to fundamentally transform Europe's energy system. Under this strategy, each EU country is required to establish and submit an integrated 10-year national energy and climate plans (NECPs) for 2021-2030 by December 2018. The NECPs outline how EU countries will achieve their respective targets on all 5 dimensions of the energy union, including a longer-term view towards 2050.

The initial NECP of Romania was submitted by December 2018 as required. Following the European Commission assessment of the NECPs of all EU countries, an updated version of the Romanian NECP was finalized and submitted to the European Commission in April 2020.

The comparison of the RES scenarios is based on the updated NECP (April 2020) as available on European Commission website[2].

3.2 National Energy and Climate Plan of Romania

The revised NECP of Romania with updated energy and climate targets was submitted to the European Commission in April 2020. The revised NECP of Romania is identifying the national contribution to the EU objectives by 2030 as outlined in the Table 3-1 below:

[2] https://ec.europa.eu/energy/sites/default/files/documents/ro_final_necp_main_en.pdf

Table 3-1:NECP: Overview of the energy and climate targets by 2030 [4]

Overview of the energy and climate targets in NECP by 2030	
ETS emissions (% compared to 2005)	**-43.9 %***
Non-ETS emissions (% compared to 2005)	**-2 %**
Overall share of renewable energy in gross final energy consumption	**30.7 %**
↓	
RES-E share	49.4 %
RES-T share	14.2 %
RES-H&C share	33.0 %
Energy efficiency (% compared to the PRIMES 2007 projection for 2030)	
Primary energy consumption	-45.1 %
Final Energy Consumption	-40.4 %
Primary energy consumption (Mtoe)	32.3
Final energy consumption (Mtoe)	25.7

The overall effort to reach 30.7% share of renewable energy in gross final energy consumption translates to an additional 946.8 ktoe contribution of new renewable energy capacities by 2030 as illustrated in Table 3-2.

Table 3-2: NECP: Indicative trajectory, as broken by technology, for renewable energy in gross final electricity consumption [ktoe], 2021-2030 [4]

ktoe	**2020**	**2025**	**2030**
Hydro	1,415.9	1,457.9	1,460.3
Wind	564.6	828.8	1,004.9
Solar	170.4	424.6	632.6
Other renewable sources	77.4	77.4	77.4
Gross final energy consumption of electricity from renewable sources	**2,228.4**	**2,788.7**	**3,175.2**

NECP identified the development of more than 7 GW of additionally installed RES capacities compared to 2020 in order to reach the share of renewable energy of 30.7 % in 2030. The split per RES technology is illustrated in the Figure 3-1 below, where the highest increase can be observed in solar (3.7 GW), wind (2.3 GW) and hydro (1.1 GW).

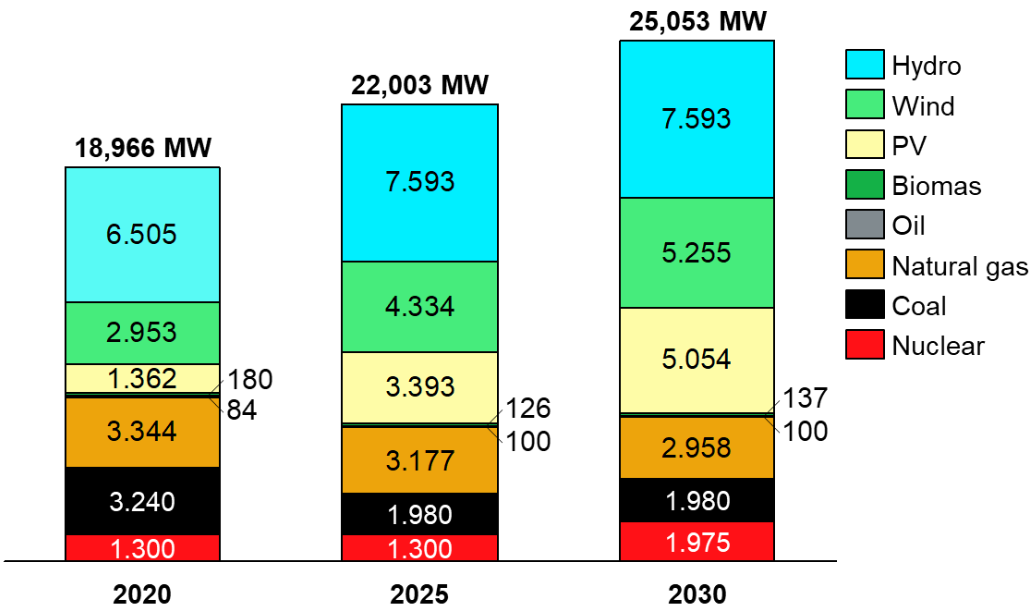


Figure 3-1: NECP: Indicative trajectory of the net installed capacity per source [MW] [4]

In order to meet the trajectory reaching 30.7% RES share in gross final energy consumption, the additional variable RES generation capacities needed to be deployed are:

a) Wind:

- +822 MW additional installed capacity in 2022 compared to 2020
- +559 MW additional installed capacity in 2025 compared to 2022
- +556 MW additional installed capacity in 2027 compared to 2025
- +365 MW additional installed capacity in 2030 compared to 2027

b) Solar:

- +994 MW additional installed capacity in 2022 compared to 2020
- +1037 MW additional installed capacity in 2025 compared to 2022
- +528 MW additional installed capacity in 2027 compared to 2025
- +1133 MW additional installed capacity in 2030 compared to 2027

Moreover, by 2030, besides the deployment of new wind and solar PV additional capacities, there is the need to preserve the existing capacity by repowering. In this respect, it is envisaged that about 3 GW wind and 1.35 GW solar PV will result from repowering.

Assessment by the European Commission

The European Commission issued the *Assessment of the final NECP of Romania* in October 2020[3]. The Commission addressed Romania 's renewable energy contribution to the 2030 EU level target of 30.7% in the revised NECP compared with 34% share resulting from the formula in Annex II to Regulation (EU) 2018/1999 on the Governance of the Energy Union and Climate Action (Governance Regulation). This is triggering the need for the revision of Romania's NECP by 30 June 2023 as stipulated in Article 14 of Governance Regulation[4].

3.3 The Ten Years Network Development Plan (TYNDP)

According to the Romanian legislation transposing the European Directives and Regulations, TYNDP is the outcome of a two-years process, starting with the development of scenarios or visions of how the Romanian power system will contribute to reach the energy and climate objective to 2030 and the vision for decarbonisation to 2050.

According to TYNDP 2020-2029 as latest TYNDP adopted by Transelectrica, the grid development plan is designed to achieve the following goals:

- Secure operation of the national energy system and transmission of electricity at quality standards and conditions set out in the *Technical Grid Code* and the *Performance Standards for Electricity Transmission Service and System Service*
- Transmission grid development to meet the forecasted electricity demand, imports, exports and transits
- Increasing the interconnection capacities of electricity networks
- Meeting the sustainability objectives by integrating the renewable energy into the grid and transmission of renewable energy to the consumers
- Coupling with the single European market on all tiers
- Ensuring non-discriminatory access and connection to the transmission network for all applicants according to the applicable laws and regulations
- Minimize the investment costs when deciding about solutions to develop the transmission grid.

In accordance with Article 30 of Regulation (EC) No 943/2019, ENTSO-E - the European Association for the cooperation of Transmission System Operators (TSOs) for electricity - shall develop and adopt the 'Ten-Year Network Development Plan' - TYNDP. This plan shall be updated and published every two years and is a non-binding **Community-wide ten-year network development plan**, including an assessment of the adequacy of the pan-European electricity system.

The scenarios analysed in the TYNDP 2018[5] were based on national policies and the achievement of the EU energy targets for 2020/2030/2050:

- for the **2020** and **2025** time horizon:

[3] https://ec.europa.eu/energy/sites/default/files/documents/staff_working_document_assessment_necp_romania_en.pdf
[4] https://ec.europa.eu/clima/eu-action/climate-strategies-targets/progress-made-cutting-emissions/governance-energy-union-and-climate-action_en
[5] Ten-Year Network Development Plan Package 2018, ENTSO-E, 2018

- "**Best Estimate Scenario**" - built on data provided by TSOs, reflecting national and European targets.

- for the **2030** time horizon:
  - **"Sustainable Transition (ST)"** - built on data provided by the OTS, considers that CO2 emissions are reduced by replacing coal with gas, national regulations and support schemes are complied with, economic growth is moderate, electricity consumption increases moderately, etc.
  - **"Distributed Generation (DG)"** built on the assumption of the fulfillment of EU energy policies, puts prosumers in the forefront, it is considered a strong economic development, an increase in the number of electric vehicles, the number of photovoltaic panels mounted on buildings, the influence of consumers in flattening the load curve is important, etc. It is considered that electricity is used more in heating, transport, in the production of hydrogen, etc.
  - **"EUCO 30 - External Scenario"** built on a scenario from the European Commission that aims to meet the older 2030 targets set by the European Council in 2014 but includes the 30% efficiency target. This scenario replaced the Global Climate Action (GCA) scenario that had originally been established under ENTSO-E
- for the **2040** time horizon (to make the transition to **2050**):
  - **"Sustainable Transition (ST)**" - built on the 2030 Sustainable Transition (ST) scenario.
  - **"Distributed Generation (DG)"** - built on the "Distributed Generation (GT)" 2030 scenario.
  - **"Global Climate Action (GCA)"** built on the 2030 "Sustainable Transition (ST)" scenario. This scenario emphasises the integration of localised renewables according to wind and solar potential and is based on a global decarbonisation effort. The influence of consumers in flattening the load curve is important. Electricity is considered to be used more in heating, transport, hydrogen production, etc.

Scenarios for 2040 were used to identify new projects to develop the European transport network and scenarios for 2025 and 2030 to estimate the benefits of projects introduced in the TYNDP 2018.

In terms of sustainability requirements, Romanian TYNDP 2020-2029 was build based on two scenarios: **Reference Scenario (RS)** and **Green Scenario (GS)** in order to accommodate an increased uptake of renewable electricity injected into the grid and, subsequently, to develop the transmission grid to meet an increase demand of renewable energy by the final customers.

The projected new generation capacities by 2024 and 2029 are illustrated in the Table 3-3.

Table 3-3: TYNDP: Overview of the generation capacities objectives included in Reference and Green Scenarios [2]

Nr. crt.	Total generation capacities (MW)	TYNDP 2020-2029					
		Reference scenario (RS)			Green Scenario (GS)		
	Year	2020	2024	2029	2020	2024	2029
1	**Nuclear**	**1,325**	**1,325**	**1,325**	**1,325**	**1,325**	**1,990**
2	**Fossil fuels, out of which:**	**7,101**	**6,544**	**6,544**	**7,101**	**6,544**	**6,544**
	Lignite	3,112	3,112	3,112	3,112	2,112	**3,112**
	Brown coal	1050	430	430	1050	430	**430**
	Gas and liquid fuels	2,939	3,002	3,002	2,939	3,002	**3,002**
3	**RES, out of which:**	**4,779**	**5,249**	**6,119**	**4,779**	**5,249**	**7,100**
	Wind	3,200	3,500	**4,000**	3,200	3,500	**4,300**
	Solar	1,400	1,500	**1,800**	1,400	1,500	**2,300**
	Biomass	180	250	**320**	180	250	**500**
4	**Hydro, out of which:**	**6,471**	**6,778**	**6,778**	**6,471**	**6,778**	**7,778**
	Pumped storage	0	0	**0**	0	0	**1,000**
5	**Net generating capacity [5=1+2+3+4]**	**19,676**	**19,896**	**20,766**	**19,676**	**19,896**	**24,412**

It can be noted the total capacity objectives differ with about 3.6 GW in the Green Scenario vs. Reference Scenario in 2029, while the capacity objectives for the intermediate year 2024 is the same in both scenarios.

By 2024 in the Reference Scenario and Green Scenario there is an overall increase of about 230 MW generation capacities by 2024, mostly due to increase of 470 MW RES and of 300 MW hydro offset by a decrease of fossil fuels of about 550 MW.

By 2029, the Green Scenario includes an increase of nuclear generating capacity reaching 1,900 MW with the commissioning of unit 3 (about 665 MW net) in Nuclear Power Plant (Cernavoda), an addition of 300 MW wind, 500 MW solar and 180 MW biomass compared to the Reference Scenario.

The increase of about 1 GW in new RES generation compared with the Reference Scenario is backed for system adequacy purposes by the addition of 1 GW planned in pumped storage (Tarnita). There is no capacity decrease in fossil fuels in the Green Scenario by 2029 compared with 2024 and only a decommissioning of 620 MW in fossil fuels to be reached by 2024.

3.4 COMPARISON NECP 2020-2030 VS. TYNDP 2020-2029

As a general note, the starting point 2020 displays an underestimation of generation capacities in NECP of about 0.7 GW compared with TYNDP.

When comparing the capacity objectives in NECP with TYNDP for years 2029/2030 illustrated in Table 4-1, we can also identify a significant gap mostly in terms of RES and fossil fuels capacities.

The RES capacities are underestimated with about 3.3 GW in Green Scenario in TYNDP 2030 vs. NECP 2030. This translated to an underestimation of 1 GW in wind, 2.7 GW solar and an overestimation of 343 MW of biomass. Moreover, the significant increase of 3.3 GW in wind and solar capacities in NECP remain highly questionable to be achieved as planned by 2025.

While the system adequacy analysis in the Green Scenario TYNDP identifies the need for an additional 1 GW in pumped storage by 2029, NECP foresees an increase of more than 1 GW hydro that can be hardly achieved as planned by 2025.

In terms of decarbonisation measures, the NECP considers a significant reduction of about 1.5 GW of fossil fuels capacities by 2025, while TYNDP envisaged a reduction of only 650 MW by 2024 constant to 2030.

Table 3-4: Projected total installed capacities NECP vs. Green Scenario TYNDP 2020-2029

Nr. crt.	Total generation capacities (MW)	TYNDP 2020-2029 Green Scenario			NECP		
	Year	2020	2024	2029	2020	2025	2030
1	**Nuclear**	**1,325**	**1,325**	**1,990**	**1,300**	**1,300**	**1,975**
2	**Fossil fuels, out of which:**	**7,101**	**6,544**	**6,544**	**6,764**	**5,257**	**5,038**
	Lignite	3,112	3,112	3,112	3,240	1,980	1,980
	Brown coal	1,050	430	430			
	Gas and liquid fuels	2,939	3,002	3,002	3,524	3,277	3,058
3	**RES, out of which:**	**4,779**	**5,249**	**7,100**	**4,399**	**7,853**	**10,446**
	Wind	3,200	3,500	**4,300**	**2,953**	**4,334**	**5,255**
	Solar	1,400	1,500	**2,300**	**1,362**	**3,393**	**5,054**
	Biomass	180	250	**500**	**84**	**126**	**137**
4	**Hydro, out of which:**	**6,471**	**6,778**	**7,778**	**6,505**	**7,593**	**7,593**
	Pumped storage	0	0	1,000			
5	**Net generating capacity [5=1+2+3+4]**	**19,676**	**19,896**	**24,412**	**18,968**	**22,003**	**25,053**

Whereas the RES share in the total installed generation capacity [GW] as reflected in the NECP amounts to 23 % in 2020, 36 % in 2025 and 42 % in 2030, lacking a full-year market simulation with at least hourly granularity the latest release of Romanian TYNDP cannot provide concrete RES penetration values [TWh] for the future time horizons.

3.5 COMPARISON NECP 2020-2030 VS. draft TYNDP 2022-2031

The next TYNDP is currently in preparation, this TYNDP 2022-2031 is expected to be submitted for approval to the Regulator by mid 2022.

In January 2022, Transelectrica confirmed the power mix in the Green Scenario used in the draft version of TYNDP 2022-2031. According to the company representatives, the draft TYNDP 2022-2031 uses only one scenario (the Reference Scenario describes the Green Scenario) for the 2030 energy mix aligned with the variable renewable energy capacities projected in NECP.

According to the draft Reference/Green Scenario 2022-2031, the comparison of energy mix TYNDP – NECP is as follows:

Table 3-5: Projected total installed capacities NECP vs. Green Scenario draft TYNDP 2022-2031

Nr. crt.	Total generation capacities (MW)	TYNDP 2022-2031 Reference/Green Scenario			NECP		
	Year	2022	2026	2031	2020	2025	2030
1	**Nuclear**	**1,300**	**1,300**	**2,630**	**1,300**	**1,300**	**1,975**
2	**Fossil fuels, out of which:**	**6,048**	**7,135**	**7,047.5**	**6,764**	**5,257**	**5,038**
	Lignite	3,189	2,270	2,270.5	3,240	1,980	1,980
	Brown coal	0	0	0			
	Gas and liquid fuels	2,859	4,865	4,777	3,524	3,277	3,058
3	**RES, out of which:**	**5,026**	**8,126**	**10,540**	**4,399**	**7,853**	**10,446**
	Wind	3,400	4,500	**5,300**	**2,953**	**4,334**	**5,255**
	Solar	1,500	3,500	**5,100**	**1,362**	**3,393**	**5,054**
	Biomass	126	126	**140**	**84**	**126**	**137**
4	**Hydro, out of which:**	**5,987**	**6,380**	**6,420.6**	**6,505**	**7,593**	**7,593**
	Pumped storage	0	0	**0**			
5	**Net generating capacity [5=1+2+3+4]**	**18,361**	**22,941**	**26,638**	**18,968**	**22,003**	**25,053**

Analysing the new capacity projections in the draft TYNDP 2022-2031, we remark:

- Overall, the net generating capacities are 1.6 GW higher in TYNDP than in NECP;
- The TYNDP projects one additional nuclear unit of 0.66 GW (Cernavoda) and additional 2 GW in fossil fuels than in the NECP, mostly new gas fired;
- The variable renewable energy capacities projections are aligned with the NECP values;
- The hydro capacities in 2031 do not account for at least 1.1 GW, therefore there is a discrepancy in terms of renewable energy to be generated 2026-2030 to reach the 2030 projected target.

Also for the TYNDP 2022-2031, lacking a full-year market simulation with at least hourly granularity concrete RES penetration values [TWh] cannot be derived for the future time horizons.

3.6 Summary of Task 1 findings

In first step, the comparison of RES scenarios focused on the RES scenarios of the latest TYNDP release (2020-2029). However, since peak load and off-peak load snapshots are analyzed instead of type days or full-year market simulations with hourly granularity, from the Romanian TYNDP only scenarios on the development of installed generation capacities can be derived, but no concrete numbers for the resulting RES penetration levels for Romania. With regard to the installed generation mix, there are significant inconsistencies between the sustainable energy objectives in NECP compared with the Reference and Green Scenarios in TYNDP release 2020-2029.

For the ongoing elaboration of the TYNDP 2022-2031, Transelectrica foresees variable renewable energy capacities aligned with the objectives in the NECP. However, there is only one reference scenario envisaged in the draft which describes also the green scenario. Also for the TYNDP 2022-2031, no concretely resulting RES penetration levels for Romania can be derived lacking full-year market simulations with hourly granularity. But according to the projected capacity mix in TYNDP 2022-2031, additional variable RES capacities in GW scale will be needed to contribute to the 30.7% renewable energy target in 2030, in case additional 1.1 GW hydro is not installed by 2030.

Generally, the 2030 RES target set in NECP was challenged as not ambitious enough by the European Commission and it is possibly triggering an update of the NECP by June 2023 as required by the Governance Regulation. However, the latest TYNDP release is not aligned in terms of RES scenarios or decarbonisation measures with the NECP yet.

4 ANALYSIS OF GRID DEVELOPMENT AND FLEXIBILITY POTENTIAL (TASKS 2 & 3)

Chapter 4 covers Tasks 2 & 3 and will in first step analyze to which extent the RES scenarios of NECP & Energy Strategy are reflected in the ongoing TYNDP looking at 2022 –2031 and related grid models, and the related RES production characteristic will be investigated. In next step, the grid development and considered flexibility measures in frame of the ongoing TYNDP 2022 –2031 will be analyzed. For the evaluation of the adequacy of grid development measures identified in the TYNDP, based on the grid model and generation and load scenarios concrete load flow and contingency analyses were conducted with PSS/E.

4.1 Provided Initial Network Files

DNV has received four scenarios, containing PSS/E network data simulation files, each for the years 2022, 2026 and 2031. The scenarios provided for each year is:

- Summer Maximum
- Summer Minimum
- Winter Maximum
- Winter Morning

The scenarios represent different snapshots in time of dispatch of generation and load demand, which has been analyzed by DNV. Furthermore, with the provided network data files DNV had in addition to verify whether the installed capacity meets the TYNDP target values and the actual dispatch value of each generation type. As part of the analysis, DNV conducted N-0 and N-1 contingency analyses inside the Romanian grid for 110 kV, 220 kV and 400 kV branches.

The PSS/E grid model files contained topology maps for the Romanian transmission system. Figure 4-1 on next page shows exemplarily the topology map for the 2031 time horizon.

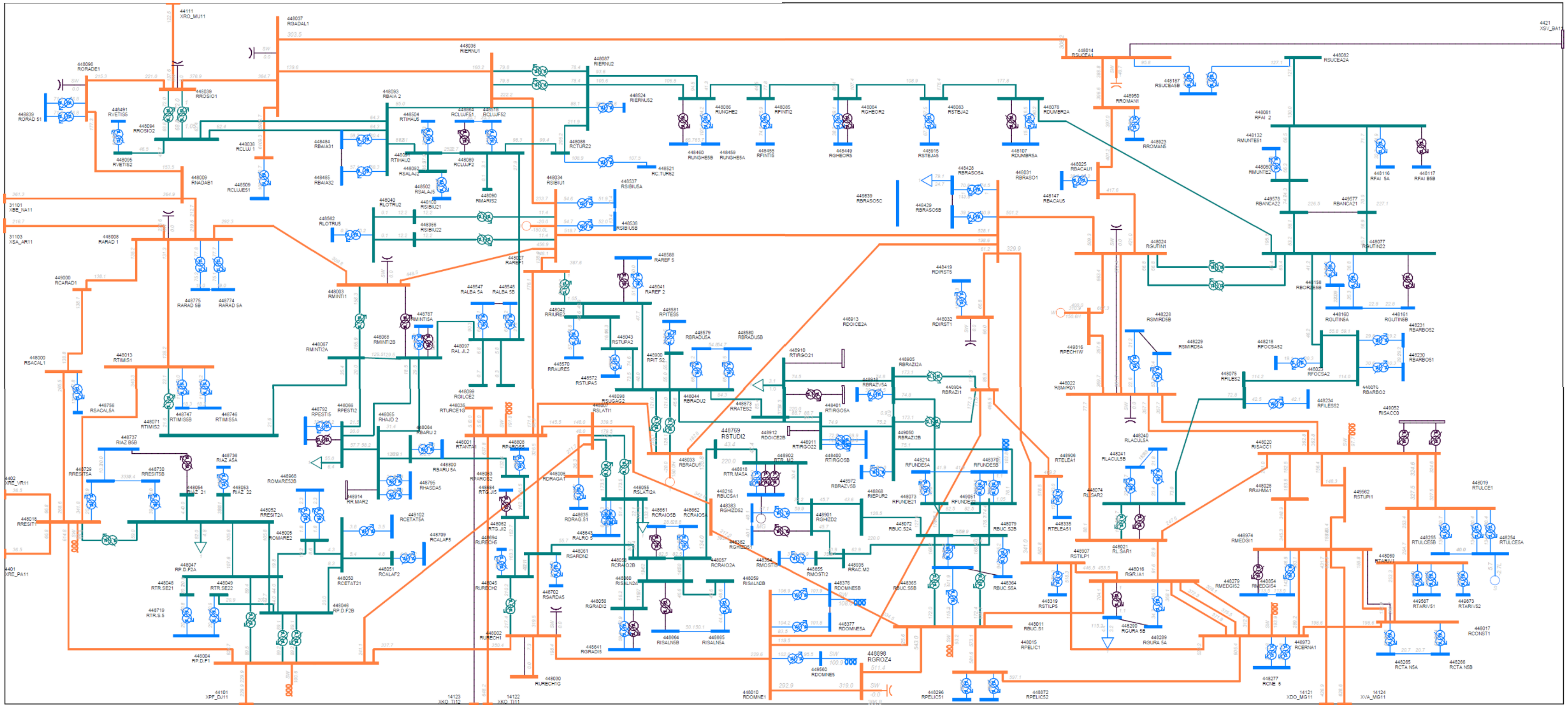


Figure 4-1: Grid topology map for 2031 time horizon like reflected in Transelectrica's PSS/E grid model file

4.2 Initial Cases – Installed capacity, dispatch and load demand

Based on the provided network files DNV did a throughout assessment to document in details the status quo especially concerning the installed capacity and the actual dispatch and load demand. As main finding, the installed capacity is aligned with the TYNDP (with minor deviations) for all scenarios in the network simulation file. The different generation types to meet the targets can be seen in Table 4-1.

Table 4-1: Generation types and installed power inside the PSS/E files

Total installed generation capacities (MW)	Generation type in PSS/E	TYNDP 2022-2031		
		Reference/Green Scenario		
Year		**2022**	**2026**	**2031**
Nuclear	Nuclear	**1,300**	**1,300**	**2,630**
Fossil fuels, out of which:		**6,048**	**7,135**	**7,047.5**
Lignite	Lignite old 1, Hard coal old 1	3,189	2,270	2,270.5
Gas and liquid fuels	Gas conventional old 1, Gas OCGT new, Gas CCGT new	2,859	4,865	4,777
RES, out of which:		**5,026**	**8,126**	**10,540**
Wind	Onshore Wind	3,400	4,500	**5,300**
Solar	Solar PV	1,500	3,500	**5,100**
Biomass	Biomass	126	126	**140**
Hydro	Hydro	**5,987**	**6,380**	**6,420.6**
Net installed capacity		**18,361**	**22,941**	**26,638**

DNV notes that - to meet the renewable targets for 2031 - Transelectrica has implemented several fictious renewable generation farms. The farms that have been added are:

- Three fictious wind farms with a total installed capacity of 359.4 MW and,
- 75 fictious solar PV farms with a total installed capacity of 1,177.4 MW

These fictious farms do not yet have any permit or study stage but have been added as outlook estimation to meet the renewable target. For scaling the dispatch, they are treated similar as the non-fictious onshore wind and solar PV.

DNV notes that even though the installed capacity meets the targets set by the TYNDP, the actual dispatch of the generation is far from the installed capacity. The loads (demand) as well as the actual setpoints for the generation for the different scenarios and years can be seen in Table 4-2, Table 4-3 and Table 4-4. The *"% of total dispatch"* is the percentage of how much a certain type of generation is producing compared to the total generation.

Table 4-2: Loads (demand) and dispatch for 2022

	2022								
	Installed capacity [MW]	Dispatch Summer Max [MW]	% of total dispatch	Dispatch Summer Min [MW]	% of total dispatch	Dispatch Winter Max [MW]	% of total dispatch	Dispatch Winter morning [MW]	% of total dispatch
Nuclear	**1**	**1,300**	**18**	**1,300**	**29.6**	**1,300**	**16**	**1,300**	**16.1**
Fossil fuels, out of which:	**6**	**1,613**	**22**	**1,332**	**30.3**	**2,683**	**33**	**2,682**	**33.3**
Lignite + Hard coal	3	421	6	422	9.6	929	11	928	11.5
Gas and liquid fuel	2,859	1,192	17	910	20.7	1754	22	1,754	21.8
RES, out of which:	**5,028**	**1,695**	**24**	**714**	**16.3**	**1,147**	**14**	**1,372**	**17.0**
Wind	3,400	680	9	679	15.5	1021	13	1,021	12.7
Solar	1,501	975	14	0	0,0	0	0	225	2,8
Biomass	126	40	1	35	0,8	126	2	126	1,6
Hydro	**5,987**	**2,600**	**36**	**1,042**	**23.7**	**3,000**	**37**	**2,700**	**33.5**
Net generation dispatched	**18,363**	**7,209**		**4,388**		**8,130**		**8,055**	
Load inside Romania (MW)		**7,713**		**4,425**		**9,002**		**8,656**	
Internal Losses (MW)		**217**		**144**		**268**		**243**	
Export (MW)		**-722**		**-181**		**-1,140**		**-845**	

Table 4-3: Load demand and dispatch for 2026

	2026								
	Installed capacity [MW]	Dispatch Summer Max [MW]	% of total dispatch	Dispatch Summer Min [MW]	% of total dispatch	Dispatch Winter Max [MW]	% of total dispatch	Dispatch Winter morning [MW]	% of total dispatch
Nuclear	**1,300**	**1,300**	**15.1**	**1,300**	**27.2**	**1,300**	**15.7**	**1,300**	**15.3**
Fossil fuels, out of which:	**7,135**	**1,526**	**17.7**	**1,260**	**26.4**	**2,507**	**30.3**	**2,515**	**29.5**
Lignite + Hard coal	2,270	363	4.2	330	6.9	497	6.0	481	5.6
Gas and liquid fuel	4,865	1,163	13.5	930	19.5	2010	24.3	2,034	23.9
RES, out of which:	**8,127**	**3,209**	**37.2**	**972**	**20.4**	**1,476**	**17.8**	**2,001**	**23.5**
Wind	4,500	900	10.4	900	18.8	1350	16.3	1,350	15.9
Solar	3,501	2,276	26.4	0	0.0	0	0,0	525	6.2
Biomass	126	33	0.4	72	1.5	126	1,5	126	1.5
Hydro	**6,380**	**2,600**	**30.1**	**1,243**	**26.0**	**3,000**	**36.2**	**2,700**	**31.7**
Net generation dispatched	**22,942**	**8,635**		**4,775**		**8,283**		**8,516**	
Load inside Romania (MW)		**8,112**		**4,740**		**9,870**		**9,531**	
Internal Losses (MW)		**221**		**171**		**267**		**243**	
Export (MW)		**302**		**-136**		**-1,854**		**-1,258**	

Table 4-4: Load demand and dispatch for 2031

	2031								
	Installed capacity [MW]	Dispatch Summer Max [MW]	% of total dispatch	Dispatch Summer Min [MW]	% of total dispatch	Dispatch Winter Max [MW]	% of total dispatch	Dispatch Winter morning [MW]	% of total dispatch
Nuclear	**2,630**	**1,800**	**18.8**	**1,965**	**37.0**	**2630**	**26.4**	**2,630**	**26.8**
Fossil fuels, out of which:	**7,047**	**975**	**10.2**	**977**	**18.4**	**2,400**	**24.1**	**2,391**	**24.4**
Lignite + Hard coal	2,271	0	0.0	0	0.0	19	0.2	23	0.2
Gas and liquid fuel	4,777	979	10.2	986	18.6	2381	23.9	2,367	24.1
RES, out of which:	**10,541**	**4,387**	**45.9**	**1,088**	**20.5**	**1,730**	**17.4**	**2,495**	**25.4**
Wind	5,300	1,060	11.1	1,060	20.0	1590	16.0	1,590	16.2
Solar	5,101	3,316	34.7	0	0.0	0	0.0	765	7.8
Biomass	140	11	0.1	28	0.5	140	1.4	140	1.4
Hydro	**6,421**	**2,393**	**25.0**	**1,274**	**24.0**	**3,200**	**32.1**	**2,300**	**23.4**
Net generation dispatched	**26,639**	**9,554**		**5,304**		**9,960**		**9,816**	
Load inside Romania (MW)		**8,419**		**4,922**		**10,283**		**9,914**	
Internal Losses (MW)		**Static case**							

From the tables the penetration of renewables (based on the snapshot scenarios) increases for each year. However, there is large difference between each scenario. This is explained by the lack of solar PV production for several cases. The setpoint for the renewable production is consistent for all years and can be seen in Table 4-5.

Table 4-5: Dispatch setpoint for Renewable production for the different PSS/E cases

	Production setpoint percentage compared to installed capacity			
	Summer Max	Summer Min	Winter Max	Winter Morning
Onshore Wind	20%	20%	30%	30%
Solar PV	65%	0%	0%	15%
Biomass	31.8%/26.3%/7.9% 2022/2026/2031	27.8%/57.2%/20.0% 2022/2026/2031	100%	100%

For solar PV the scaling percentage for each individual unit varies but the average of all units meets the target percentage. For onshore wind each unit is scaled to the target infeed. For biomass plants for

Summer Maximum and Minimum only few are operating which leads to the low dispatch percentage reflected in Table 4-5.

4.3 N-0 and N-1 Contingency Analysis on Initial Scenarios

The initial scenarios describe the PSS/E grid models received from Transelectrica. All scenarios received have been checked for bus voltage violation and branch loading violation during N-0 (base case) and N-1 contingencies. During the N-1 contingencies the branches monitored were all branches within Romania (including tie-lines) connected to either 110 kV, 220 kV or 400kV bus bars. Focus of these contingency analyses is on loading and voltage violations within the 220 kV and 400 kV grid. The 110 kV violations will only be referenced. Full contingency reports can be seen in the Appendices.

DNV noted that for some scenarios the swing bus generator (generator in PSS/E that changes production value to obtain stable simulation results, also known as slack bus) operates out of its limits, and for some cases this caused overloading of the transformer to the swing bus. The mismatch between generation and load would in reality be split between several generators and not just one. For that reason, the scenarios with a base case having an overloaded transformer to the swing bus, the transformer branch was neglected for the N-1 contingency check.

The voltage limits in PSS/E were updated in line with Transelectrica's grid planning rules [5] as follows:

- 400 kV: 0.95 p.u.– 1.05 p.u.
- 220 kV: 0.9 p.u.– 1.1 p.u
- 110 kV: 0.9 p.u.– 1.1182 p.u

For the loading the ratings as found in the network topology data models were used.

4.3.1 2022 Summer Maximum

4.3.1.1 Base Case (N-0)

No violations were present during the 2022 Summer Maximum snapshot case.

4.3.1.2 Contingency Analysis (N-1)

For 2022 Summer Maximum case there was a total of 1,561 monitored branches and contingencies simulated in PSS/E. There was also a total of 1,021 monitored buses for voltage violations. The complete result file can be found in *2022_SummerMax.xlsx*.

Voltage Violations

A total of three voltage violations during three different contingencies was obtained during the N-1 analysis. These consisted of two 400 kV under-voltage violations and one 110 kV over-voltage violation. The 400 kV violations can be seen in Table 4-6.

Table 4-6: 400 kV voltage violations during N-1 analysis for 2022 Summer Maximum

Violation #	Contingency event	Bus number	Bus name	Bus voltage-level [kV]	Base case voltage [p.u]	Contingency voltage [p.u]
1	448006-448007(1)	448006	RDRAGA1	400	0.9804	0.9089
2	448014-448950(1)	448014	RSUCEA1	400	0.9934	0.9238

DNV notes that the 400 kV violations are similar in the way that both are connected to an endpoint in the network tropology, in N-1 case with no further connection to the 400 kV grid, only connected to the 110 kV grid. DNV has analyzed the contingencies and highlights that these can be solved by so called *Special Protection Schemes, SPS*. DNV suggest the following:

For violation #1: Using a SPS which, if this contingency occurs, disconnects the 400 kV bus (448006) from the transformer to the 110 kV bus (448006 to 448635). This solves the issue.

If there is a need to keep bus 448006 energized, another solution is to activate the tap-changer for transformer 448006 to 448635 with modified V_{min}/V_{max} to be 0.95/1.05 which is the limits for 400 kV buses. This increases the voltage level at bus 448006 to 0.9540 p.u. which is within limits.

For violation #2: Using a SPS which, if this contingency occurs, disconnects the 400 kV bus (448014) from the transformer to the 110 kV bus (448014 to 448923). This solves the issue.

If there is a need to keep bus 448014 energized, another solution would also be in this case to activate the tap-changer for transformer 448014 to 448923 with modified V_{min}/V_{max} to be 0.95/1.05 which is the limits for 400 kV buses. This increases the voltage level at bus 448014 to 0.9583 p.u, which is within limits.

Loading Violations

For the N-1 analysis in total 41 flow violations were monitored. These consist of:

- Two cases of 400/100 kV transformers
- Four cases of 400/24 kV transformers

- 17 cases of 110 kV lines
- 18 cases of 110 kV to under-voltage level transformers

The 400 kV violations can be seen in Table 4-7.

Table 4-7: 400 kV loading violations during the N-1 analysis for 2022 Summer Maximum

Violation #	From Bus	To Bus	Id	Contingency event	Loading [%]	Type of branch
1	448010 - RDOMNE1	448377 RDOMNE5A	1	448010-448376(1)	102.55	400/110kV transformer
2	448010 - RDOMNE1	448376 - RDOMNE5B	1	448010-448377(1)	101.93	400/110kV transformer
3	448973-RCERNA1	449218 - RCERNAN1	2	448973-449218(1)	148.82	400/24 kV transformer
4	448973-RCERNA1	449218 - RCERNAN1	1	448973-449218(2)	148.82	400/24 kV transformer
5	448973-RCERNA1	449332-RCERNAN2	2	448973-449332(1)	148.79	400/24 kV transformer
6	448973-RCERNA1	449332 – RCERNAN2	1	448973-449332(2)	148.79	400/24 kV transformer

DNV analyzed the contingencies causing overloads. For Violation # 1 and 2 DNV noted that even though the transformers are connected at 2 different 110 kV busbars they are connected in parallel to the same 400 kV busbar. Tripping of one transformer causes overload for the other. DNV highlights that the overload is less than 3 % and that the typical permissible overload of transformers of this size is assumed with 20% (which is assumed also for these transformers). Hence no further action is suggested.

DNV also noted that all 400 kV branch violations (Violation # 3-6) are all related to the step-up transformers of the nuclear power plants. The contingencies that cause overloading is if one of 2 parallel units to each plant is taken out of service. DNV assumes that there is measures already taken to prevent damage to these transformers, such as connections to auxiliary busbars. Hence no further action will be considered by DNV than reporting the violations.

4.3.2 2022 Summer Minimum

4.3.2.1 Base Case (N-0)

For 2022 Summer Maximum snapshot case, the transformer to the swing bus was overloaded, as shown below:

Branch		
From Bus	***To Bus***	***Loading [%]***
448030 RURECH1G	449120 RROVINT6	105.1

No other violations were monitored during the Base Case.

4.3.2.2 Contingency Analysis (N-1)

For 2022 Summer Minimum case there was a total of 1,462 monitored branches and contingencies simulated in PSS/E. There was also a total of 1,012 monitored buses for voltage violations. The complete result file can be found in *2022_SummerMin.xlsx*.

Voltage Violations

During the contingency analysis a total of 19 voltage violations were monitored during 10 different contingencies. These consisted of 7 400 kV under-voltage violations during 6 different contingencies and 12 110 kV over-voltage violations. The 400 kV violations can be seen in Table 4-8.

Table 4-8:400 kV voltage violations during N-1 analysis for 2022 Summer Minimum

Violation #	Contingency event	Bus number	Bus name	Bus voltage-level [kV]	Base case voltage [p.u]	Contingency voltage [p.u]
1	448006-448007(1)	448006	RDRAGA1	400	0.9824	0.9466
2	448014-448950(1)	448014	RSUCEA1	400	0.9568	0.8254
3	448022-448024(1)	448014	RSUCEA1	400	0.9568	0.9476
4	448024-448025(1)	448014	RSUCEA1	400	0.9568	0.9494
5	448024-448031(1)	448014	RSUCEA1	400	0.9568	0.9486
6	448025-448950(1)	448014	RSUCEA1	400	0.9568	0.9299
7	448025-448950(1)	448950	RROMAN1	400	0.9709	0.9389

DNV notes that violation #1 and #2 creates endpoints for the violation bus in the network topology. Furthermore violation #6 and #7 occurs during the same contingency.

For violation #1: Using a SPS which, if this contingency occurs, disconnects the 400 kV bus (448006) from the transformer to the 110 kV bus (448006 to 448635). This solves the issue.

If there is a need to keep bus 448006 energized, another solution is to activate the tap-changer for transformer 448006 to 448635 with modified V_{min}/V_{max} to be 0.95/1.05 which is the limits for 400 kV buses. This increases the voltage level at bus 448006 to 0.9581 p.u. which is within limits.

For violation #2: Even though this contingency causes the 400 kV bus to be an end-point, analysis has shown that it is sufficient to use a SPS which, if this contingency occurs, disconnects the reactive shunt at bus 448014. This raises the contingency voltage at that bus to 0.9673 p.u. which is above limits.

For violation #3: Using a SPS that disconnects the reactive shunt at bus 448014 raises the voltage at the violated bus to 1.0011 p.u. which is within the limits.

For violation #4: DNV has analyzed tree alternatives:

- SPS to disconnect reactive shunt at 448014 solves 400 kV issue (Bus voltage is increased to 1.0417 p.u.) but creates 110 kV over-voltage violations.
- SPS to disconnect reactive shunt at 448020 raises bus voltage to 0.9535 p.u. which is within limits, without creating new issues.
- SPS to disconnect reactive shunt at 448022 raises the bus voltage to 0.9570 p.u. which is within limits, without creating new issues.

For violation #5: Using a SPS that disconnects the reactive shunt at bus 448014 raises the voltage at the violated bus to 1.0032 p.u. which is within the limits.

For violation #6 and #7: These two violations can be solved by a SPS to disconnect the reactive shunt at 448014. However, this causes two over-voltage violations on the 110 kV level. However, by activating the tap-changer in transformer from 448014 to 448187, with modified V_{min}/V_{max} to 0.95/1.05, solves the violation without creating new 110 kV violations.

Loading Violations

If N-0 flow violation is excluded, the N-1 analysis monitors 6 flow violations during 6 contingencies. These consists of:

- Four cases of 400/24 kV transformers
- 2 cases of 110/10.5 kV transformers

DNV notes that all 400 kV branch violations (Violation # 1-4) are all related to the step-up transformers from the nuclear power plants. The contingencies that cause overloading is if one of 2 parallel units to each plant is taken out of service. DNV assumes that there is measures already taken to prevent damage to these transformers, such as connections to auxiliary busbars. Hence no further action will be considered by DNV than reporting the violations. The 400 kV violations are shown in Table 4-9.

Table 4-9: 400 kV loading violations during N-1 analysis for 2022 Summer Minimum

Violation #	From Bus	To Bus	Id	Contingency event	Loading [%]	Type of Branch
1	448973-RCERNA1	449218 - RCERNAN1	2	448973-449218(1)	148.78	400/24 kV transformer
2	448973-RCERNA1	449218 - RCERNAN1	1	448973-449218(2)	148.78	400/24 kV transformer
3	448973-RCERNA1	449332-RCERNAN2	2	448973-449332(1)	148.76	400/24 kV transformer
4	448973-RCERNA1	449332 – RCERNAN2	1	448973-449332(2)	148.76	400/24 kV transformer

4.3.3 2022 Winter Maximum

4.3.3.1 Base Case (N-0)

No violations were present during the 2022 Winter Maximum snapshot case.

4.3.3.2 Contingency Analysis (N-1)

For 2022 Winter Maximum case there were a total of 1,565 monitored branches and contingencies simulated in PSS/E. There was also a total of 1,020 monitored buses for voltage violations. The complete result file can be found in *2022_WinterMax.xlsx*.

Voltage Violations

A total of 22 voltage violations was monitored during the N-1 analysis. These consisted of six 400 kV under-voltage violations monitored during 3 contingencies and sixteen 110 kV over-voltage violations monitored during 5 contingencies. The 400 kV violations can be seen in Table 4-10.

Table 4-10: 400 kV voltage violations during N-1 analysis for 2022 Winter Maximum

Violation #	Contingency event	Bus number	Bus name	Bus voltage-level [kV]	Base case voltage [p.u]	Contingency voltage [p.u]
1	448006-448007(1)	448006	RDRAGA1	400	0.9851	0.9379
2	448014-448950(1)	448014	RSUCEA1	400	0.9859	0.9224
3	448004-44101(1)	31103	XSA_AR11	400	1.0016	0.9483
4	448004-44101(1)	44101	XPF_DJ11	400	0.9922	0.4554
5	448004-44101(1)	311085	MSAFA 1	400	1.0023	0.9218
6	448004-44101(1)	460015	JHDJE111	400	0.9921	0.4554

DNV notes that for contingency 448004-44101(1) (violation #3-#6), which is an interconnector tripping to another area, 3 of the 4 violations are in an area outside Romania. The fourth bus is the interconnector bus (violation #4), which is now an endpoint in the network topology and can be disconnected for this contingency. Hence DNV will not suggest other solutions for this contingency.

DNV also highlights that, like previous cases, violation #1 and #2 creates endpoints in the network topology. DNV suggests the following to avoid violations:

For violation #1: Using a SPS which, if this contingency occurs, disconnects the 400 kV bus (448006) from the transformer to the 110 kV bus (448006 to 448635). This solves the issue.

If there is a need to keep bus 448006 energized, another solution is to activate the tap-changer for transformer 448006 to 448635 with modified V_{min}/V_{max} to be 0.95/1.05 which are the limits for 400 kV buses. This increases the voltage level at bus 448006 to 0.9611 p.u. which is within limits.

For violation #2: Using a SPS which, if this contingency occurs, disconnects both the 400 kV bus (448014) from the transformer to the 110 kV bus (448014 to 448923). This solves the issue.

If there is a need to keep bus 448014 energized, another solution is to activate the tap-changer for transformer 448014 to 448923 with modified V_{min}/V_{max} to be 0.95/1.05 which is the limits for 400 kV buses. This increases the voltage level at bus 448014 to 0.9570 p.u. which is within limits.

Loading Violations

During the N-1 analysis a total of 36 flow violations were monitored during 35 contingencies. The flow violation consisted of:

- Two cases of 400/110kV transformers
- Eight cases of 400/24 kV transformers
- Two cases of 220/110 kV transformer
- Two cases of 110 kV lines
- 22 cases of 110 kV to lower voltage level transformers

The 400 kV and 220 kV violations can be seen in Table 4-11.

Table 4-11: 400 and 220 kV loading violations during N-1 analysis for 2022 Winter Maximum

Violation #	From Bus	To Bus	Id	Contingency event	Loading [%]	Type of Branch
1	448010 - RDOMNE1	448377 - RDOMNE5A	1	448010-448376(1)	124.75	400/110 kV transformer
2	448010 - RDOMNE1	448376 - RDOMNE5B	1	448010-448377(1)	123.74	400/110 kV transformer
3	448030 - RURECH1G	449120 - RROVINT6	1	448004-44101(1)	128.26	400/24 kV transformer to swing-bus
4	448030 - RURECH1G	449120 - RROVINT6	1	448030-449121(1)	119.92	400/24 kV transformer to swing-bus
5	448030 - RURECH1G	449120 - RROVINT6	1	448904-449476(1)	111.38	400/24 kV transformer to swing-bus
6	448030 - RURECH1G	449120 - RROVINT6	1	449050-449478(1)	111.09	400/24 kV transformer to swing-bus
7	448973- RCERNA1	449218 - RCERNAN1	2	448973-449218(1)	148.82	400/24 kV transformer
8	448973- RCERNA1	449218 - RCERNAN1	1	448973-449218(2)	148.82	400/24 kV transformer
9	448973- RCERNA1	449332- RCERNAN2	2	448973-449332(1)	148.82	400/24 kV transformer
10	448973- RCERNA1	449332 – RCERNAN2	1	448973-449332(2)	148.82	400/24 kV transformer
11	448370 - RFUNDE5B	449051 - RFUNDE22	1	448073-448214(1)	106.58%	220/110 kV transformer
12	448073 - RFUNDE21	448214 - RFUNDE5A	1	448370-449051(1)	106.58%	220/110 kV transformer

DNV highlights that violation #3- #6 is caused by the overloading of the transformer to the swing bus. These are solved by having more than one generator contributing during the contingencies to the load-change. Hence, DNV will not analyses those further.

Violation #1 and #2: Two parallel transformers to the 110 kV voltage level. The overloading is caused by one of the 2 tripping leading to the healthy transformer experiencing overload. Since the loading is above the typical permissible overload of 20% (assumed also for these transformers), reinforcements should be considered.

Violation #7-#10: All are related to the step-up transformers from the nuclear power plants. The contingencies cause overloading if one of 2 parallel units to each plant is taken out of service. DNV assumes that there is measures already taken to prevent damage to these transformers, such as connections to auxiliary busbars. Hence no further action will be considered by DNV than reporting the violations.

Violation #11 and #12: Two parallel transformers to the 110 kV voltage level. The overloading is caused if one transformer trips which overloads the other transformer. The overload is less than 7% and below the typical permissible overload of 20% (which is assumed also for these transformers). Thus, no reinforcements are suggested.

4.3.4 2022 Winter Morning

4.3.4.1 Base Case (N-0)

No violations were present during the 2022 Winter Morning snapshot case.

4.3.4.2 Contingency Analysis (N-1)

For 2022 Winter Morning there was a total of 1,551 monitored branches and contingencies simulated in PSS/E. There was also a total of 1,021 monitored buses for voltage violations. The complete result file can be found in *2022_WinterMorning.xlsx*.

Voltage Violations

A total of 16 voltage violations was monitored during the N-1 analysis. They consisted of two single 400 kV under-voltage violations and fourteen 110 kV over-voltage violations during 4 contingencies. The 400 kV violations can be seen in Table 4-12.

Table 4-12: 400 kV voltage violations during N-1 analysis for 2022 Winter Morning

Violation #	Contingency event	Bus number	Bus name	Bus voltage-level [kV]	Base case voltage [p.u]	Contingency voltage [p.u]
1	448006-448007(1)	448006	RDRAGA1	400	0.9912	0.9391
2	448014-448950(1)	448014	RSUCEA1	400	0.9863	0.9237

Like previous cases the voltage violations are related to the bus being an endpoint in the network topology with no further connection to the 400 kV grid. DNV suggest the following:

For violation #1: Using a SPS which, if this contingency occurs, disconnects both the 400 kV bus (448006) from the transformer to the 110 kV bus (448006 to 448635). This solves the issue.

If there is a need to keep bus 448006 energized, another solution is to activate the tap-changer for transformer 448006 to 448635 with modified V_{min}/V_{max} to be 0.95/1.05 which is the limits for 400 kV buses. This increases the voltage level at bus 448006 to 0.9501 p.u. which is within limits.

For violation #2: Using a SPS which, if this contingency occurs, disconnects both the 400 kV bus (448014) from the transformer to the 110 kV bus (448014 to 448923). This solves the issue.

If there is a need to keep bus 448014 energized, another solution is to activate the tap-changer for transformer 448014 to 448923 with modified V_{min}/V_{max} to be 0.95/1.05 which is the limits for 400 kV buses. This increases the voltage level at bus 448014 to 0.9583 p.u. which is within limits.

Loading Violations

During the N-1 analysis a total of 30 single flow violations were monitored. The flow violation consisted of:

- Two cases of 400/110kV transformers
- Nine cases of 400/24 kV transformers
- Two cases of 220/110 kV transformer
- One cases of 110 kV lines
- 18 cases of 110 kV to lower voltage level transformers

The 400 kV and 220 kV violations can be seen in Table 4-13.

Table 4-13: 400 kV and 220 kV loading violations during N-1 analysis for 2022 Winter Morning

Violation #	From Bus	To Bus	Id	Contingency event	Loading [%]	Type of Branch
1	448010 - RDOMNE1	448377 - RDOMNE5A	1	448010-448376(1)	113.79	400/110 kV transformer
2	448010 - RDOMNE1	448376 - RDOMNE5B	1	448010-448377(1)	112.95	400/110 kV transformer
3	448030 - RURECH1G	449120 - RROVINT6	1	448030-449121(1)	122.88	400/24 kV transformer to swing-bus
4	448030 - RURECH1G	449120 - RROVINT6	1	448039-44111(1)	100.42	400/24 kV transformer to swing-bus
5	448030 - RURECH1G	449120 - RROVINT6	1	448904-449476(1)	113.5	400/24 kV transformer to swing-bus
6	448030 - RURECH1G	449120 - RROVINT6	1	448904-449477(1)	113.75	400/24 kV transformer to swing-bus
7	448030 - RURECH1G	449120 - RROVINT6	1	449050-449478(1)	113.33	400/24 kV transformer to swing-bus

8	448973-RCERNA1	449218 - RCERNAN1	2	448973-449218(1)	148.82	400/24 kV transformer
9	448973-RCERNA1	449218 - RCERNAN1	1	448973-449218(2)	148.82	400/24 kV transformer
10	448973-RCERNA1	449332-RCERNAN2	2	448973-449332(1)	148.82	400/24 kV transformer
11	448973-RCERNA1	449332 – RCERNAN2	1	448973-449332(2)	148.82	400/24 kV transformer
12	448370 - RFUNDE5B	449051 - RFUNDE22	1	448073-448214(1)	101.45	220/110 kV transformer
13	448073 - RFUNDE21	448214 - RFUNDE5A	1	448370-449051(1)	101.45	220/110 kV transformer

DNV highlights that violation #3- #7 is caused by the overload of the transformer to the swing bus. This describes a simplification since in reality more than one generator will contribute to balancing the active and reactive power deviations. Hence, DNV will not analyses those further.

Violation #1 and #2: Two parallel transformers to the 110 kV voltage level. The overloading is caused by one of the 2 tripping leading to the healthy transformer experiencing overload. The overload is below the assumed typical permissible overload of 20% (which is assumed also for these transformers).

Violation #8-#11: All related to the step-up transformers from the nuclear power plants. The contingencies that cause overloading is if one of 2 parallel units to each plant is taken out of service. DNV assumes that there is measures already taken to prevent damage to these transformers, such as connections to auxiliary busbars. Hence no further action will be considered by DNV than reporting the violations.

Violation #12 and #13: Two parallel transformers to the 110 kV voltage level. The overloading is caused if one transformer trips which overloads the other transformer. The overloading is less than 2% and below the typical permissible overload of 20%. No reinforcements are suggested.

4.3.5 2026 Summer Maximum

4.3.5.1 Base Case

No violations were present during the 2026 Summer maximum snapshot case.

4.3.5.2 Contingency analysis (N-1)

For 2026 Summer maximum case there were a total of 1,603 monitored branches and contingencies simulated in PSS/E. There was also a total of 1,036 monitored buses for voltage violations. The complete result file can be found in *2026_SummerMax.xlsx*.

Voltage Violations

A total of 28 Voltage violations was monitored during the N-1 analysis. These consisted of two single 400 kV under-voltage violations, two 400 kV over-voltage violations during a single contingency and 24 110 kV over-voltage violation during 8 contingencies. The 400 kV violations can be seen in Table 4-14.

Table 4-14: 400 kV voltage violations during N-1 analysis for 2026 Summer Maximum

Violation #	Contingency event	Bus number	Bus name	Bus voltage-level [kV]	Base case voltage [p.u]	Contingency voltage [p.u]
1	448006-448007(1)	448006	RDRAGA1	400	0.9837	0.9057
2	448014-448950(1)	448014	RSUCEA1	400	0.9990	0.9303
3	448004-44101(1)	44101	XPF_DJ11	400	1.0157	1.0855
4	448004-44101(1)	460015	JHDJE111	400	1.0165	1.0855

DNV highlights that, like previous cases, violation #1 and #2 creates endpoints in the network topology. Violation #3 and #4 is occurring during the same contingency (interconnector line tripping). Violation #3 is the interconnector bus, which can be considered an endpoint and taken out of service for this contingency. Violation #4 is located outside Romania and no actions will be suggested. The following can be done to avoid violation #1 and #2:

For violation #1: Using a SPS which, if this contingency occurs, disconnects both the violation bus (448006) and the transformer to the 110 kV bus (448006 to 448635). This solves the issue.

If there is a need to keep bus 448006 energized, another solution is to activate the tap-changer for transformer 448006 to 448635 with modified V_{min}/V_{max} to be 0.95/1.05 which is the limits for 400 kV buses. This increases the voltage level at bus 448006 to 0.9620 p.u. which is within limits.

For violation #2: Using a SPS which, if this contingency occurs, disconnects 400 kV bus (448014) from the transformer to the 110 kV bus (448014 to 448923). This solves the issue.

If there is a need to keep bus 448014 energized, another solution is to activate the tap-changer for transformer 448014 to 448923 modified V_{min}/V_{max} to be 0.95/1.05 which is the limits for 400 kV buses. This increases the voltage level at bus 448014 to 0.9528 p.u. which is within limits.

Loading Violations

During the N-1 analysis a total of 44 flow violations were monitored during 33 contingencies. The flow violation consisted of:

- Four cases of 400/24 kV transformers
- 26 cases of 110 kV lines
- 14 cases of 110 kV to lower voltage level transformers

The 400 kV violations can be seen in Table 4-15.

Table 4-15: 400 kV loading violations during N-1 analysis for 2026 Summer Maximum

Violation #	From Bus	To Bus	Id	Contingency event	Loading [%]	Type of Branch
1	448973-RCERNA1	449218 - RCERNAN1	2	448973-449218(1)	148.75	400/24 kV transformer
2	448973-RCERNA1	449218 - RCERNAN1	1	448973-449218(2)	148.75	400/24 kV transformer
3	448973-RCERNA1	449332-RCERNAN2	2	448973-449332(1)	148.75	400/24 kV transformer
4	448973-RCERNA1	449332 – RCERNAN2	1	448973-449332(2)	148.75	400/24 kV transformer

DNV notes that all 400 kV branch violations (Violation #1-4) are all related to the step-up transformers from the nuclear power plants. The contingencies that cause overloading is if one of 2 parallel units to each plant is taken out of service. DNV assumes that there is measures already taken to prevent damage to these transformers, such as connections to other busbars. Hence no further action will be considered by DNV than reporting the violations.

4.3.6 2026 Summer Minimum

4.3.6.1 Base Case (N-0)

No violations were present during the 2022 Summer Minimum snapshot case.

4.3.6.2 Contingency analysis (N-1)

For 2026 Summer minimum, there was a total of 1,544 monitored branches and contingencies simulated in PSS/E. There was also a total of 1,034 monitored buses for voltage violations. The complete result file can be found in *2026_SummerMin.xlsx*.

Voltage Violations

A total of 31 voltage violations were monitored during the N-1 analysis during ten different contingencies. These consisted of seven 400 kV low voltage violations, 15 110 kV under-voltage violations (all during same contingency) and nine 110 kV over-voltage violations. The 400 kV violations can be seen in Table 4-16.

Table 4-16: 400 kV voltage violations during N-1 analysis for 2026 Summer Minimum

Violation #	Contingency event	Bus number	Bus name	Bus voltage-level [kV]	Base case voltage [p.u]	Contingency voltage [p.u]
1	448001-448007(1)	448006	RDRAGA1	400	0.9703	0.9443
2	448001-448007(1)	448007	RSLATI1	400	0.9709	0.9447
3	448006-448007(1)	448006	RDRAGA1	400	0.9703	0.9338
4	448007-448216(1)	448006	RDRAGA1	400	0.9703	0.9496
5	448014-448950(1)	448014	RSUCEA1	400	0.9717	0.8556
6	448025-448950(1)	448014	RSUCEA1	400	0.9717	0.9367
7	448025-448950(1)	448950	RROMAN1	400	0.9854	0.9462

DNV notes that violation #1 and #2 occurs during the same contingency, same as for violation #6 and #7 that occurs during the same contingency. DNV also highlights that violation #3 and #5 like the previous cases leaves the violation bus as an endpoint in the network topology. DNV suggests the following actions:

For violation #1 and #2: SPS that disconnects the reactive shunt at 448011 solves the voltage violations during this contingency.

For violation #3: Using a SPS which, if this contingency occurs, disconnects both the 400 kV bus (448006) from the transformer to the 110 kV bus (448006 to 448635). This solves the issue.

If there is a need to keep bus 448006 energized, another solution is to activate the tap-changer for transformer 448006 to 448635 with modified V_{min}/V_{max} to be 0.95/1.05 which is the limits for 400 kV buses. This increases the voltage level at bus 448006 to 0.9561 p.u. which is within limits.

For violation #4: SPS that disconnects reactive shunt at bus 448001 solves the violation for this contingency (raises voltage at 448006 to 0.9561 p.u.). Or enabling the tap-changer as for violation #3 raises voltage at 448006 to 0.9503 p.u. which is within limits.

For violation #5: For this contingency, even though the violation bus is an endpoint in the 400 kV network topology, it is sufficient using a SPS to disconnect the reactive shunt at the violation bus, 448014. This raises the voltage to 0.9837 p.u. which is within limits.

For violation 6# and #7: A SPS that disconnects the reactive shunt at 448014 solves the 400 kV violations but creates several 110 kV over-voltage violations.

To avoid the over-voltage violations DNV suggest SPS that disconnects the reactive shunt at bus 448024 and 448020, which will solve the violations without creating new 110 kV over-voltage violations.

Loading Violations

A total of 14 single flow violations were monitored during the N-1 analysis. These consisted of:

- Four cases of 400/24 kV transformers
- Ten cases of 110 kV to under-voltage level transformers

The 400 kV violations can be seen in Table 4-17.

Table 4-17: 400 kV loading violations during N-1 analysis for 2026 Summer Minimum

Violation #	From Bus	To Bus	Id	Contingency event	Loading [%]	Type of Branch
1	448973-RCERNA1	449218 - RCERNAN1	2	448973-449218(1)	149.2	400/24 kV transformer
2	448973-RCERNA1	449218 - RCERNAN1	1	448973-449218(2)	149.2	400/24 kV transformer
3	448973-RCERNA1	449332-RCERNAN2	2	448973-449332(1)	149.18	400/24 kV transformer
4	448973-RCERNA1	449332 – RCERNAN2	1	448973-449332(2)	149.18	400/24 kV transformer

DNV notes that all 400 kV branch violations (Violation # 1-4) are all related to the step-up transformers from the nuclear power plants. The contingencies that cause overloading is if one of 2 parallel units to each plant is taken out of service. DNV assumes that there is measures already taken to prevent damage to these transformers, such as connections to auxiliary busbars. Hence no further action will be considered by DNV than reporting the violations.

4.3.7 2026 Winter Maximum

4.3.7.1 Base Case (N-0)

For 2026 Winter maximum snapshot case, the transformer to the swing bus were overloaded. As shown below:

Branch		
From Bus	***To Bus***	***Loading [%]***
448030 RURECH1G	449120 RROVINT6	120.9

No other violations were monitored during the Base Case.

4.3.7.2 Contingency Analysis (N-1)

For 2026 Winter Maximum there were a total of 1,621 monitored branches and contingencies simulated in PSS/E. There was also a total of 1,038 monitored buses for voltage violations. The complete result file can be found in *2026_WinterMax.xlsx*.

Voltage Violations

A total of 36 voltage violations was monitored. These consisted of two single 400 kV under-voltage violations and 34 violations in total of 110 kV over-voltage violations during 11 contingencies. The 400 kV violations can be seen in Table 4-18.

Table 4-18: 400 kV voltage violations during N-1 analysis for 2026 Winter Maximum

Violation #	Contingency event	Bus number	Bus name	Bus voltage-level [kV]	Base case voltage [p.u]	Contingency voltage [p.u]
1	448006-448007(1)	448006	RDRAGA1	400	0.9820	0.9104
2	448014-448950(1)	448014	RSUCEA1	400	0.9975	0.9251

Like previous cases the voltage violations are related to the violation-bus being an endpoint in the network topology with no further connection to the 400 kV grid. DNV suggest the following:

For violation #1: Using a SPS which, if this contingency occurs, disconnects the violation bus (448006) from the transformer to the 110 kV bus (448006 to 448635). This solves the issue.

If there is a need to keep bus 448006 energized, another solution is to activate the tap-changer for transformer 448006 to 448635, present within the PSS/E simulation model with modified V_{min}/V_{max} to be 0.95/1.05 which is the limits for 400 kV buses. This increases the voltage level at bus 448006 to 0.9558 p.u. which is within limits.

For violation #2: Using a SPS which, if this contingency occurs, disconnects the 400 kV bus (448014) from the transformer to the 110 kV bus (448014 to 448923). This solves the issue.

If there is a need to keep bus 448014 energized, another solution is to activate the tap-changer for transformer 448014 to 448923 with modified V_{min}/V_{max} to be 0.95/1.05 which is the limits for 400 kV buses. This increases the voltage level at bus 448014 to 0.9597 p.u. which is within limits.

Loading Violations

If the base case violation is excluded, a total of 31 flow violations during 30 contingencies is monitored. These consisted of:

- Two cases of 400/110 kV transformers
- Four cases of 400/24 kV transformers
- Three cases of 110 kV lines
- 22 cases of 110 kV to lower voltage level transformers

The 400 kV transformers can be seen in Table 4-19.

Table 4-19: 400 kV loading violations during N-1 analysis for 2026 Winter Maximum

Violation #	From Bus	To Bus	Id	Contingency event	Loading [%]	Type of Branch
1	448010 - RDOMNE1	448377 - RDOMNE5A	1	448010-448376(1)	136.16	400/110 kV transformer
2	448010 - RDOMNE1	448376 - RDOMNE5B	1	448010-448377(1)	136.02	400/110 kV transformer
3	448973-RCERNA1	449218 - RCERNAN1	2	448973-449218(1)	150.41	400/24 kV transformer
4	448973-RCERNA1	449218 - RCERNAN1	1	448973-449218(2)	150.41	400/24 kV transformer
5	448973-RCERNA1	449332-RCERNAN2	2	448973-449332(1)	148.75	400/24 kV transformer
6	448973-RCERNA1	449332 – RCERNAN2	1	448973-449332(2)	148.75	400/24 kV transformer

DNV notes that violation # 1-4 are related to the step-up transformers from the nuclear power plants. The contingencies that cause overloading is if one of 2 parallel units to each plant is taken out of service. DNV assumes that there is measures already taken to prevent damage to these transformers, such as connections to auxiliary busbars. Hence no further action will be considered by DNV than reporting these violations.

For violation #1 and #2: Two parallel transformers to the 110 kV voltage level. The overloading is caused if one transformer trips which overloads the other transformer. The load is above the typical permissible overload of 20% and reinforcement should be considered.

4.3.8 2026 Winter Morning

4.3.8.1 Base Case (N-0)

No violations were present during the 2026 Winter Minimum snapshot case.

4.3.8.2 Contingency Analysis (N-1)

For 2026 Winter Minimum, there was a total of 1,617 monitored branches and contingencies simulated in PSS/E. There was also a total of 1,037 monitored buses for voltage violations. The complete result file can be found in *2026_WinterMorning.xlsx*.

Voltage Violations

A total of 33 violations was monitored during 12 contingencies. These consisted of two single 400 kV under-voltage violations and 31 110 kV over-voltage violations. The 400 kV violations can be seen in Table 4-20.

Table 4-20: 400 kV voltage violations during N-1 analysis for 2026 Winter Morning

Violation #	Contingency event	Bus number	Bus Name	Bus Voltage-level [kV]	Base case Voltage [p.u]	Contingency Voltage [p.u]
1	448006-448007(1)	448006	RDRAGA1	400	0.9880	0.9104
2	448014-448950(1)	448014	RSUCEA1	400	1.0002	0.9217

Like previous cases the voltage violations are related to the bus being an endpoint in the network topology with no further connection to the 400 kV grid. DNV suggest the following:

For violation #1: Using a SPS which, if this contingency occurs, disconnects both the violation bus (448006) and the transformer to the 110 kV bus (448006 to 448635). This solves the issue.

If there is a need to keep bus 448006 energized, another solution is to activate the tap-changer for transformer 448006 to 448635 with modified V_{min}/V_{max} to be 0.95/1.05 which is the limits for 400 kV buses. This increases the voltage level at bus 448006 to 0.9557 p.u. which is within limits.

For violation #2: Using a SPS which, if this contingency occurs, disconnects both the violation bus (448014) and the transformer to the 110 kV bus (448014 to 448923). This solves the issue.

If there is a need to keep bus 448014 energized, another solution is to activate the tap-changer for transformer 448014 to 448923 with modified V_{min}/V_{max} to be 0.95/1.05 which is the limits for 400 kV buses. This increases the voltage level at bus 448014 to 0.9608 p.u. which is within limits.

Loading Violations

A total of 33 flow violations during 31 contingencies were monitored during the N-1 analysis. The violations consisted of:

- Two cases of 400/110 kV transformers
- Eight cases of 400/24 kV transformers
- Three cases of 110 kV lines
- 23 cases of 110 kV to lower voltage level transformers

The 400 kV violations can be seen in Table 4-21.

Table 4-21: 400 kV loading violations during N-1 analysis for 2026 Winter Morning

Violation #	From Bus	To Bus	Id	Contingency event	Loading [%]	Type of Branch
1	448010 - RDOMNE1	448377 - RDOMNE5A	1	448010-448376(1)	145.16	400/110 kV transformer
2	448010 - RDOMNE1	448376 - RDOMNE5B	1	448010-448377(1)	143.68	400/110 kV transformer
3	448030 - RURECH1G	449120 - RROVINT6	1	448039-44111(1)	100.50	400/24 kV transformer to swing-bus
4	448030 - RURECH1G	449120 - RROVINT6	1	448904-449476(1)	102.07	400/24 kV transformer to swing-bus
5	448030 - RURECH1G	449120 - RROVINT6	1	448904-449477(1)	104.07	400/24 kV transformer to swing-bus
6	448973-RCERNA1	449218 - RCERNAN1	2	448973-449218(1)	150.87	400/24 kV transformer
7	448973-RCERNA1	449218 - RCERNAN1	1	448973-449218(2)	150.87	400/24 kV transformer
8	448973-RCERNA1	449332-RCERNAN2	2	448973-449332(1)	148.77	400/24 kV transformer
9	448973-RCERNA1	449332 – RCERNAN2	1	448973-449332(2)	148.77	400/24 kV transformer
10	448030 - RURECH1G	449120 - RROVINT6	1	449050-449478(1)	102.14	400/24 kV transformer to swing-bus

DNV highlights that violation #3- #5 and #10 is caused by the overloading of the transformer to the swing bus. This describes a simplification since in reality more than one generator will contribute to balancing the active and reactive power deviations. Hence, DNV will not analyses those further.

Violation #1 and #2: Two parallel transformers to the 110 kV voltage level. The overloading is caused if one transformer trips which overloads the other transformer. The overload is above the typical permissible overload of 20%. Reinforcements should be considered.

Violation #6-#9: All related to the step-up transformers from the nuclear power plants. The contingencies that cause overloading is if one of 2 parallel units to each plant is taken out of service. DNV assumes that there is measures already taken to prevent damage to these transformers, such as connections to auxiliary busbars. Hence no further action will be considered by DNV than reporting the violations.

4.3.9 2031 Summer Maximum

4.3.9.1 Base Case (N-0)

For 2031 Summer Maximum snapshot case, the transformer to the swing bus were overloaded. As shown below:

Branch		
From Bus	***To Bus***	***Loading [%]***
448904 RBRAZI1	449477 ROMVBZT2	103.47

Since the Swing bus was overloaded in the base case, it was also overloaded during the contingencies. The branch was excluded from the N-1 results to highlight issues during the contingencies. There was no voltage violation during the Base Case.

4.3.9.2 Contingency analysis (N-1)

For 2031 Summer Maximum case there was a total of 1,626 monitored branches and contingencies simulated in PSS/E. There was also a total of 1,044 monitored buses for voltage violations. The complete result file can be found in *2031_SummerMax.xlsx*.

Voltage Violations

Of the monitored buses, three cases of voltage violations in total were obtained during 3 different contingencies. Two 400 kV under-voltage violations and one 110 kV over-voltage violation. The 400 kV voltage violations can be seen in Table 4-22.

Table 4-22: 400 kV voltage violations during N-1 analysis for 2031 Summer Maximum

Violation #	Contingency event	Bus number	Bus Name	Bus Voltage-level [kV]	Base case Voltage [p.u]	Contingency Voltage [p.u]
1	448004-448007(1)	448006	RDRAGA1	400	0.9659	0.9481
2	448006-448007(1)	448006	RDRAGA1	400	0.9659	0.9035

DNV notes that the 400 kV violations are at the same bus, 448006 - RDRAGA1. DNV has analyzed the contingencies and suggest the following:

For Violation #1: This can be solved by either creating an SPS that automatically disconnects the reactive shunt at Bus 448001 for this contingency. This would increase the voltage level at Bus 448006 to 0.9557 p.u. which is within the limits.

Another solution would be to activate the tap-changer for transformer 448006 to 448635, present within the PSS/E simulation model with modified V_{min}/V_{max} to be 0.95/1.05 which is the limits for 400 kV buses. This increases the voltage level at bus 448006 to 0.9502 p.u. which is within limits.

For Violation #2: DNV notes that this contingency leads to the violation bus 448006 being an endpoint in the network tropology with no further connection to the 400 kV grid, only connected to the 110 kV grid. DNV suggest implementing an SPS that for this contingency, so that the 400 kV bus (448006) and transformer from the 110 kV bus (448006 to 448635), is disconnected. This solves the issue.

If there is a need to keep bus 448006 energized, another solution is to activate the tap-changer for transformer 448006 to 448635 with modified V_{min}/V_{max} to be 0.95/1.05 which is the limits for 400 kV buses. This increases the voltage level at bus 448006 to 0.9597 p.u. which is within limits.

Loading Violations

If the N-0 Loading violation is excluded the N-1 analysis monitors in total 63 flow violations. These consists of:

- Six cases of 400 kV to 24 kV transformers
- Two cases of 220 kV lines
- 39 cases of 110 kV lines
- 16 cases of 110 kV transformers to lower voltage level

The 400 kV and 220 kV violations can be seen in Table 4-23.

Table 4-23: 400 kV and 220 kV loading violations during N-1 analysis for 2031 Summer Maximum

Violation #	From Bus	To Bus	Id	Contingency event	Loading [%]	Type of Branch
1	448079 - RBUC.S2B	449051 - RFUNDE22	1	448072-448073(1)	102.94	220 kV line
2	448072 - RBUC.S2A	448073 - RFUNDE21	1	448079-449051(1)	102.92	220 kV line
3	448973- RCERNA1	449218 - RCERNAN1	2	448973-449218(1)	137.27	400/24 kV transformer
4	448973- RCERNA1	449218 - RCERNAN1	1	448973-449218(2)	137.27	400/24 kV transformer
5	448973- RCERNA1	449332- RCERNAN2	2	448973-449332(1)	137.25	400/24 kV transformer
6	448973- RCERNA1	449332 – RCERNAN2	1	448973-449332(2)	137.25	400/24 kV transformer
7	448973- RCERNA1	449470 - RCERNAN3	2	448973-449470(1)	137.25	400/24 kV transformer
8	448973- RCERNA1	449470 - RCERNAN3	1	448973-449470(2)	137.25	400/24 kV transformer

DNV noted that all 400 kV branch violations (Violation # 3-8) are all related to the step-up transformers from the nuclear power plants. The contingencies that cause overloading is if one of 2 parallel units to each plant is taken out of service. DNV assumes that there is measures already taken to prevent damage to these transformers, such as connections to auxiliary busbars. Hence no further action will be considered by DNV than reporting the violations.

Violation #1 and #2: Is moderate overload of less than 3% on 2 parallel 220 kV lines if during the contingency of one of them tripping, typically solvable via operating this line in the upper part of permissible voltage range. However, flexibility or reinforcements should be considered if the 2031 scenarios show a further N-1 overload increase.

4.3.10 2031 Summer Minimum

4.3.10.1 Base Case (N-0)

No violations were present during the 2031 Summer Minimum snapshot case.

4.3.10.2 Contingency Analysis (N-1)

For 2031 Summer Minimum case there was a total of 1,545 monitored branches and contingencies simulated in PSS/E. There was also a total of 1,033 monitored buses for voltage violations. The complete result file can be found in *2031_SummerMin.xlsx*.

Voltage Violations

Of the monitored buses, a total of 43 voltage violations during 11 different contingencies were obtained. Of these, one was a 400 kV under-voltage violation, and the rest were 110 kV over-voltage violations. In Table 4-24 the 400 kV violation can be seen.

Table 4-24: The 400 kV voltage violation during N-1 analysis for 2031 Summer Minimum

Violation #	Contingency event	Bus Number	Bus Name	Bus Voltage-level [kV]	Base case Voltage [p.u]	Contingency Voltage [p.u]
1	448006-448007(1)	448006	RDRAGA1	400	0.9826	0.9483

For Violation #1: DNV notes that this contingency leads to the violation bus 448006 being an endpoint in the network tropology with no further connection to the 400 kV grid, only connected to the 110 kV grid. DNV suggest implementing an SPS that for this contingency, so that the 400 kV bus (448006) and transformer is connected from the 110 kV bus (448006 to 448635). This solves the issue.

Another solution if there is a need to keep bus 448006 energized is to activate the tap-changer for transformer 448006 to 448635, present within the PSS/E simulation model with modified V_{min}/V_{max} to be 0.95/1.05 which is the limits for 400 kV buses. This increases the voltage level at bus 448006 to 0.9596 p.u. which is within limits.

Loading Violations

N-1 analysis monitors in total eight flow violations. These consists of:

- Six cases of 400/24 kV transformers
- Two cases of 110/10.5 kV transformers

The 400 kV loading violations can be seen in Table 4-25.

Table 4-25: 400 kV loading violation during N-1 analysis for 2031 Summer Minimum

Violation #	From Bus	To Bus	Id	Contingency event	Loading [%]	Type of Branch
1	448973-RCERNA1	449218 - RCERNAN1	2	448973-449218(1)	149.05	400/24 kV transformer
2	448973-RCERNA1	449218 - RCERNAN1	1	448973-449218(2)	149.05	400/24 kV transformer
3	448973-RCERNA1	449332-RCERNAN2	2	448973-449332(1)	149.02	400/24 kV transformer
4	448973-RCERNA1	449332 – RCERNAN2	1	448973-449332(2)	149.02	400/24 kV transformer
5	448973-RCERNA1	449470 - RCERNAN3	2	448973-449470(1)	152.5	400/24 kV transformer
6	448973-RCERNA1	449470 - RCERNAN3	1	448973-449470(2)	152.5	400/24 kV transformer

DNV notes that all 400 kV branch violations (Violation # 1-6) are all related to the step-up transformers from the nuclear power plants. The contingencies that cause overloading is if one of 2 parallel units to each plant is taken out of service. DNV assumes that there is measures already taken to prevent damage to these transformers, such as connections to auxiliary busbars. Hence no further action will be considered by DNV than reporting the violations.

4.3.11 2031 Winter Maximum

4.3.11.1 Base Case (N-0)

No violations were present during the 2031 Winter Maximum snapshot case.

4.3.11.2 Contingency analysis (N-1)

For 2031 Winter Maximum there were a total of 1,655 monitored branches and contingencies simulated in PSS/E. There was also a total of 1,045 monitored buses for voltage violations. The complete result file can be found in *2031_WinterMax.xlsx*.

Voltage Violations

Of the monitored buses, a total of 15 voltage violations during 6 different contingencies were obtained. They consisted of 2 cases of 400 kV under-voltage violations and 13 110 kV over-voltage violations. The 400 kV violations can be seen in Table 4-26.

Table 4-26: 400 kV voltage violations during N-1 analysis for 2031 Winter Maximum

Violation #	Contingency event	Bus Number	Bus Name	Bus Voltage-level [kV]	Base case Voltage [p.u]	Contingency Voltage [p.u]
1	448006-448007(1)	448006	RDRAGA1	400	0.9907	0.9388
2	448037-448038(1)	448038	RCLUJ 1	400	1.0074	0.9278

DNV notes that both contingencies are similar in the way that they both leads to the bus having under-voltage violation being an endpoint in the network tropology with no further connection to the 400 kV grid, only connected to the 110 kV grid.

DNV suggest implementing an SPS that for these contingencies so that the transformer and 400 kV bus is also disconnected during the contingency.

For Violation #1: As mentioned above, DNV suggest implementing an SPS that for this contingency, so that the 400 kV bus (448006) and transformer is disconnected from the 110 kV bus (448006 to 448635). This solves the issue.

If there is a need to keep bus 448006 energized, another solution is to activate the tap-changer for transformer 448006 to 448635 with modified V_{min}/V_{max} to be 0.95/1.05 which is the limits for 400 kV buses. This increases the voltage level at bus 448006 to 0.9501 p.u. which is within limits.

For Violation #2: As mentioned above, DNV suggest implementing an SPS that for this contingency, so that the 400 kV bus (448038) and transformer is connected from the 110 kV bus (448038 to 448509). This solves the issue.

If there is a need to keep bus 448038 energized, another solution is to activate the tap-changer for transformer 448038 to 448509 with modified V_{min}/V_{max} to be 0.95/1.05, which is the limits for 400 kV buses. This increases the voltage level at bus 448038 to 0.9623 p.u. which is within limits.

Loading Violations

N-1 analysis monitors in total 44 flow violations during 43 contingencies. These consists of:

- Two cases of 400/220 kV transformers
- Eight cases of 400/24 kV transformers
- Eight cases of 110 kV lines
- 26 cases of 110 kV to lower voltage level transformers

The 400 kV violations are shown in Table 4-27.

Table 4-27: 400 kV loading violations during N-1 analysis for 2031 Winter Maximum

Violation #	From Bus	To Bus	Id	Contingency event	Loading [%]	Type of Branch
1	448011 - RBUC.S1	448079 - RBUC.S2B	1	448011-448072(2)	103.97	400/220 kV transformer
2	448011 - RBUC.S1	448072 - RBUC.S2A	2	448011-448079(1)	103.93	400/220 kV transformer
3	448973-RCERNA1	449218 - RCERNAN1	2	448973-449218(1)	148.79	400/24 kV transformer
4	448973-RCERNA1	449218 - RCERNAN1	1	448973-449218(2)	148.79	400/24 kV transformer
5	448973-RCERNA1	449332-RCERNAN2	2	448973-449332(1)	148.77	400/24 kV transformer
6	448973-RCERNA1	449332 – RCERNAN2	1	448973-449332(2)	148.77	400/24 kV transformer
7	448973-RCERNA1	449470 - RCERNAN3	2	448973-449470(1)	152.17	400/24 kV transformer
8	448973-RCERNA1	449470 - RCERNAN3	1	448973-449470(2)	152.17	400/24 kV transformer
9	448973-RCERNA1	449475 – RCERNAN4	2	448973-449475(1)	152.17	400/24 kV transformer
10	448973-RCERNA1	449475 – RCERNAN4	1	448973-449475(2)	152.17	400/24 kV transformer

DNV has analyzed the contingencies causing overload.

For Violation # 1 and 2: DNV notes that even though the transformers are connected at 2 different 220 kV busbars they are connected in parallel to the same 400 kV busbar. Tripping of one transformer causes overload for the other. DNV highlights that the overload is less than 4% and that the typical permissible overload of transformers of this size is 20% (also assumed for these transformers). Hence no further action is suggested.

DNV also notes that all 400 kV branch violations (Violation # 3-10) are all related to the step-up transformers from the nuclear power plants. The contingencies that cause overloading is if one of 2 parallel units to each plant is taken out of service. DNV assumes that there is measures already taken to prevent damage to these transformers, such as connections to auxiliary busbars. Hence no further action will be considered by DNV than reporting the violations.

4.3.12 2031 Winter Morning

4.3.12.1 Base Case (N-0)

4.3.12.2 Contingency Analysis (N-1)

For 2031 Winter Morning case there were a total of 1,635 monitored branches and contingencies simulated in PSS/E. There was also a total of 1,042 monitored buses for voltage violations. The complete result file can be found in *2031_WinterMorning.xlsx*.

Voltage Violations

During the contingencies a total of seven voltage violations during five different contingencies was obtained. These consisted of one 400 kV under-voltage violation and six 110 kV over-voltage violations. The 400 kV violation can be seen in Table 4-28.

Table 4-28: The 400 kV voltage violation during N-1 analysis for 2031 Winter Morning

Violation #	Contingency event	Bus number	Bus Name	Bus Voltage-level [kV]	Base case Voltage [p.u]	Contingency Voltage [p.u]
1	448006-448007(1)	448006	RDRAGA1	400	0.9788	0.9106

For Violation #1: DNV notes that this contingency leads to the violation of bus 448006 being an endpoint in the network tropology with no further connection to the 400 kV grid, only connected to the 110 kV grid. DNV suggest implementing an SPS that for this contingency, so that the 400 kV bus (448006) and transformer is disconnected from the 110 kV bus (448006 to 448635). This solves the issue.

If there is a need to keep bus 448006 energized, another solution is to activate the tap-changer for transformer 448006 to 448635 with modified V_{min}/V_{max} to be 0.95/1.05 which is the limits for 400 kV buses. This increases the voltage level at bus 448006 to 0.9596 p.u. which is within limits.

Loading Violations

N-1 analysis monitors in total 34 flow violations during 34 contingencies. These consists of:

- Eight cases of 400/24 kV transformers
- Four cases of 110 kV lines
- 22 cases of 110 kV to lower voltage level transformers

The 400 kV violations can be seen in Table 4-29.

Table 4-29: 400 kV loading violations during N-1 analysis for 2031 Winter Morning

Violation #	From Bus	To Bus	Id	Contingency event	Loading [%]	Type of Branch
1	448973-RCERNA1	449218 - RCERNAN1	2	448973-449218(1)	148.84	400/24 kV transformer
2	448973-RCERNA1	449218 - RCERNAN1	1	448973-449218(2)	148.84	400/24 kV transformer
3	448973-RCERNA1	449332-RCERNAN2	2	448973-449332(1)	148.82	400/24 kV transformer
4	448973-RCERNA1	449332 – RCERNAN2	1	448973-449332(2)	148.82	400/24 kV transformer
5	448973-RCERNA1	449470 - RCERNAN3	2	448973-449470(1)	152.29	400/24 kV transformer
6	448973-RCERNA1	449470 - RCERNAN3	1	448973-449470(2)	152.29	400/24 kV transformer
7	448973-RCERNA1	449475 – RCERNAN4	2	448973-449475(1)	152.29	400/24 kV transformer
8	448973-RCERNA1	449475 – RCERNAN4	1	448973-449475(2)	152.29	400/24 kV transformer

DNV notes that all 400 kV branch violations (Violation # 1-8) are all related to the step-up transformers from the nuclear power plants. The contingencies that cause overloading is if one of 2 parallel units to each plant is taken out of service. DNV assumes that there is measures already taken to prevent damage to these transformers, such as connections to auxiliary busbars. Hence no further action will be considered by DNV than reporting the violations

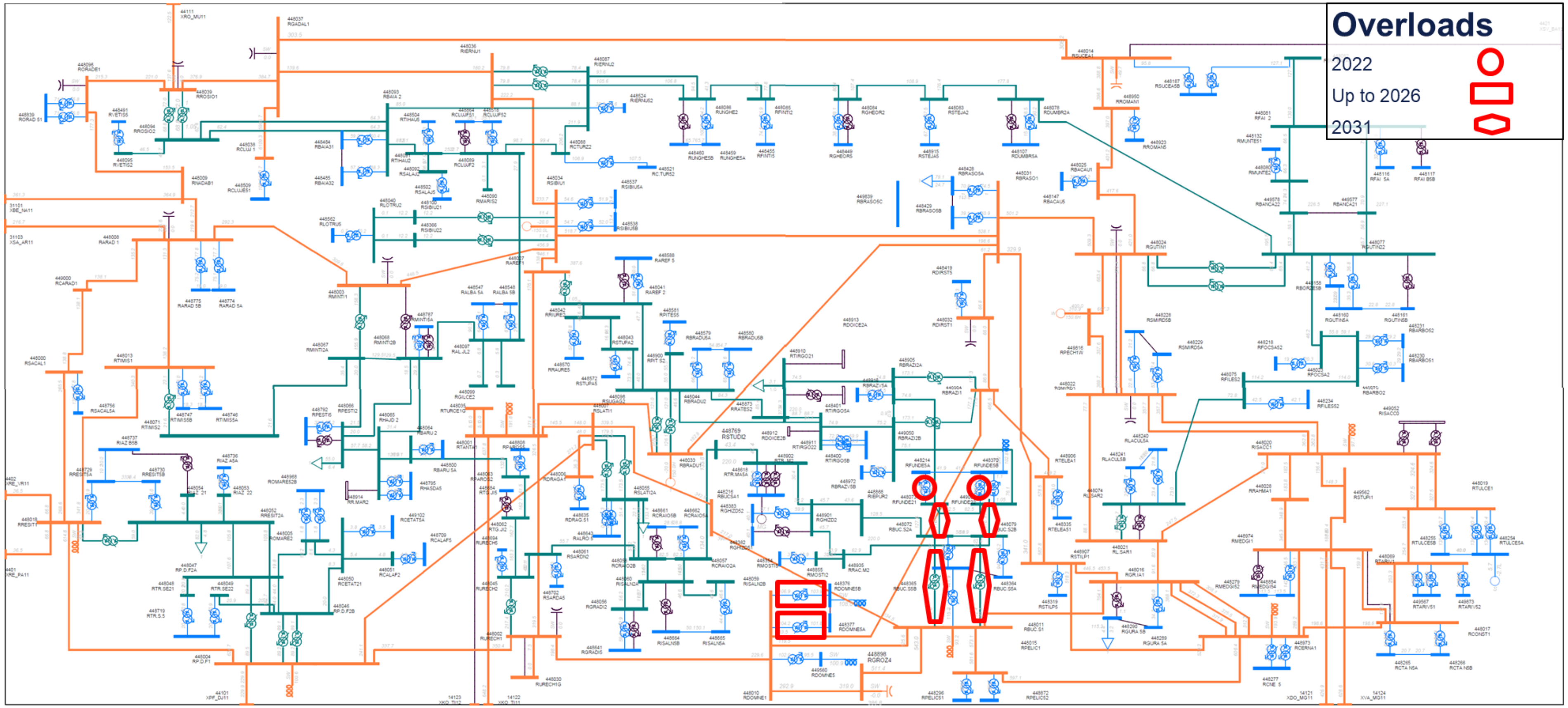


Figure 4-2: Grid topology highlighting the violated branches for the provided scenarios. Up to is referring to that the violation is present for both 2022 and 2026. Note that overloading of the transformers to the NPPs has been excluded.

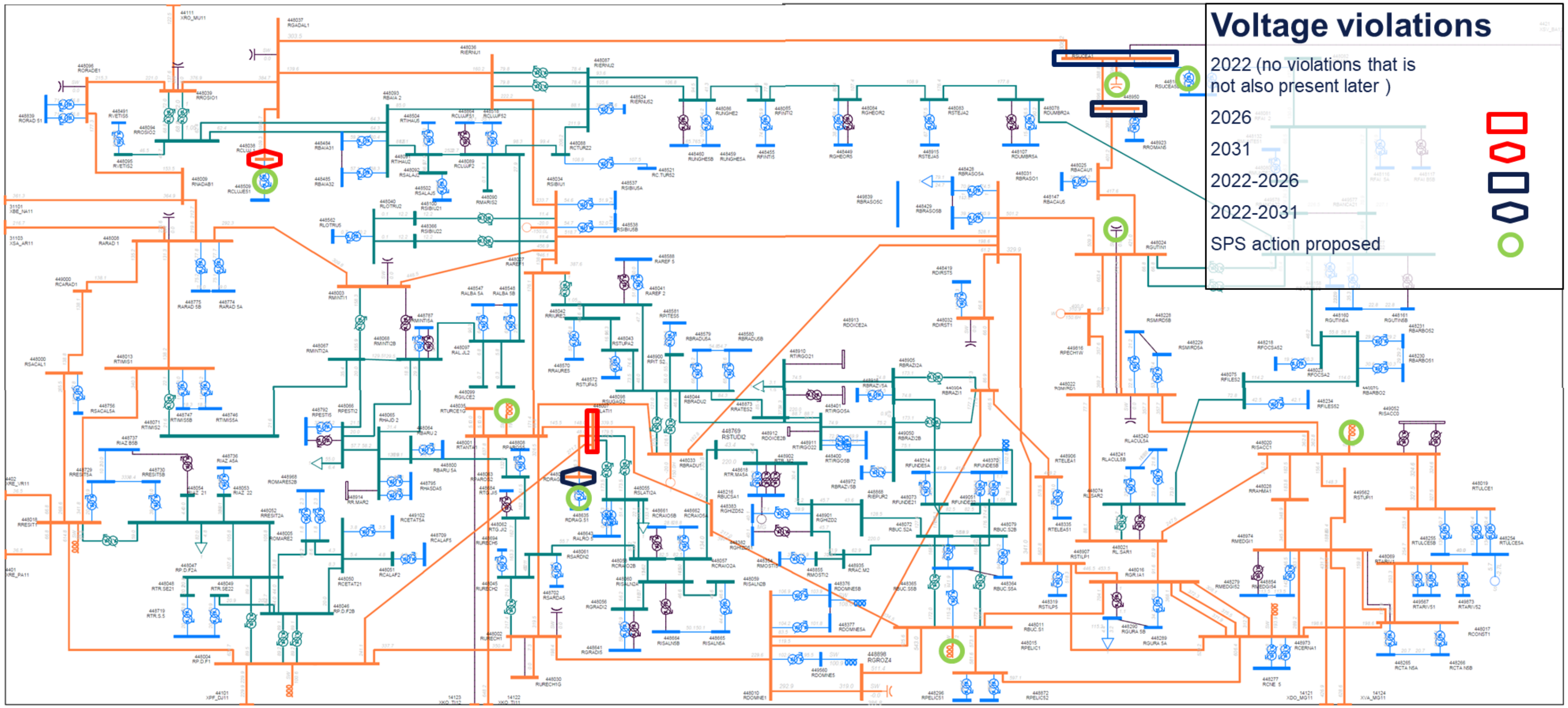


Figure 4-3: Grid topology highlighting the buses experiencing voltage violations aswell as the suggested SPS-actions for provided scenarios.

4.4 Green scenarios

Based on previous findings that the actual dispatch of onshore wind is only 20% for the summer maximum and summer minimum case, DNV analysed the resilience of the Romanian grid by creating two more green scenarios while focussing on 2031 time horizon with the highest VRE penetration level. The scenarios created by DNV are:

- 2031 Summer Maximum – Green
- 2031 Summer Minimum – Green

The scenarios have been chosen as a sunny and windy day (2031 Summer Max - Green) and a windy evening/night (2031 Summer Minimum - Green).

The percentage values for the maximum simultaneous (onshore) wind power respectively PV feed-in compared to installed power was derived from the last (2021) published version of the German TYNDP (scenario 2035, [6]):

- PV = 61.24% max. infeed compared to installed PV power
- Onshore wind = 82.81% max. infeed compared to installed onshore wind power

DNV acknowledges that the PV value used by Transelectrica is in the same level but slightly higher compared to the German case, 65.00% compared to 61.24% which appears adequate to the smaller area of Romania compared to Germany. For the same reason, DNV slightly rounded up also the maximum simultaneous (onshore) wind power feed-in value to 85.00% compared to 82.81% considered for Germany, see Table 4-31:

Table 4-30: Maximum simultaneous infeed compared to installed power applied by DNV

	Production setpoint percentage compared to installed capacity	
	Summer Max - Green	Summer Min - Green
Onshore Wind	85%	85%
Solar PV	65%	0%

Because of increasing renewable power DNV ramped down other generation types in order to reflect the market principle. The merit order for the change of dispatch has been based on information from Transelectrica. However, all non-renewable generation, except from nuclear (based on instructions from Transelectrica), had to be taken out of service to accommodate for the increased generation from renewables. Any control power (FCR, FFR) contracts and reactive power provisions of other power plants have been neglected at this stage in order account for real maximum green conditions. However, DNV highlights the importance that in all modelled scenarios all renewable farms are contributing to reactive power provision/voltage stability. And looking at the 2030 time horizon, it can be expected that BESS and VRE farms will contribute also to control power provision incl. virtual inertia and thus support the inertia provision of the hydro power and NPP units.

In the following sub-chapters DNV presents both base case scenarios with changed dispatch and improved cases taken into account the measures derived from the contingency analysis of the non-improved green scenarios.

4.4.1 2031 Summer Maximum – Green, Case set-up

The Summer Maximum – Green scenario is showing the case if a windy and sunny day occurs, with high generation from both wind and PV. DNV has changed the dispatch of other generation types according to Table 4-31.

Table 4-31: Dispatch of different types of generation in the Summer Maximum - Green simulation scenario

	2031 Summer Maximum- Green		
	Installed capacity [MW]	Dispatch Summer Max [MW]	% of total dispatch
Nuclear	**2630**	**1800**	**18,7**
Fossil fuels, out of which:	**7047**	**0**	**0,0**
Lignite + Hard coal	2271	0	0,0
Gas and liquid fuel	4777	0	0,0
RES, out of which:	**10541**	**7832**	**81,3**
Wind	5300	4505	46,8
Solar	5101	3316	34,4
Biomass	140	11	0,1
Hydro	**6421**	**0**	**0,0**
Net generation dispatched	**26639**	**9632**	

Considering the Summer Max Green scenario, the change in dispatch increases generation inside Romania by 72.7 MW in total compared to the original scenario. To properly view the export flow and to ensure that the generation mix inside Romania is as depicted in the table, the swing-bus (slack bus) inside Romania was disconnected. It was left only a swing-bus in neighbouring country which is assumed to properly depict the flow over the interconnectors.

As previously stated, all renewables are actively contributing to voltage stability by regulating the reactive power generation. To create a N-0 Base Case without voltage violations, the scheduled voltage for all onshore wind and PV plants was changed to 1.0 p.u..

As a result of the changes made to dispatch and equipment the export from Romania to neighbouring countries and the internal losses was changed as shown below with Table 4-32:

Table 4-32: Export and internal losses for 2031 Summer Maximum - Green

	Export [MW]	Internal losses [MW] incl. SVC losses etc.
Non-modified case	829.1	274.7
Green Scenario	733.7	443.1

The internal loss in the Romanian grid increases significantly in the green scenario, especially due to the high loading of the distribution grid during high wind and PV infeed despite of peak load situation. In frame of the analyses, the distribution grid conditions were only monitored but not subject of reinforcement considerations.

4.4.2 2031 Summer Minimum – Green, Case set-up

The Summer Minimum – Green scenario is made to reflect a windy evening/night with no PV but high generation from onshore wind. DNV changed the dispatch of other generation types according to Table 4-33.

Table 4-33: Dispatch of different types of generation in the Summer Minimum - Green simulation scenario

	2031 Summer Minimum- Green		
	Installed capacity [MW]	Dispatch Summer Max [MW]	% of total dispatch
Nuclear	**2630**	**1965**	**30,2**
Fossil fuels, out of which:	**7047**	**0**	**0,0**
Lignite + Hard coal	2271	0	0,0
Gas and liquid fuel	4777	0	0,0
RES, out of which:	**10541**	**4533**	**69,8**
Wind	5300	4505	69,3
Solar	5101	0	0,0
Biomass	140	28	0,4
Hydro	**6421**	**0**	**0,0**
Net generation dispatched	**26639**	**6498**	

DNV acknowledges that this scenario increases the generation inside Romania by 1,185.1 MW compared to the original scenario. Remark: The internal load is increased by 20 MW as a result of adding one extra SVC. To properly view the export flow and to ensure that the generation mix inside Romania is as depicted in the table, the swing-bus (slack) inside Romania was disconnected. Leaving only a swing-bus in neighbouring country which is assumed to properly depict the flow over the interconnectors.

To create a N-0 base case without voltage violations for this scenario the following was altered:

- Addition of a copy of previously installed SVC (+/-150 MVar, scheduled voltage 1p.u.) for reactive support at bus 448904 (in later step replaced by MSCDN).
- Scheduled voltage for all onshore wind was set to 1 p.u.
- Scheduled voltage for SVC at bus 448034 changed from 0.95 p.u.to 1 p.u.
- And these reactive shunts in operation, connected to the following buses, were switched off:
    - 448039
    - 448001
    - 448004
    - 448014
    - 448037
    - 448032
    - 448024
    - 448022

The modifications to the grid are highlighted in Figure 4-4. As a result of the changes made to dispatch and equipment the power flow from Romania to neighbouring countries was changed from slight import to export as shown below with Table 4-34:

Table 4-34: Export and internal losses for 2031 Summer Minimum - Green

	Export [MW]	Internal Losses [MW] incl. SVC losses etc.
Non-modified case	160.3	192.7
Green Scenario	1031.4	486.4

The internal loss in the Romanian grid increases significantly in the green scenario, especially due to the high loading of the distribution grid during high wind power infeed in off-peak load situation. In frame of the analyses, the distribution grid conditions were only monitored but not subject of reinforcement considerations.

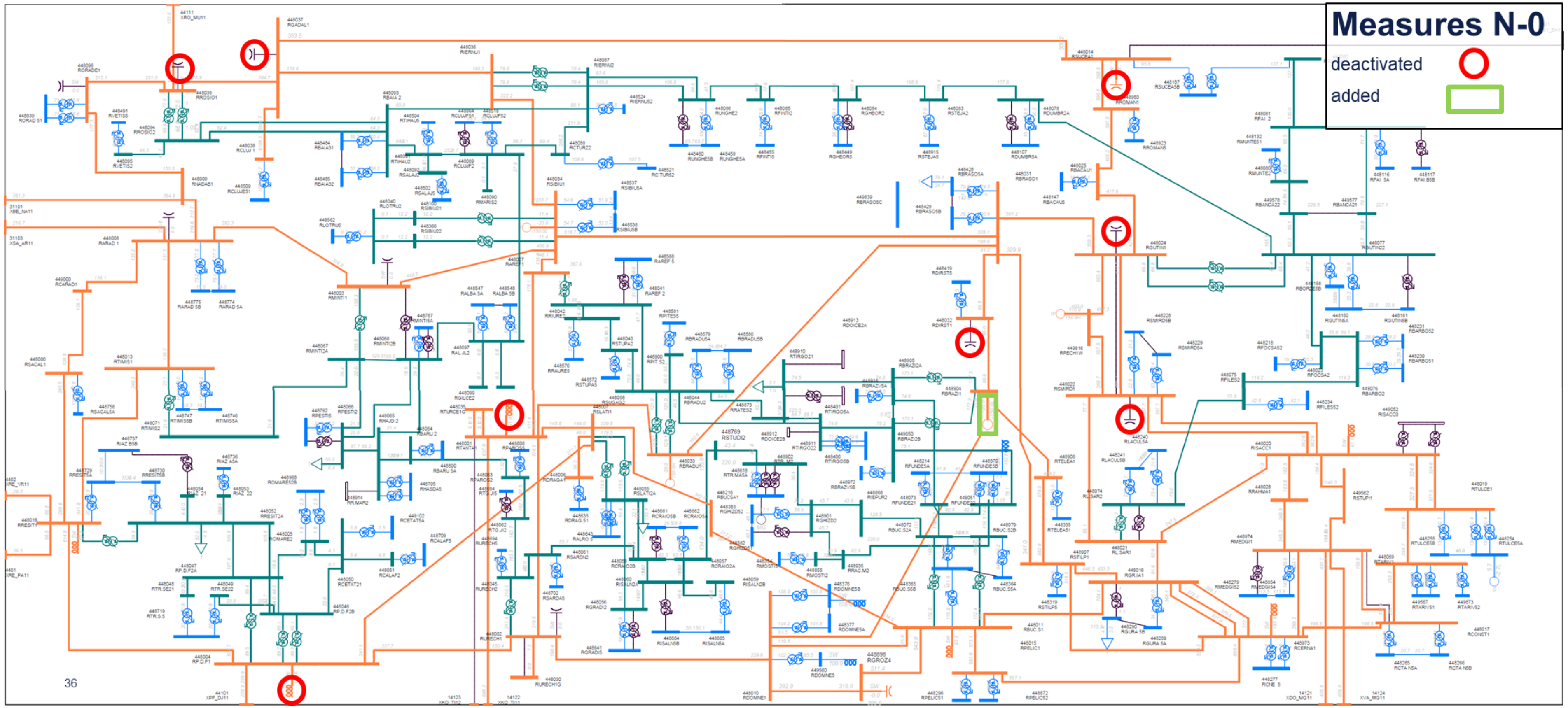


Figure 4-4: Grid topology highlighting changes to run Summer Minimum Green scenario without N-0 voltage violations

4.4.3 Analysis 2031 Summer Maximum - Green

4.4.3.1 Base Case (N-0)

The N-0 case was tuned as previously described so that no 110 kV, 220 kV or 400 kV voltage violation were monitored. However, flow violations were monitored for

- Two 400/110 kV transformers
- One 110 kV line
- 11 cases of 110 kV to under-voltage level transformers

Since the N-1 analysis is the basis for designing the size of the reinforcements no actions were taken before the base case. The 400 kV violations are shown below.

Table 4-35: The 400 kV overloads during N-1 analysis for 2031 Summer Maximum - Green

Branch			
From Bus	***To Bus***	***Type of Branch***	***Loading [%]***
448028	449874	400/110 kV transformer	106.99
448028	449874	400/110 kV transformer	106.99

The 400/110 kV transformers that are overloaded in N-0 are parallel transformers and DNV highlights the need for reinforcements.

4.4.3.2 Contingency analysis (N-1)

For 2031 Summer Maximum-Green case there were a total of 1,626 monitored branches and contingencies simulated in PSS/E. There was also a total of 1,044 monitored buses for voltage violations. The complete result file can be found in *2031_SummerMaxGreen.xlsx*.

Voltage Violations

A total of 164 voltage violations were monitored during the N-1 analysis. These consisted of:

- 92 cases of 400 kV under-voltage violations during 53 different contingencies,
- 72 cases of 110 kV violations (38 under-voltage violations and 34 over-voltage violations) during 40 different contingencies

DNV suggests SPS solutions for all 400 kV violations. The SPS can be described as, depending on contingency, either disconnecting the reactive shunt at Bus 448011 or 448001 or activating the tap changer for certain transformers. However, for 4 contingencies, DNV did not manage to restore the voltage by means SPS inside the Romanian grid, see Table 4-36.

Table 4-36: 400 kV voltage violations that could not be solved with SPS

Violation #	Contingency event	Bus number	Bus name	Bus voltage-level [kV]	Base case voltage [p.u]	Contingency voltage [p.u]
1	448011-448015(1)	448904	RBRAZI1	400	0.9541	0.9463
2	448011-448016(1)	448904	RBRAZI1	400	0.9541	0.9446
3	448024-448031(1)	448904	RBRAZI1	400	0.9541	0.9462
4	448001-14122(1)	448904	RBRAZI1	400	0.9541	0.9455

DNV highlights that all violations that could not be solved is occurring at the same bus.

Violation #1: This contingency leads to five 400kV under-voltage violations. While four violations can be solved by SPS via switching off the reactive shunt connected to bus 448011 - RBUC.S1, the violation reflected in Table 4-39 could not be cleared with SPS.

Violation #2: This contingency leads to six 400kV under-voltage violations. While four of these violations could be solved by SPS via switching off the reactive shunt connected to bus 448011 - RBUC.S1 and another could be solved by activating the tap-changer from bus 448906 to 448335 with V_{min} 0.95, the violation reflected could in Table 4 34 could not be cleared with SPS or tap changer measure.

Violation #3: This contingency leads to four 400kV under-voltage violations. While three violations can be solved by SPS via switching off the reactive shunt connected to bus 448011 - RBUC.S1, the violation reflected in Table 4-39 could not be cleared with SPS.

Violation #4: This contingency leads to six 400kV under-voltage violations. While four of these violations could be solved by SPS via switching off the reactive shunt connected to bus 448011 - RBUC.S1, the violation reflected in Table 4-39 could not be cleared with SPS.

DNV concludes that reactive support is needed at bus 448904 - RBRAZI1 to avoid all above voltage violations. This will be presented in the improved cases based on reactive support needed for the Summer Minimum – Green scenario, which has higher need for added support.

The violated bus and the contingencies causing the violation are highlighted in Figure 4-5.

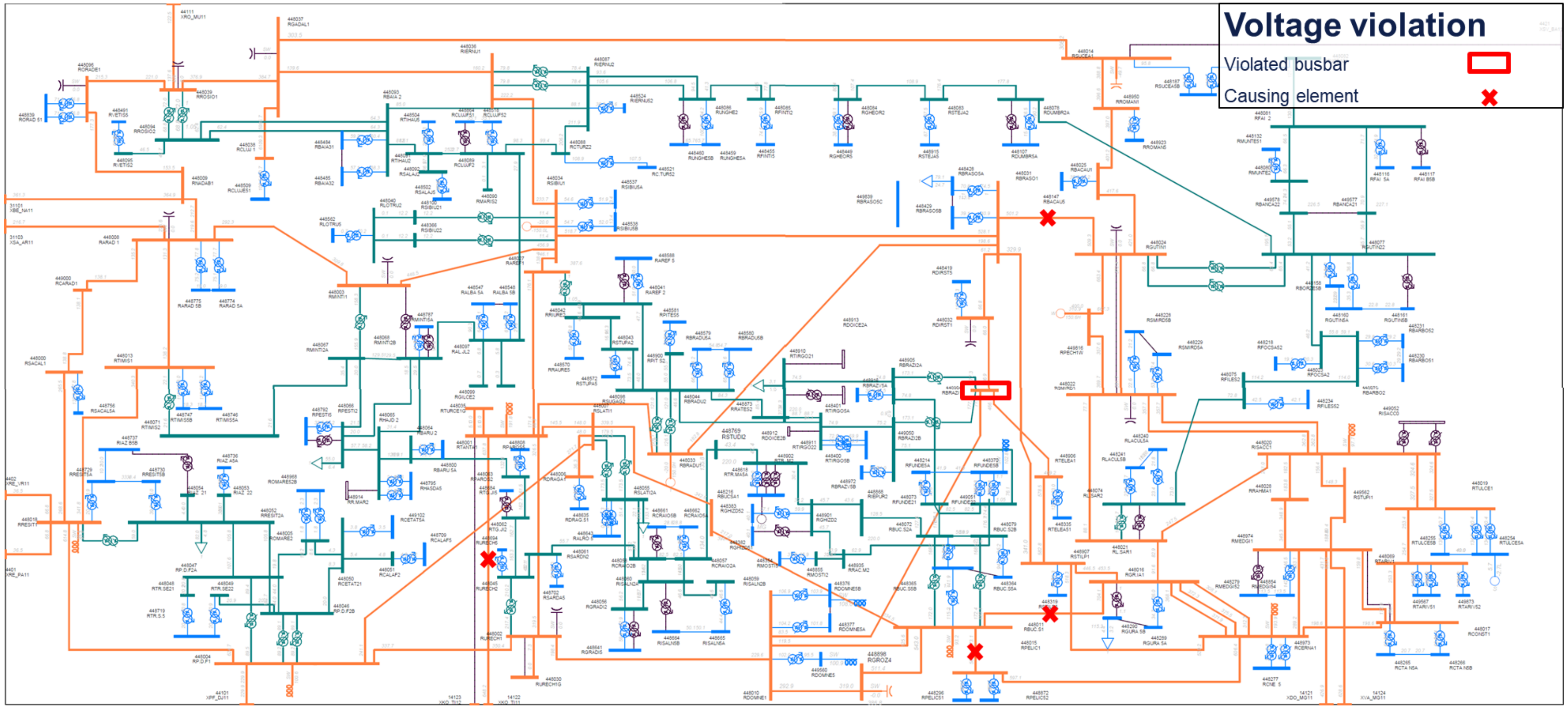


Figure 4-5: Grip topology highlighting the violated bus and the contingencies that cause it in the Summer Maximum Green scenario

Loading Violations

If the base case no violations are observed, but 99 flow violations were monitored during the N-1 analysis. These consisted of:

- Two cases of 400/110 kV transformers
- Six cases of 400/24 kV transformers
- Two cases of 220 kV lines
- 63 cases of 110 kV lines
- 26 cases of 110 kV to lower voltage levels transformers

The 220 kV and 400 kV violations are shown in Table 4-37.

Table 4-37: 400 kV and 220 kV violations during N-1 analysis for Summer Maximum -Green

Violation #	From Bus	To Bus	Id	Contingency event	Loading [%]	Type of Branch
1	448069 - RTARIV1	449567 - RTARIV51	2	448069-449567(1)	116.93	400/110 kV transformer
2	448069 - RTARIV1	449567 - RTARIV51	1	448069-449567(2)	116.93	400/110 kV transformer
3	448079 - RBUC.S2B	449051 - RFUNDE22	1	448072-448073(1)	111.19	220 kV line
4	448072 - RBUC.S2A	448073 - RFUNDE21	1	448079-449051(1)	111.17	220 kV line
5	448973- RCERNA1	449218 - RCERNAN1	2	448973-449218(1)	137.3	400/24 kV transformer
6	448973- RCERNA1	449218 - RCERNAN1	1	448973-449218(2)	137.3	400/24 kV transformer
7	448973- RCERNA1	449332- RCERNAN2	2	448973-449332(1)	137.28	400/24 kV transformer
8	448973- RCERNA1	449332 – RCERNAN2	1	448973-449332(2)	137.28	400/24 kV transformer
9	448973- RCERNA1	449470 - RCERNAN3	2	448973-449470(1)	137.28	400/24 kV transformer
10	448973- RCERNA1	449470 - RCERNAN3	1	448973-449470(2)	137.28	400/24 kV transformer

For Violation #1 and #2: These violations are two parallel transformers, the flow violation occurs during tripping of one which leads to overload of the other. Since the loading is below the typical permissible overload of 20 % (assumed also for these transformers), no further action is presented.

For violation #3 and #4: These lines are functioning as two parallel 220 kV lines. The violations occur during tripping of one, which leads to overload of the other. This requires the application of a flexibility or reinforcement measure. Transelectrica informed that both lines are already planned to be reinforced in context of the upgrade of the substation Fundeni from 220 kV to 400 kV level after 2031.

Violation #5-#10: Are all related to the step-up transformers from the nuclear power plants. The contingencies that cause overloading is if one of 2 parallel units to each plant is taken out of service. DNV assumes that there is measures already taken to prevent damage to these transformers, such as connections to other busbars. Hence no further action will be considered by DNV than reporting the violations.

4.4.4 Analysis 2031 Summer Minimum – Green

4.4.4.1 Base Case (N-0)

The N-0 case was tuned as previously described so that no 110 kV, 220 kV or 400 kV voltage violation were monitored. However, flow violations were monitored for

- Two 400/110 kV transformers
- 11 cases of 110 kV to lower voltage level transformers

Since the N-1 analysis is the basis for designing the size of the reinforcements no actions were taken before the base case. The 400 kV violation are shown below with Table 4-38.

Table 4-38: The 400 kV overloads during N-1 analysis for 2031 Summer Minimum - Green

Branch			
From Bus	***To Bus***	***Type of Branch***	***Loading [%]***
448028	449874	400/110 kV transformer	106.69
448028	449874	400/110 kV transformer	106.69

The 400/110 kV transformers that are overloaded already in N-0 situation are parallel transformers and DNV therefore highlights the need for reinforcements. Furthermore, it is the same transformers that are overloaded in the Summer Maximum – Green scenario.

4.4.4.2 Contingency analysis (N-1)

For 2031 Summer Minimum - Green there were a total of 1,545 monitored branches and contingencies simulated in PSS/E. There was also a total of 1,033 monitored buses for voltage violations. The complete result file can be found in *2031_SummerMinGreen.xlsx*.

Voltage Violations

A total of 151 voltage violations were monitored during the N-1 analysis. These consisted of:

- 106 cases of 400 kV under-voltage violations during 21 different contingencies,
- One case of 220 kV under-voltage violation
- 44 cases of 110 kV violations (35 under-voltage violations and 4 over-voltage violations) during 4 different contingencies

For Summer maximum -Green the SPS action that solved a lot of N-1 voltage violations were to disconnect reactive shunts. For summer minimum – Green, a large number of reactive shunts were disconnected in the N-0 case to avoid voltage violation in the N-0 analysis. Hence, a large part of the violations to the 400 kV and the 220 kV violation could not be solved without additional reactive support. The Summer minimum -Green N-1 violations are not presented in the report because of the high number of cases but all violations can be seen in *2031_SummerMinGreen.xlsx*.

DNV has based on knowledge from the N-1 analysis identified several buses that require additional reactive support which was added to the improved case.

Loading Violations

If the base case violations are excluded, 59 under-violations were monitored during the N-1 analysis. These consisted of:

- Three cases of 400/110 kV transformers
- Six cases of 400/24 kV transformers
- 12 cases of 220 kV lines (4 different lines)
- One case of 220/110 kV transformer
- 11 cases of 110 kV lines
- 26 cases of 110 kV to lower voltage levels transformers

The 400 kV violations, the highest violation for each 220 kV line and the 220/110 kV transformer violation are shown in Table 4-39.

Table 4-39: 400 kV and 220 kV loading violations during N-1 analysis for Summer Minimum - Green

Violation #	From Bus	To Bus	Id	Contingency event	Loading [%]	Type of Branch
1	448069 - RTARIV1	449567 - RTARIV51	2	448069-449567(1)	116.87	400/110 kV transformer
2	448069 - RTARIV1	449567 - RTARIV51	1	448069-449567(2)	116.87	400/110 kV transformer
3	448335 - RTELEA51	448906 - RTELEA1	1	448904-448906(1)	104.17	400/110 kV transformer
4	448973- RCERNA1	449218 - RCERNAN1	2	448973-449218(1)	148.75	400/24 kV transformer

5	448973-RCERNA1	449218 - RCERNAN1	1	448973-449218(2)	148.75	400/24 kV transformer
6	448973-RCERNA1	449332-RCERNAN2	2	448973-449332(1)	148.75	400/24 kV transformer
7	448973-RCERNA1	449332 – RCERNAN2	1	448973-449332(2)	148.75	400/24 kV transformer
8	448973-RCERNA1	449470 - RCERNAN3	2	448973-449470(1)	152.21	400/24 kV transformer
9	448973-RCERNA1	449470 - RCERNAN3	1	448973-449470(2)	152.21	400/24 kV transformer
10	448072 - RBUC.S2A	448079 - RBUC.S2B	1	448011-448079(1)	120.02	220 kV line (no violation*)
11	448083 - RSTEJA2	448084 - RGHEOR2	1	448014-448037(1)	110.6	220 kV line (2 violations)
12	448078 - RDUMBR2A	448083 - RSTEJA2	1	448014-448950(1)	104.07	220 kV line (2 violations)
13	448079 - RBUC.S2B	449051 - RFUNDE22	1	448906-448907(1)	122.39	220 kV line (7 violations)
14	448082 - RSUCEA2A	448187 - RSUCEA5B	1	448014-448950(1)	109.74	220/110 kV transformer

* This 220kV busbar coupler loading violation turned out not to be relevant due to a wrong current limit in the PSS/E models

For Violation #1 and #2: These violations are two parallel transformers, the flow violation occurs during tripping of one which leads to overload of the other. Since the loading is below the typical permissible overload of 20% (which is the assumption also for these transformers), no further action is presented.

For violation #3: The overload is below the typical permissible overload of 20% for transformers. Since the loading is below the typical permissible overload of 20% (which is the assumption also for these transformers) no reinforcements are considered.

Violation #4-#9: These are all related to the step-up transformers from the nuclear power plants. The contingencies that cause overloading is if one of 2 parallel units to each plant is taken out of service. DNV assumes that there is measures already taken to prevent damage to these transformers, such as connections to auxiliary busbars. Hence no further action will be considered by DNV than reporting the violations.

For violation #10 - #13: The highest violation for each of the 220 kV lines are presented. In maximum 22 % N-1 overload is registered; this is still in the typical range for application of flexibility measures.

Violation #14: The overload is below the typical permissible overload of 20% for transformers. Hence, no reinforcements are considered.

Clarified non converging contingency case

DNV notes that the contingency event of 448001-14122(1), which is reflected as a single-circuit interconnector line tripping does not converge because of significantly changed load flows. However, DNV noted that there is a parallel second interconnector branch located in the PSS/E file not in operation in the respective grid model. The branches in question can be seen in Figure 4-6, where the critical line has been highlighted with green circles at the edges. Transelectrica confirmed that the parallel second interconnector circuit from 448001 RTANTA1 to 14123 XKO_TI12 can be fully utilized which allows tripping one of the interconnection circuits without load flow convergence problems. Otherwise, significant reactive power measures would have been proposed for the respective grid section.

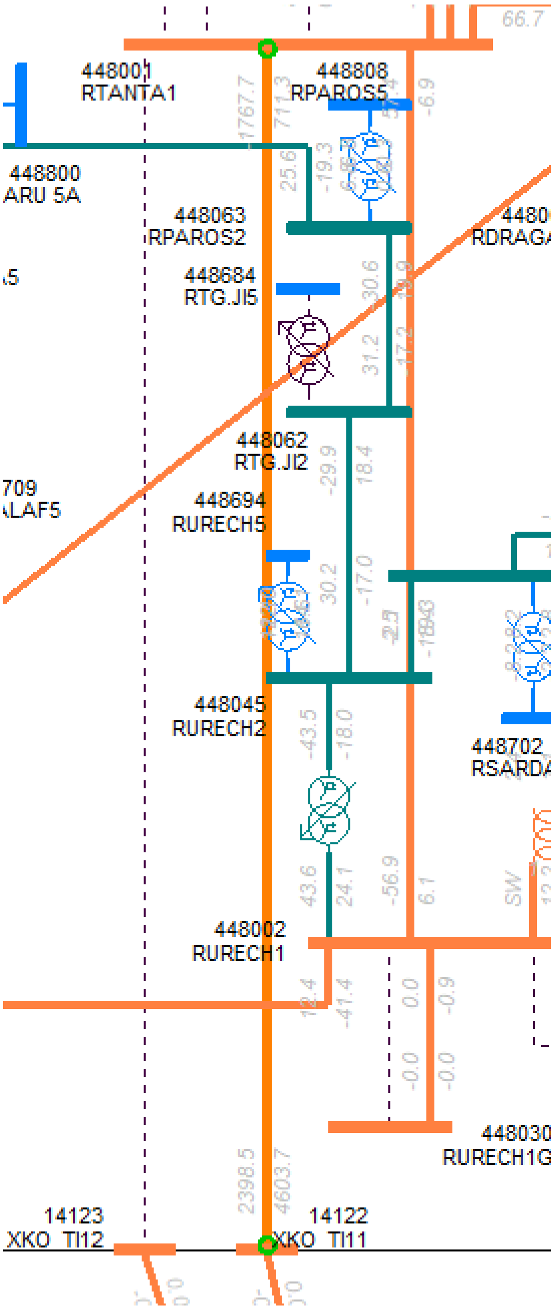


Figure 4-6: Picture showing the N-0 situation ahead of contingency event of 448001-14122(1)

4.5 Green scenarios - Improved cases

The reinforcements and additions which has been proposed and simulated is based on the analysis of the green scenarios. An additional transformer has been added between bus 448028 RRAHMA1 and 449874 RRAHMA5. DNV has opted in installing a third identical transformer same like the two already installed, 400/110 kV, 250 MVA. Another solution would be to upgrade both the already existing transformers if they are nearing end of life. However, this is not known by DNV. Upgrading of one of the transformers would be only allowed if the following is considered:

- Same no-load transmission ratio (a percentage deviation of the transmission ratio of up to 1/20 of the relative short-circuit voltage is still permissible - e.g.: u_K of a transformer is 10% - its transmission ratio may deviate by 0.5% from that of a parallel end).
- Same short-circuit voltage (max. 10% permissible deviation)
- Same vector group
- Nominal power difference between the transformers not greater than factor 3

The voltage support reinforcements have been based on an iterative methodology in the Summer Minimum -Green scenario, where violations that could not be solved by other means were solved by addition of *Mechanically Switched Capacitors with Damping Network, so-called MSCDNs.*

The total MVAr size was chosen so that the violation was solved, and the number and size of steps was chosen so that each step correlated to less than 2% change compared to busbar nominal voltage, which is comparable to German guidelines (this was tested in the N-0 scenario by activating one step and monitoring the voltage at the busbar). The following MSCDNs have been added:

1. 2x20 MVAr at bus 448097, 220 kV voltage level
2. 2x50 MVAr at bus 448006, 400 kV voltage level
3. 2x50MVAr at bus 448014, 400 kV voltage level. Note that this bus previously also had a reactance of 100 MVAr, the capacitive shunt was added in addition, which leads to the need of control structure to be implemented between the shunts
4. 2x50 MVAr at bus 448031, 400 kV voltage level
5. 3x60 MVAr at bus 448904, 400 kV voltage level. This MSCDN replaced the previous added SVC. MSCDN is a cheaper technology than SVC. Hence DNV opted to replace this.

The implemented reinforcements are shown in Figure 4-7.

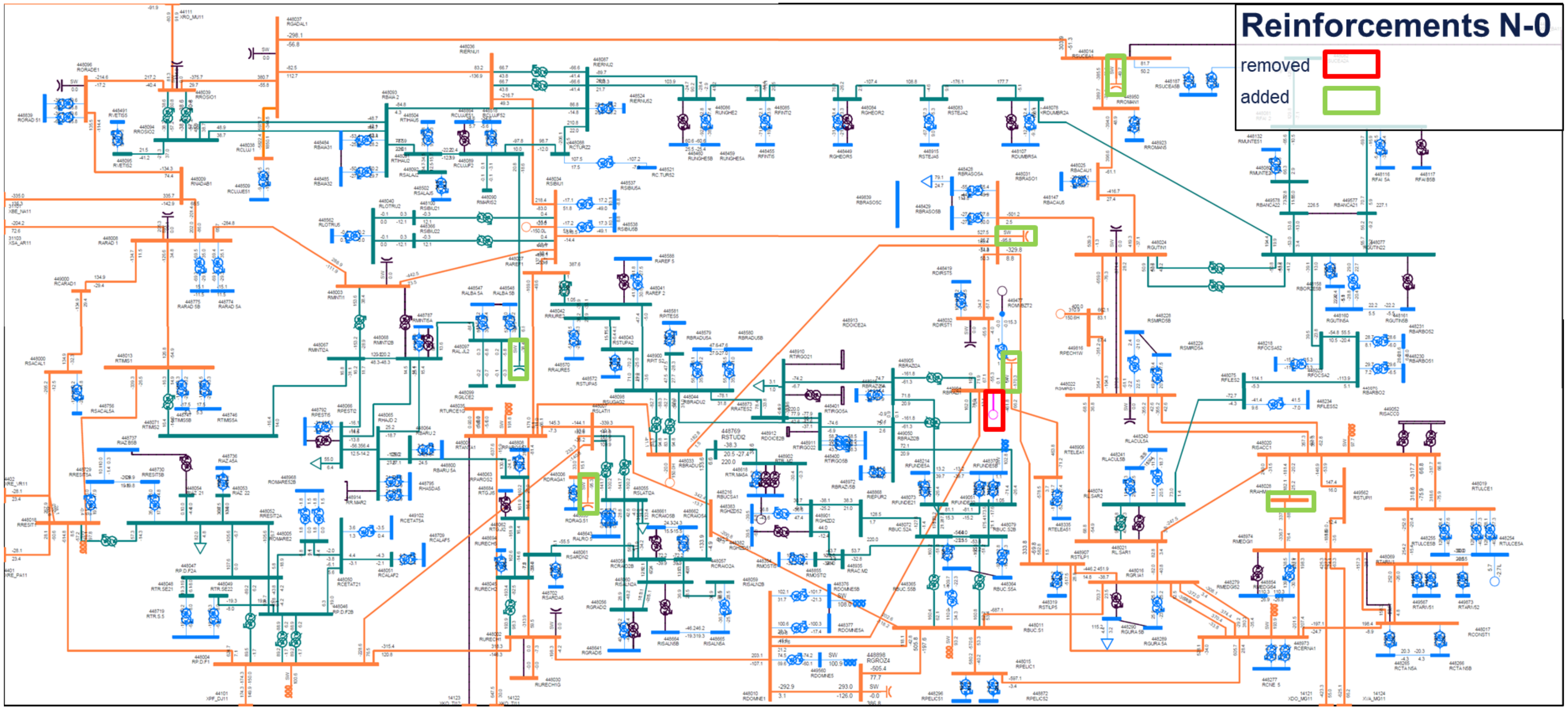


Figure 4-7: Grip topology highlighting the suggested reinforcements and the removal of the previously (by DNV) introduced SVC.

4.5.1 2031 Summer Maximum Green – Improved case

4.5.1.1 Base Case

In N-0 situation, the addition of MSCDNs creates 2 over-voltage violations to the 110 kV grid. To create a N-0 case without any 110 kV, 220 kV or 400 kV voltage violations the following was done after connection of certain new capacitive elements:

- After connection of the 2x50MVAr at bus 448014. Monitored over-voltage violation at 110 kV bus 449572. Solved by re-connection of reactive shunt at bus 448020.
- After connection of the 3x60MVAr at bus 448904. Monitored over-voltage violation at 110 kV bus 449572. Solved by changing the scheduled voltage for wind farm at bus 449897 – RSTUP3W from 1.0 p.u.to 0.9.

The addition of the third 400kV transformer between bus 448028 and 449874 solved all 400 kV N-0 loading violations. DNV only registered but didn’t solve/improve the situation for the 110 kV violations which consisted in the improved case of:

- One case of 110 kV line
- 11 cases of 110 kV to lower voltage level transformers

4.5.1.2 Contingency Analysis (N-1)

For 2031 Summer Maximum Improved Green case there were a total of 1627 monitored branches and contingencies simulated in PSS/E. There was also a total of 1044 monitored buses for voltage violations. The complete result file can be found in *SummerMax_ImprovedGreen.xlsx*.

Voltage Violations

A total of 46 voltage violations were monitored during the improved N-1 analysis (compared to 164 in the non-improved case). These consisted of:

- 2 cases of 400 kV single under-voltage violations (compared to 92 cases during 53 contingencies in the non-improved case)
- 44 cases of 110 kV violations (32 under-voltage violations and 12 over-voltage violations) during 11 different contingencies (compared to a total of 72 cases during 40 contingencies in the non-improved case)

The 400 kV violation can be seen in Table 4-40.

Table 4-40: 400 kV voltage violation during N-1 analysis on the Improved Summer Maximum - Green scenario

Violation #	Contingency event	Bus number	Bus Name	Bus Voltage-level [kV]	Base case Voltage [p.u]	Contingency Voltage [p.u]
1	448003-448008(1)	448003	RMINTI1	400	0.9682	0.9499
2	448037-448038(1)	448038	RCLUJ 1	400	0.9709	0.9064

DNV has analysed both violation and suggest the following:

For Violation #1: DNV has two potential solutions. First solution is to increase the scheduled voltage, from 0.95 p.u. to 1p.u, during this contingency for the SVC connected to bus 448034. Another solution is to create an SPS to disconnect the reactive shunt at bus 448001.

For Violation #2: DNV notes that this contingency leads to the violation bus, 448038 - RCLUJ 1 being a network endpoint, only connected to the 110 kV grid. An SPS that also disconnects the violation bus and the transformer to the 110 kV grid solves the issue.

The voltage violations and the SPS-actions are highlighted in Figure 4-8.

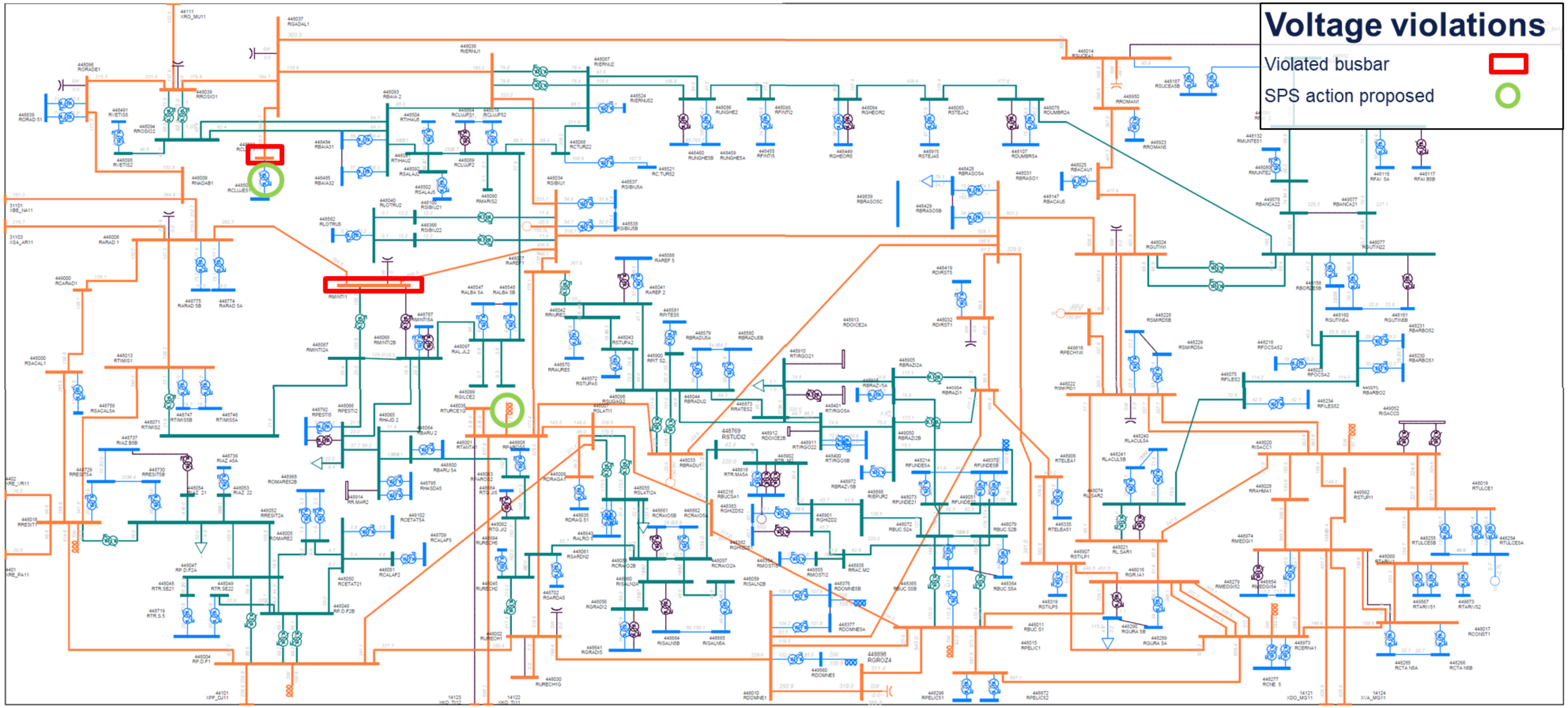


Figure 4-8: Grid topology highlighting the 2 violated buses and the suggested SPS actions. For the violation to the left the SPS action highlighted below is used and for the other violation the SPS action to the right.

Loading Violations

If the N-0 110kV violations are excluded, 103 flow violations were monitored during the N-1 analysis, this is similar to the non-improved case of 99 flow violations since DNV did not improve any of the N-1 loading violations. The flow violations consisted of:

- Eight cases of 400/110 kV transformers (compared to 2 in the non-improved case) DNV notes that the addition of 6 more cases in the improved case originates from the reinforcement of the third transformer. If one of the 3 trips, the other 2 gets overloaded (similar to the non-improved N-0 case)
- 6 cases of 400/24 kV transformers (same as the non-improved, all violations are the same)
- 61 cases of 110 kV line (compared to 63 in the non-improved)
- 26 cases of 110 kV to lower voltage level transformers (same as the non-improved.)

In Table 4-41 the 400 kV and 220 kV violations are presented. DNV has neglected to present the 400/24kV transformer flow violations since they are all connected to the nuclear power plants. As for previous cases DNV assumes other measures to be available to protect the NPP step-up transformers.

Table 4-41: 400kV and 220 kV loading violations for the improved Summer Maximum - Green scenario. Note that the 400/24 kV transformers to the NPPs have been excluded.

Violation #	From Bus	To Bus	Id	Contingency event	Loading [%]	Type of Branch
1	448069 - RTARIV1	449567 - RTARIV51	2	448069-449567(1)	116.79	400/110 kV transformer
2	448069 - RTARIV1	449567 - RTARIV51	1	448069-449567(2)	116.79	400/110 kV transformer
3	448079 - RBUC.S2B	449051 - RFUNDE22	1	448072-448073(1)	109.86	220 kV line
4	448072 - RBUC.S2A	448073 - RFUNDE21	1	448079-449051(1)	109.84	220 kV line
5	448028 - RRAHMA1	449874 - RRAHMA5	2	448028-449874(1)	106.91	400/110kV transformer
6	448028 - RRAHMA1	449874 - RRAHMA5	3	448028-449874(1)	106.91	400/110kV transformer
7	448028 - RRAHMA1	449874 - RRAHMA5	1	448028-449874(2)	106.91	400/110kV transformer
8	448028 - RRAHMA1	449874 - RRAHMA5	3	448028-449874(2)	106.91	400/110kV transformer
9	448028 - RRAHMA1	449874 - RRAHMA5	1	448028-449874(3)	106.91	400/110kV transformer

10	448028 - RRAHMA1	449874 - RRAHMA5	2	448028-449874(3)	106.91	400/110kV transformer

DNV highlights the need for reinforcement to 220 kV lines in violation #3 and #4. Reinforcements could also be considered for violation #1 and #2. However, the overloading is below the typical permissible overload of 20% for transformers. This should nonetheless be investigated. Violation #5 - #10 are all on the reinforced branch (the branch where a third transformer was added). Tripping of one transformer leads to a moderate overload of less than 7% in the two healthy transformers. This is considered as an acceptable scenario by DNV.

The loading violations is highlighted in Figure 4-9. Remark, the loading violations on the NPP step-up transformers are not included in the figure.

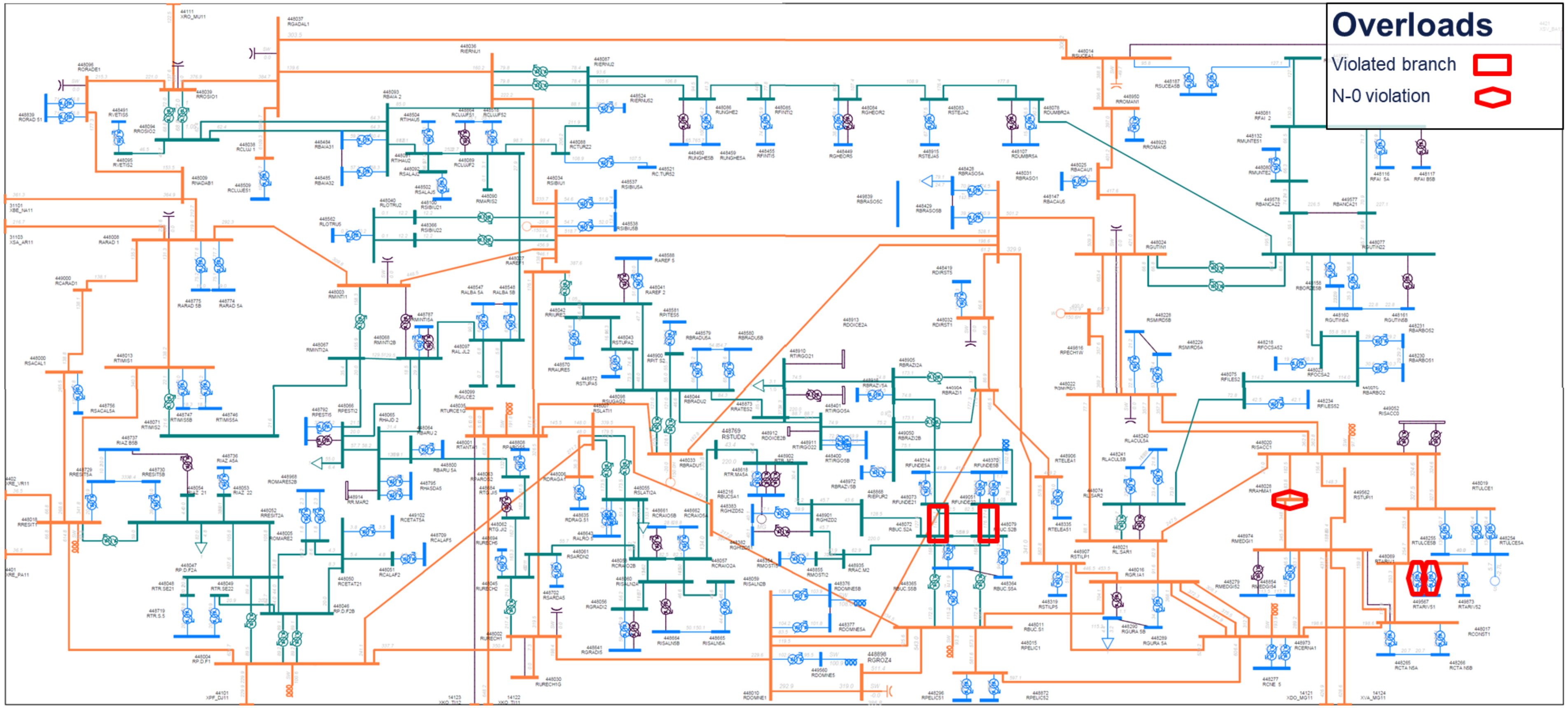


Figure 4-9: Grid topology highlighting the monitored violations during the improved summer max- Green N-1 analysis. Note that one of the highlights is green to better visualize that this branch is the reinforced transformer.

4.5.2 2031 Summer Minimum Green – Improved case

4.5.2.1 Base Case (N-0)

The addition of MSCDNs creates 1 over-voltage violations to the 110 kV grid. To create a N-0 case without any 110 kV, 220 kV or 400 kV voltage violations the following was done after connection of certain new capacitive elements.

- After connection of the 2x50MVAr at bus 448014. Monitored over-voltage violation at 110 kV bus 448708. Solved by re-connection of reactive shunt at bus 448004.

The addition of the third 400kV transformer between bus 448028 and 449874 solved all 400 kV N-0 loading violations. DNV did not improve the situation for the 110 kV violations which consisted in the improved case of:

- 11 cases of 110 kV to lower voltage level transformers

4.5.2.2 Contingency Analysis (N-1)

For 2031 Summer Minimum -Improved Green there were a total of 1,546 monitored branches and contingencies simulated in PSS/E. There was also a total of 1,033 monitored buses for voltage violations. The complete result file can be found in *SummerMin_ImprovedGreen.xlsx*.

Voltage Violations

A total of 44 voltage violations were monitored during the improved N-1 analysis (compared to 151 in the non-improved case). These consisted of:

- 17 cases of 400 kV under-voltage violations during 6 contingencies (compared to 106 cases during 21 contingencies in the non-improved case)
- 27 cases of 110 kV violations (19 under-voltage violations and 8 over-voltage violations) during 9 different contingencies (compared to a total of 44 cases during 4 contingencies in the non-improved case)

The largest 400 kV violation for each contingency causing a 400 kV violation is shown in Table 4-42.

Table 4-42: Largest 400 kV violations for each contingency causing a 400 kV voltage violation.

Violation #	Contingency event	# Of violations in contingency	Bus number	Bus name	Base case voltage [p.u]	*Contingency voltage [p.u]*
1	448001-448007(1)	2	448006	RDRAGA1	0.9824	0.9368
2	448010-448898(1)	3	448010	RDOMNE1	0.9745	0.9459
3	448011-448016(1)	3	448011	RBUC.S1	0.9738	0.9370
4	448011-448898(1)	3	448898	RGROZ4	0.9743	0.9453
5	448974-14124(1)	3	448011	RBUC.S1	0.9738	0.9427
6	448011-448015(1)	3	448011	RBUC.S1	0.9738	0.9459

DNV has analysed the voltage violations and they can all be solved by an SPS to disconnect a reactive shunt.

For Violation #1: Disconnect reactive shunt at bus 448004. Alternatively, violation 1 may also be solved by making the added MSCDN at bus 448006 even larger.

For violation #2-6: Disconnect reactive shunt at bus 448011.

The violated buses and the suggested SPS actions are highlighted in Figure 4-10.

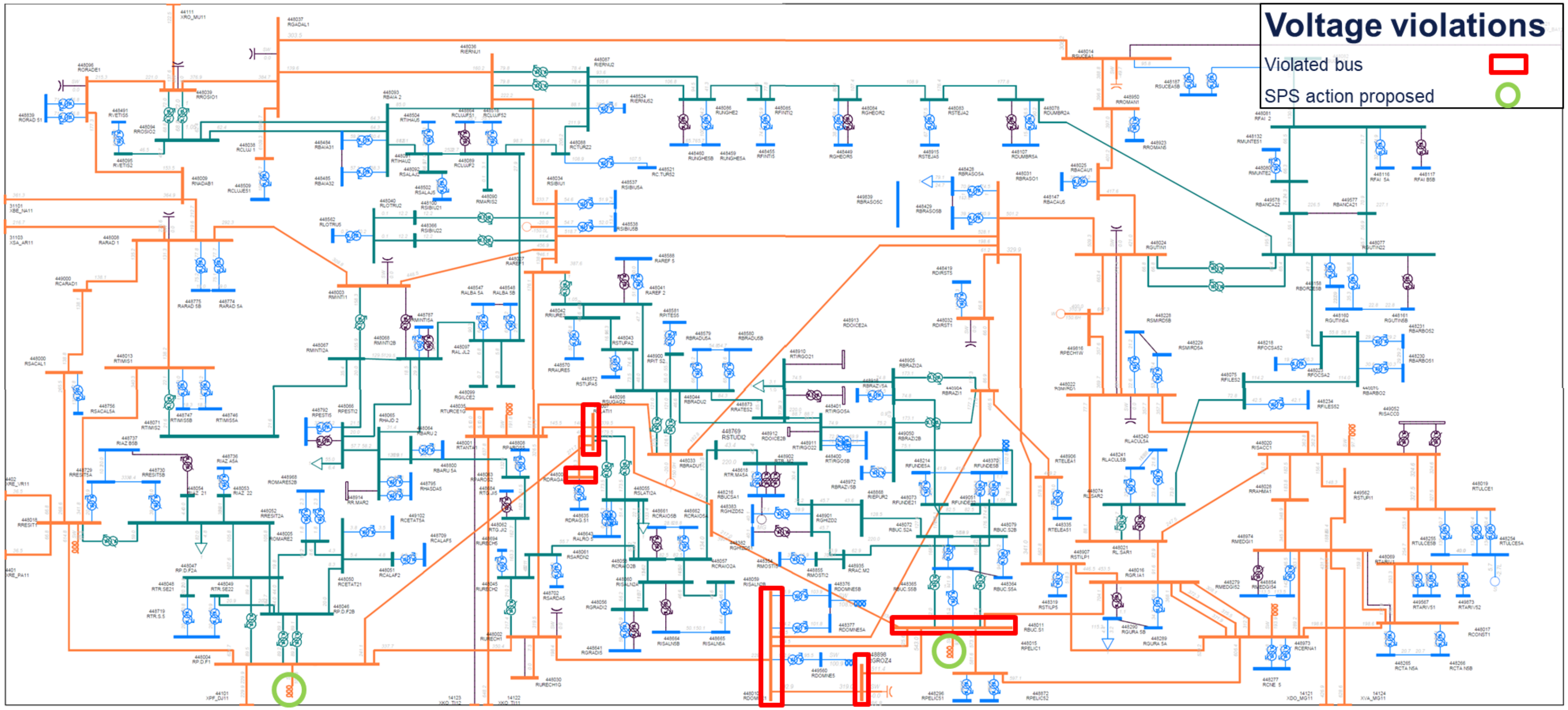


Figure 4-10: Grid topology highlighting violations monitored during Summer Minimum high wind N-1 analysis as well as suggested SPS actions

Loading Violations

If the 110 kV N-0 violations are excluded, a total of 62 flow violations were monitored during the N-1 analysis. This is similar to the non-improved case having 59 flow violations. This is expected since at this stage DNV did not reinforce any of the branches causing N-1 flow violations. The flow violations consisted of:

- 9 cases of 400/110 kV transformers (compared to 3 in the non-improved case). DNV notes that the addition of 6 more cases originates from the reinforcement of the third transformer. If one of the 3 trips, the other 2 gets overloaded (similar to the non-improved N-0 scenario).
- 6 cases of 400/24 kV transformers (same as the non-improved scenario, all violations are the same)
- 11 cases of 220 kV line (compared to 12 in the non-improved case). These violations occurred on 4 different lines (same 4 lines as the non-improved scenario)
- 2 cases of 220/110 kV transformers (compared to one in the non-improved scenario)
- 8 cases of 110 kV lines (compared to 11 in the non-improved scenario)
- 26 cases of 110 kV to lower voltage level transformer (same as the non-improved scenario)

The 400 kV violations, the highest violation for each 220 kV line and the 220/110 kV transformers violation is shown in Table 4-43. Note that DNV neglected to present the 400/24kV transformer flow violations since they are all connected to the nuclear power plants. As for previous cases DNV assumes other measures to be available to release the NPP- step-up transformers, esp. by making use of auxiliary bus bars.

Table 4-43: 400 kV and 220 kV loading violations during N-1 analysis for Improved Summer Minimum -Green scenario. Note that the NPP step-up transformers have been excluded.

Violation #	From Bus	To Bus	Id	Contingency event	Loading [%]	Type of Branch
1	448069 - RTARIV1	449567 - RTARIV51	2	448069-449567(1)	116.8	400/110 kV transformer
2	448069 - RTARIV1	449567 - RTARIV51	1	448069-449567(2)	116.8	400/110 kV transformer
3	448906 - RTELEA1	448335 - RTELEA51	1	448904-448906(1)	103.93	400/110 kV transformer
4	448072 - RBUC.S2A	448079 - RBUC.S2B	1	448011-448079(1)	118.8	220 kV line (no violation*)
5	448083 - RSTEJA2	448084 - RGHEOR2	1	448014-448037(1)	110.11	220 kV line (2 violations)
6	448078 - RDUMBR2A	448083 - RSTEJA2	1	448014-448950(1)	103.8	220 kV line (1 violations)
7	448079 - RBUC.S2B	449051 - RFUNDE22	1	448906-448907(1)	119.9	220 kV line (7 violations)
8	448082 - RSUCEA2A	448187 - RSUCEA5B	1	448014-448050(1)	113.2	220/110 kV transformer
9	448088 - RCTURZ2	448521 - RC.TUR52	1	448037-448039(1)	101.11	220/110 kV transformer
10	448028 - RRAHMA1	449874 - RRAHMA5	2	448028-449874(1)	106.9	400/110kV transformer
11	448028 - RRAHMA1	449874 - RRAHMA5	3	448028-449874(1)	106.9	400/110kV transformer
12	448028 - RRAHMA1	449874 - RRAHMA5	1	448028-449874(2)	106.9	400/110kV transformer
13	448028 - RRAHMA1	449874 - RRAHMA5	3	448028-449874(2)	106.9	400/110kV transformer
14	448028 - RRAHMA1	449874 - RRAHMA5	1	448028-449874(3)	106.9	400/110kV transformer
15	448028 - RRAHMA1	449874 - RRAHMA5	2	448028-449874(3)	106.9	400/110kV transformer

* This 220kV busbar coupler loading violation turned out not to be relevant due to a wrong current limit in the PSS/E models

Violation #1 and #2: These violations are two parallel transformers, the flow violation occurs during tripping of one which leads to overload of the other. Since the loading is below the typical permissible overload of 20% (which is assumed also for these transformers), no further action is presented, but reinforcements could be considered.

Violation #3: The contingency leads to a moderate overload of less than 4%, typically still solvable via operating this line in the upper part of permissible voltage range.

Violation #4 - #7: The highest violation for each of the 220 kV lines are presented with 20%, this is an indication for application of flexibility measures.

Violation #8 and #9: 220/110 kV transformers. The overload for violation #8 is over 13% and reinforcements could be considered. For violation #9 the overload is less than 2% which is considered acceptable by DNV.

Violation #10 - #15: Are all on the reinforced branch (the branch where a third transformer was added). Tripping of one transformer led to a moderate overload of less than 7% in the two healthy transformers. This is considered as an acceptable scenario by DNV.

The loading violation violations are shown in Figure 4-11.

Clarified non converging contingency case

DNV notes that the contingency event of 448001-14122(1), which is reflected as a single-circuit interconnector line tripping does not converge because of significantly changed load flows. However, DNV noted that there is a parallel second interconnector branch located in the PSS/E file not in operation in the respective grid model. The branches in question were already be reflected in Figure 4-6, where the critical line has been highlighted with green circles at the edges. Transelectrica confirmed that the parallel second interconnector circuit from 448001 RTANTA1 to 14123 XKO_TI12 can be fully utilized which allows tripping one of the interconnection circuits without load flow convergence problems. Otherwise, significant reactive power measures would have been proposed for the respective grid section.

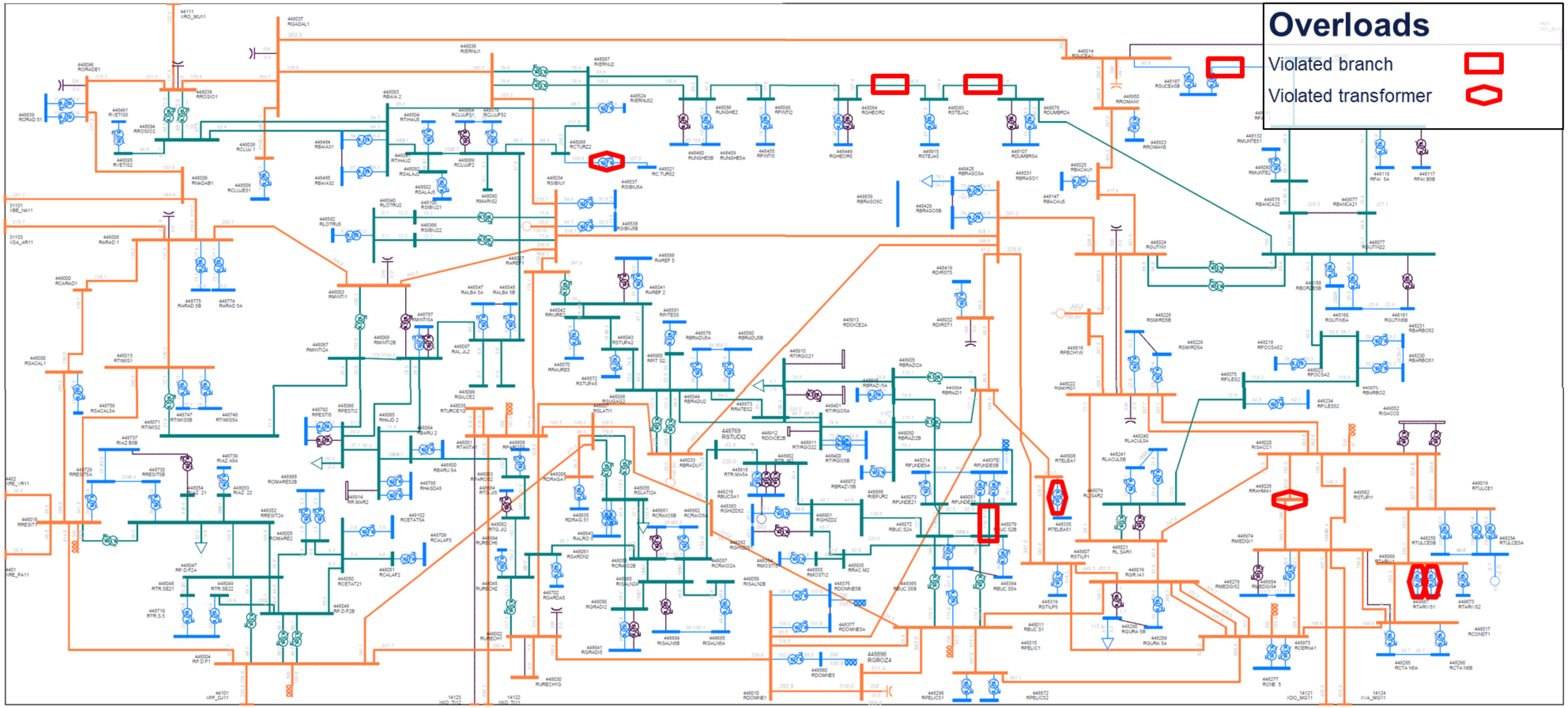


Figure 4-11: Grid topology highlighting the 220 kV/400 kV loading violations during the N-1 analysis for Improved Summer Minimum - Green scenario. Note that the NPP step-up transformers have been excluded. Green represents the reinforced transformer.

4.6 Summary of Grid Development Analyses

DNV analyzed the Romanian grid models in PSS/E simulations software for 2022, 2026 and 2031. The first part of the analysis was focused on comparing the installed capacity with the aimed TYNDP 2022-2031 numbers to verify that the installed capacity in the grid meets the target values. DNV has also analyzed the status of the Romanian grid through N-0 load flow and N-1 contingency simulations with focus on the 220 kV and 400 kV grid to evaluate any potential grid issue potentially caused by the large increase of installed renewable generation that is added for 2026 and 2031. After reviewing the current status in the simulation files, it became clear that they did not depict any max wind scenario since Transelectrica had put the dispatched wind at a maximum of 20% of the installed capacity.

Second part of the analysis was focused on increasing the wind generation to model two more ambitious green scenarios for 2031 as below,

1) High Wind and High Solar PV

2) High Wind with no Solar PV.

For 1) the case of 2031 Summer Maximum and for 2) the 2031 Summer Minimum case was chosen. DNV opted to scale the wind generation to 85% of the installed capacity based on German experience and left the Solar PV for 1) at 65% according to the Transelectrica setting. To accommodate for the increased wind generation DNV scaled down other generation types based on the current merit order provided by Transelectrica. The result for both cases was that all non-renewable generation was ramped down to zero respectively disconnected except the NPP units as agreed with Transelectrica to not change the dispatch of those units.

DNV analyzed how the current Romanian grid model for 2031 could handle the increased wind through the same approach as earlier by N-0 load flow and N-1 contingency analysis. For the green scenarios DNV noticed several needs for reinforcements which lead to the recommendation of the installation of five *Mechanically Switched Capacitors with Damping networks, MSCDNs* to provide reactive support for voltage stability during contingencies. DNV also suggested reinforcement in the way of one additional 400/110 kV transformer to avoid overload in the N-0 Green scenarios.

DNV highlights the need for several reinforcements and studies to be conducted on the 110 kV level in addition to the studies conducted in this project since that there were several 110 kV branches overloaded in the N-0 and N-1 analysis. Additionally, several 110 kV voltage violations occurred during the contingencies which was out of scope by DNV in this project. The 400 kV and 220 kV N-1 load flow violations for all simulated scenarios can be seen below in Table 4-44. Note that the violations on the swing bus (slack) transformer was neglected because it is assumed – like in reality – that also other generators contribute to the compensation of active and reactive power.

Table 4-44: Identified significant 400 kV and 220 kV load flow violations

Branch	Name	Type of Branch	# Of violations Summer Maximum					# Of violations Summer Minimum					# Of violations Winter Maximum			# Of violations Winter Morning		
			2022	2026	2031	Green	Improved Green	2022	2026	2031	Green	Improved Green	2022	2026	2031	2022	2026	2031
448010-448376	TR 400/110 kV Domnești	400/110 kV transformer	1										1	1		1	1	
448010-448377	TR 400/110 kV Domnești	400/110 kV transformer	1										1	1		1	1	
448028-449874	TR 400/110 kV Rahman	400/110 kV transformer					2					2						
448028-449874	TR 400/110 kV Rahman	400/110 kV transformer					2					2						
448069-449567	TR 400/110 kV Tariverde	400/110 kV transformer				1	1				1	1						
448072-448073	L220 kV București Sud – Fundeni c1	220 kV line			1	1	1											
448078-448083	L220 kV Dumb. – Stejaru	220 kV line									2	1						
448079-449051	L220 kV București Sud – Fundeni c2	220 kV line			1	1	1				7	7						
448082-448187	AT 220/110kV Suceava	220/110 kV transformer									1	1						
448083-448084	L220 kV Stejaru – Gheorgheni	220 kV line									2	2						
448370-449051	AT 220/110kV Fundeni	220/110 kV transformer											1			1		

Transelectrica informed that the following measures of Table 4-44 are already identified/planned:

- 448010-448376 (TR 400/110 kV Domnești)
    - Tripping of transformer TR1/ TR2 causes overload for TR2/ TR1
    - Already included in NDP (new 400kV substation Grozavesti for 2029)
- 448072-448073 (OHL 220 kV București Sud – Fundeni)
    - Tripping of one circuit causes overload for the other circuit
    - Already included in NDP (new 400kV substation Fundeni after 2031)
- 448079-449051 (OHL 220 kV București Sud – Fundeni c2)
    - Tripping of OHL 400kV Stâlpu – Teleajen causes overload for the second circuit
    - Already included in NDP (new 400kV substation Fundeni after 2031)
- 448370-449051 (AT 220/110kV Fundeni)
    - Already included in NDP (new AT 220/110kV Fundeni)
- 448011-448072 (AT 400/220 kV București Sud)
    - Already included in NDP (new 400kV substation Fundeni after 2031)
- 448078-448083 (OHL220 kV Dumbrava – Stejaru)
    - Already included in NDP
- 448083-448084 (OHL220 kV Stejaru – Gheorgheni)
    - Already included in NDP (increase of capacity not in the model)

For the 400 kV voltage violations, DNV suggested several options for *System Protection Schemes, SPS* to solve voltage violations during contingencies. With Table 4-45 below an overview of the different suggested SPS applications is given incl. the information during how many contingencies it is activated and how many voltage violation the respective action solves. Note that DNV suggested for some contingencies multiple solutions, for more information refer to the analysis for each scenario.

Table 4-45: Overview on proposed System Protection Schemes

SPS action	# Of violations solved Summer Maximum				# Of violations solved Summer Minimum				# Of violations solved Winter Maximum			# Of violations solved Winter Morning		
	2022	2026	2031	Improved Green	2022	2026	2031	Improved Green	2022	2026	2031	2022	2026	2031
Disconnect bus 448014, or enable tap-changer	1	1							1	1		1	1	
Disconnect bus 448006, or enable tap-changer	1	1	1		1	1	1		1	1	1	1	1	1
Disconnect bus 448038, or enable tap-changer				1 (tapchanger does not solve issue)							1			
Disconnect shunt at 448014					4(5)	1								
Disconnect shunt at 448020 or 448022					1									
Disconnect shunt at 448011						1(2)		5(15)						
Disconnect shunt at 448001			1	1		1								
Disconnect shunts at 448024 and 448020						2								
Disconnect shunt at 448004								1(2)						

Remark to Table 4-45: The reflected numbers show during how many contingencies the action is taken. Number in brackets is if the total number of violations solved by that action if it is more than one violation per contingency.

4.7 Simplified Cost-Benefit-Analysis

Based on the 2nd CBA Guideline ("2nd ENTSO-E Guideline for Cost Benefit Analysis of Grid Development Projects") approved by the EU Commission, a cost benefit analysis is only required for identified interconnection projects, and among others the market impact needs to be evaluated in this context. Since DNV did not suggest interconnections but only internal reinforcement measures, there is no need for a dedicated CBA. Nevertheless, DNV looked at especially the costs for the proposed internal reinforcements.

Already from the start of the analysis DNV focused on operational measures that could solve violations rather than investments into grid reinforcements. Hence DNV proposed solving violations using SPS and permissible/temporary overloading instead of installing new equipment.

With focus on the 2031 time horizon as main study focus, DNV considered and recommends the following new equipment:

- 1 unit 400/110kV transformer, 250 MVA. This refers to a third transformer between bus 448028 RRAHMA1 and 449874 RRAHMA5 which was previously overloaded in N-0 analysis. However, this position serves as a dummy since it is not clear at this stage which is the best place and real number of additionally required transformers. This must be correlated with the final RES power locally planned to be connected to the distribution level.
- 1 unit 3 steps x 60 MVAR MSCDN, 400 kV
- 3 units 2 steps x 50 MVAr MSCDN, 400 kV
- 1 unit 2 steps x 20 MVAr MSCDN, 220 kV
- 6 individual SPS solutions

The proposed internal reinforcements measures would allow for a fully decarbonized Romanian network already by 2031, as the suggested reinforcements and SPS ensures N-1 stability and voltage stability for the 220 and 400 kV network. However, it should be noted that more analysis and possible reinforcements are needed for the distribution incl. 110 kV network. In Table 4-46 DNV expected CAPEX and OPEX for the suggested reinforcements is presented. The yearly OPEX has been calculated using the simplified approach of 2% of CAPEX (assumption).

Table 4-46: DNV expected CAPEX and OPEX for suggested reinforcements

Type of unit	# of units	DNV expected CAPEX million Euro/unit	DNV expected OPEX million Euro/unit and year	Comment
400/110 kV transformer, 250 MVA	1	5.2	0.104	Assumption for transformer incl. ancillary systems
3 steps x 60 MVAR MSCDN, 400 kV	1	3.0	0.06	Cost derived from 100 MVAr switchable capacitor, without switch panel
2 steps x 50 MVAr	3	2.0	0.04	Cost derived from 100

MSCDN, 400 kV				MVAr switchable capacitor, without switch panel
2 steps x 20 MVAr MSCDN, 220 kV	1	0.8	0.016	Cost derived from 100 MVAr switchable capacitor, without switch panel
Individual SPS solution	9	0.08	0.0016	
Total:		**15.72**	**0.31**	

All in all, the identified investment measures show a limited CapEX of 15.5 m€ with yearly OpEX of 310 k€. This describes only a moderate transmission investment compared to the benefits. As important part of the benefits, the following zero emission generation in Romania could be expected for 2031, avoiding significant costs for the ETS respectively CO_2 emission certificates:

- Wind power: 5,300 MW x 85% x capacity factor of 2,200 h/a = **9,911 TWh/a**
- Solar PV: 5,100 MW x 65% x capacity factor of 1,050 h/a = **3,481 TWh/a**

In the analysed extreme scenarios of maximum VRE infeed while only the NPP units keep operation, a 100% decarbonized generation seems possible for a certain number of hours per year. But also in a significant number of other hours of 2031 – in periods with less VRE production, a highly decarbonized generation can be expected looking at the planned installed power of 6.4 GW based on hydro power and 2.6 GW the NPP units.

Precondition is the related investment into VRE farms and the electricity grid. While the required CapEx for the transmission grid reinforcement remains low with only 15.7 m€ , significant investments need to be done in the distribution grid infrastructure incl. 110 kV. The conducted analyses showed various overload and voltage violations within the 110 kV level, but no concrete reinforcement measures were identified, this should be the scope of a subsequent study project.

5 ASSESSMENT OF FLEXIBILITY OPTIONS

Flexibility options had to be analyzed especially for context of congested grid elements. DNV identified several loading violations during the N-1 analysis. However, as seen in Table 5-1 some violations are only present for 2022 and 2026, meaning that reinforcements and new projects have already been planned that will solve these. Thus, the applicability of flexibility options will only be analyzed for congestions remaining for the 2031 time horizon.

Table 5-1: Monitored line load violations in percentage of maximum rating

			2022				2026				2031							
Branch	Id	Type of Branch	Summer max	Summer min	Winter Max	Winter Min	Summer max	Summer min	Winter Max	Winter Min	Summer max	Green	Improved Green	Summer min	Green	Improved Green	Winter max	Winter morning
448010-448376	1	400/110 kV transformer	101,9		123,7	113,0			136,2	143,7								
448010-448377	1	400/110 kV transformer	102,6		124,8	113,8			136,0	145,2								
448011-448072	2	400/220 kV transformer															104,0	
448011-448079	1	400/220 kV transformer															103,9	
448028-449874	1	400/110 kV transformer											106.91**			106.9**		
448028-449874	2	400/110 kV transformer											106.91**			106.9**		
448028-449874	3	400/110 kV transformer											106.91**			106.9**		
448069-449567	2	400/110 kV transformer										116,9	116,8		116,9	116,8		
448069-449567	1	400/110 kV transformer										116,9	116,8		116,9	116,8		
448072-448073	1	220 kV line									102,9	111,2	109,8					
448072-448079	1	220 kV busbar coupler													120,0*	118,8*		
448073-448214	1	220/110 kV transformer			106,6	101,5												
448078-448083	1	220 kV line													104.1**	103,8		
448079-449051	1	220 kV line									102,9	111,2	109,9		122.4**	119.9**		
448082-448187	1	220/110 kV transformer													109,7	113,2		

448083-448084	1	220 kV line													110.6**	110.11**		
448088-448521	1	220/110 kV transformer														101,1		
448335-448906	1	400/110 kV transformer													104,2	103,9		
448370-449051	1	220/110 kV transformer			106,6	101,5												

* This 220kV busbar coupler loading violation turned out not to be relevant due to a wrong current limit in the PSS/E models

Remark to Table 5-1: Red numbers indicates that it is the highest violation monitored for that branch of all scenarios. A ** indicates that the branch has more than one violation monitored during the N-1 analysis for that scenario.

Basically, there exists a number of flexibility measures to avoid or to flank regular grid reinforcement measures which describe already state-of-the-art, first of all:

- Low costs investment measures like:
    - Optimization of operational planning (improved forecasting and scheduling, optimized redispatch processes)
    - Smart voltage management, allowing an operation at the upper limit of voltage range
    - Special Protection Schemes (which were already taken into account by DNV for solving over- and under-voltages occurring esp. in frame of the Green Scenarios, but also grid congestion management applications could be available)
    - Dynamic Line Rating (DLR) based on temperature monitoring
- Moderate to high investment measures like:
    - Load flow controlling assets like phase-shifting transformers, UPFC or Smart Wires
    - Conductor change to high-temperature (HT) or high-temperature low sag (HTLS) wires
    - Reactive N-1 management based on Grid Boosters as large-scale BESS in multi-MW scale
    - OHL and related substation upgrade to next EHV level
    - Back-to-back HVDC converters

But Table 5-1 shows for 2031 a maximum OHL overload of only 22%, and for transformers of 17 %. Other OHL appeared as slightly overloaded with less than 3% which can be subject for the application of a smart voltage management (i.e. operational measure). With regard to OHLs, from grid planning perspective the identified moderate overload up to 22% is an indication for application of DLR which allows a temporary increase of OHL capacity in the range from 10-40%, depending on equipment, static rating and weather variations.

However, with Table 5-1 DNV identified a number of reinforcement needs which are already present in the last release of TYNDP, as confirmed by Transelectrica. Furthermore, DNV also confirmed the need for reinforcement projects that Transelectrica was planning on to introduce in the new National Development Plan. The following branches were confirmed by Transelectrica to be reinforced:

- 448083-448084 (Stejaru-Gheorgheni) will be upgraded (the limit will be increased by 50%).
- Plan to build a 400kV substation Fundeni after 2031. This will solve the overloading on 220 kV OHLs:
    - 448072-448073 and 448079-449051 (Bucuresti Sud – Fundeni)
- Plan to build a third transformer 220/110kV 448370-449051 (Fundeni)
- Plan to introduce in the new National Network Development Plan the upgrade of OHL 220kV 448078- 448083 (Dumbrava – Stejaru).

All in all, there were no EHV OHL identified with potential application of DLR as flexibility measure. But as an indication for DLR related investment costs, an U.S. study example shows for a 22 mile long 345 kV OHL CapEX of USD 500,000 incl. installation of sensors and required IT infrastructure, etc. [7].

Apart from the identified OHL overloads, DNV monitored loading violations for 10 transformers. These violations are all below the permissible overload of 20% and therefore no action is suggested by DNV (Transelectrica confirmed that transformers can be overloaded to 20% for a limited period of time). The monitored overloads to the transmission grid that is not yet subject to confirmed upgrade are shown in Figure 5-1.

Finally, Figure 5-2 reflects all proposed additional grid measures after evaluation of all flexibility options.

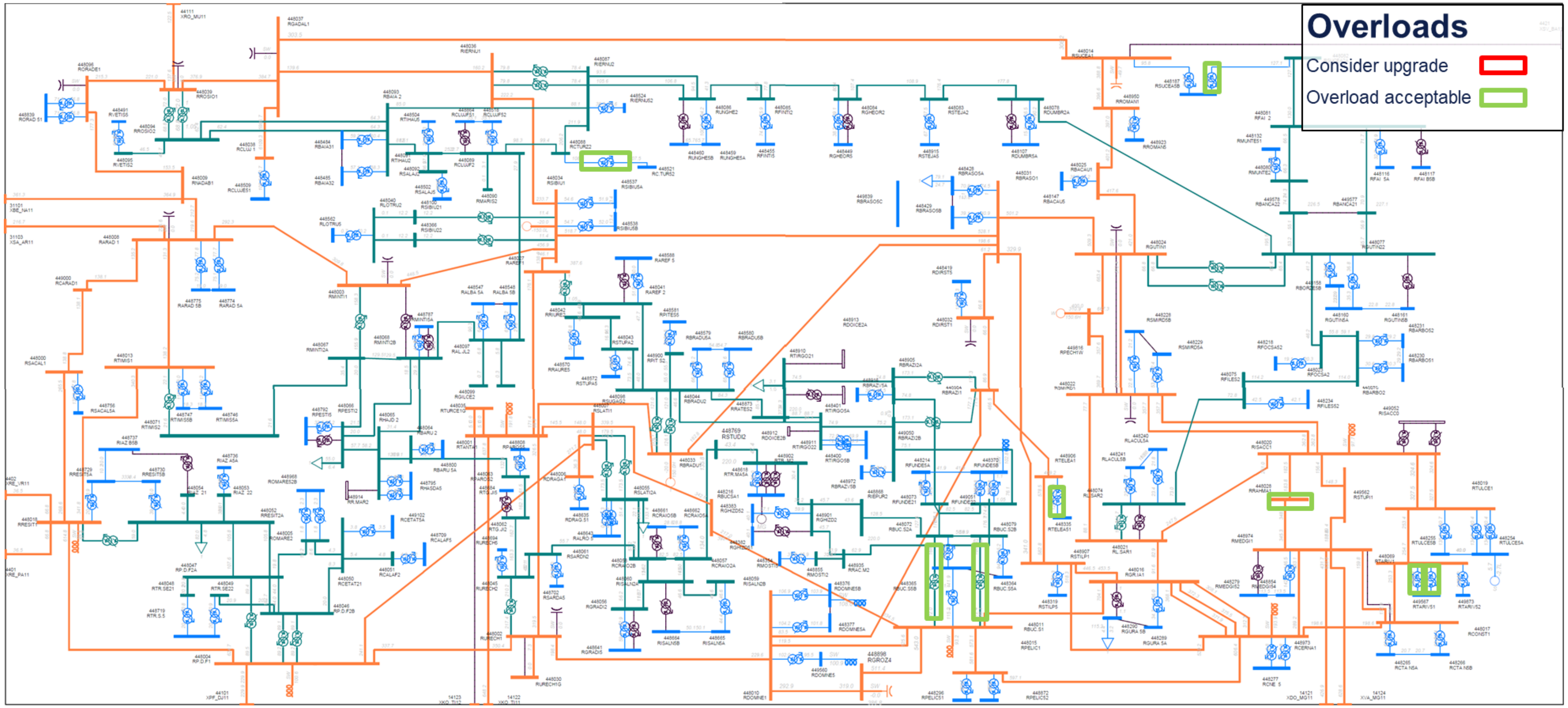
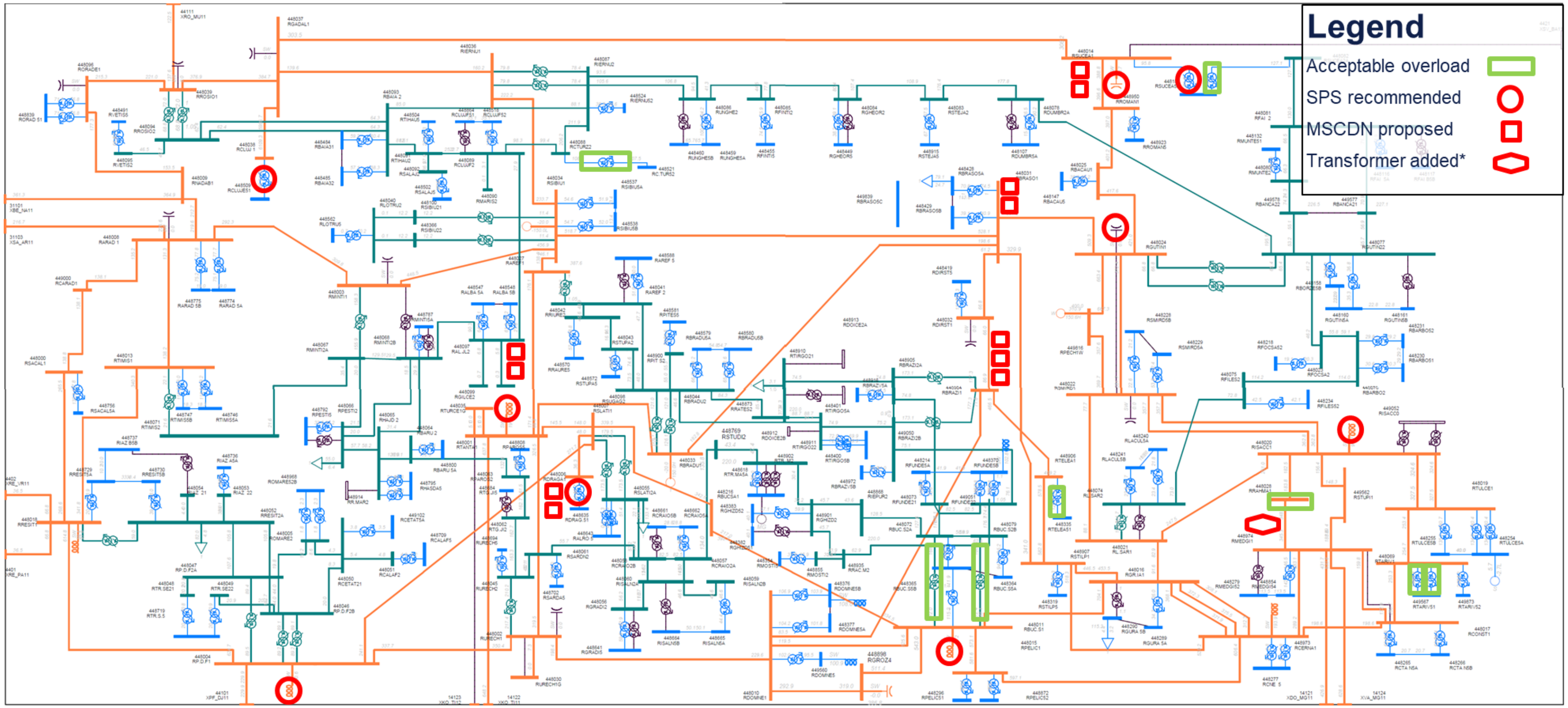


Figure 5-1: Grid topology highlighting the violations monitored not confirmed to be upgraded



* Transformer added as dummy, best location and number still to be correlated with the locally installed RES

Figure 5-2: Proposed additional grid measures after evaluation of all flexibility options

6 FINANCIAL OPTIONS AND THE REGULATORY POLICY FRAMEWORK (TASK 4)

6.1 Introduction

The main objective of Task 4 is to map how the regulatory framework in Romania can support transmission network reinforcement and flexibility measures and how do these frameworks and policy measures ensure that the necessary investments are made to accommodate the planned penetration of RES. Additionally, an overview of the key funding options (including private, public, national and EU-funding / programs) available for investments in the transmission network is provided.

Currently, the electricity transmission service is performed by a single transmission system operator – Transelectrica –certified by the energy regulator - ANRE as network owner subject to the opinion of the European Commission[6]

Transelectrica has the obligation to make investments in the entire transmission network and is required to prepare the ten years development plans for the transmission network (TYNDP) based on the status and future evolution of the consumption of energy and resources, including imports and exports. The development plans must include financing methods for investments relating to the transmission network and must be approved by ANRE. The current TYNDP refers to the period 2020-2029[7] and it is in review process for 2022-2031.

6.2 Regulatory Framework /Policy Measures

6.2.1 Status Quo

The Romanian Energy Regulatory Authority (ANRE) is the regulatory authority responsible for drafting and approving methodologies and tariffs for electricity networks, which represent the main funding source for development projects. Thus, ANRE indirectly influences the level of transmission investments based on internal funds (covered by transmission tariffs) and external funds (covered by interconnection tariffs).

The methodology for setting tariffs for the electricity transmission service, approved by means of ANRE Order No. 171/2019, entered into force in 2019, the reference year of the fourth regulatory period (2020-2024).

The revenue cap is composed of the non-controllable operating and maintenance costs, controllable operating and maintenance costs (OPEX, applying an efficiency factor for reducing inefficiencies), costs of electricity losses, annual depreciation and rentability of the regulated asset base (RAB) (i.e., the RAB multiplied by the WACC). There are efficiency requirements for controllable OPEX and for costs of electricity losses. The WACC is set in the reference year for the regulatory period and can be updated during the period to reflect the evolution of financial market conditions.

The regulated annual revenues (revenue cap) consider the evolution of the RAB, which reflects the impact of the TSO's investment plans implementation. In addition, the fixed assets used by the TSO for the performance of the transmission service are included in the RAB if they resulted from efficient investment projects. Therefore, the investment plan for the regulatory period is checked in terms of

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[6] Source: https://energy.ec.europa.eu/system/files/2022-03/Certifications_decisions_updated_0.pdf

[7] Source: https://www.transelectrica.ro/ro/web/tel/planului-de-dezvoltare-ret-2020-2029

necessity, opportunity, efficiency, and cost of investments. The structure of the plan is also verified, and the plan is approved ex-ante by ANRE. The estimated benefits that justify the efficiency of every investment in the electricity network are evaluated ex-ante and ex-post by the network operator and reported to ANRE. ANRE removes the investments that prove ex-post to be inefficient from the RAB, because the expected benefits are not realised.

Transelectrica is certified as transmission network owner however it owns only 45% of transmission assets, while 55% of the transmission grids are owned by the state [8] and are operated by Transelectrica based on a concession agreement.

Transelectrica is in charge of the investments in the entire transmission network and the assets could be included later in the RAB independent of ownership of the assets and are depreciated by the TSO subject to the type of funds (with the exception of grants or contributions from public and private sources).

Any revenues of the TSO resulting from the allocation of the transmission capacity on the interconnection lines are to be used in accordance with the provisions of art. 16, para. (6) from Regulation no. 714/2009. Those revenues represent a source for financing the investments for increasing the interconnection capacity with neighbouring systems, which are part of the investment and development plan approved by ANRE for the respective regulatory period.

With regards to the projects of common interest (PCI) there are specific measures/ incentives for stimulating the development of the electricity transmission network through investments falling under the categories set out in annex II, point 1 from the Regulation 347/2013[8]. The procedure set out by the PCI Methodology requires the TSO to submit a request for incentives to ANRE, if it considers that the PCI project presents increased risks with respect to the development, operation, and maintenance of the project, as compared to the systemic risks that a similar infrastructure project usually presents. ANRE decides whether to grant incentives to a PCI project as well as the respective incentive amount and methods.

6.2.2 Regulatory Schemes for Investments Incentives

ANRE may also consider in addition a depreciation policy different to its regular treatment of the RAB. This option would only be applicable for the selected project for transmission network reinforcement and flexibility measures. To encourage investments in these projects which are essential to accommodate the planned penetration of RES ANRE may adopt a specific accelerated depreciation policy. The applicability of this approach would also depend on the scale of the investment cost as this would mean a faster recovery of the investment via the depreciation allowance in the allowed revenues. For example, accelerated depreciation allowance (front-loaded profile, shorter asset life) would allow Transelectrica to recover the cost of the investment quicker. It also provides higher certainty that there is some recovery in case the planned RES penetration does not occur, and the assets may remain underutilise. By considering such a depreciation policy for certain projects this could be an incentive to promote investment.

[8] Regulation (EU) No. 347/2013 defines the criteria for the selection and evaluation of projects of common interest (PCI), to be eligible for inclusion by the European Commission on the Union lists; proposals for electricity transmission and storage projects should be part of the latest ten-year electricity grid development plan developed by ENTSO-E.

6.2.3 Exemption from Efficiency Analysis

The purpose of efficiency analysis is to exploit the efficiency improvement potentials of the regulated companies, to provide them with incentives to improve their efficiency performance and to ensure that network users benefit from efficiency gains. Electricity networks use a wide range of inputs (capital, labour) to provide services to customers. While all network service providers use broadly the same inputs, some providers may use proportionately more of some inputs and less of others. The mix of inputs used depends upon, among other things, management practices and the operating environment.

Similar to other regulators ANRE undertakes capex reviews examining the efficiency of the proposed investment plans. The capex reviews aim to counteract the adverse incentives for the TSO to overstate their investment projections in order to increase their allowed RAB and hence revenue for the regulatory period. The threat that capital costs of investments may be rejected, or partially disallowed, in the review process aims to encourage Transelectrica to plan and undertake efficient and prudent investments.[9]

The exclusion from efficiency analysis in the capex review process aims to exempt the cost of specified investment projects and guarantee their recognition. The list of the exempted investments can be defined by ANRE in coordination with Transelectrica, and should include the selected project for transmission network reinforcement (e.g., investments in lines / transformers, equipment for reactive power management) and flexibility measures (e.g., dynamic rating, phase shifters) necessary to accommodate the planned penetration of RES. The costs of the exempted investments will be considered non-controllable costs and therefore completely recognised in the regulatory asset base.

6.2.4 Investments in Innovation

Investment in innovation is inherently risky and severe regulatory reviews may discourage companies to invest if they retain the exposure to the downside risks of investment but do not share in the upside benefits. In addition, the individual benefits of companies investing in innovation could be less than expected and/or costs can be greater than estimated, resulting in downside risks for them.

For example, if the investment does not get rolled into RAB, it will not be able to generate a regulated return to the company. Instead, the company would need to cover costs through efficiency gains. On the other hand, even if the costs of the investment are rolled into the RAB, the length of time that they remain in the RAB may create a disincentive depending on how the asset is depreciated. For example, investments in innovation may be depreciated over a shorter period than core business assets due to the likelihood of technological obsolescence.

Therefore, ANRE may consider using explicit innovation incentives[10] as part of the regulatory framework as this facilitates development and drives improvement in processes and technology application in the

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[9] Such incentives are necessary to compensate the information advantages of Transelectrica about the prospective efficiency of the proposed investments. By making the entities accept the consequences of its investment decisions, the probability that inefficient investment by Transelectrica is therefore weakened.

[10] A notable feature in Great Britain already having a long tradition in energy regulation is its continuous enhancement of its regulatory approaches to consider the changes and development of the energy sector. As part of its current framework - RIIO (Revenues = Incentives + Innovation + Outputs), Ofgem introduced specific incentives for innovation as part of an 'innovation stimulus'. The aim of this approach is to provide incentives to drive innovation that are needed to deliver a sustainable energy network. There are two mechanisms provided under the innovation stimulus. These are the Network Innovation Allowance (NIA) and the Network Innovation Competition (NIC). The Network Innovation Allowance (NIA) is a set annual allowance that allows the regulated network operators a funding opportunity of 0.5-1% of revenue to be spent on innovation projects, 90% of which can be recovered through the incentive mechanism. The NIA funds smaller scale research, development and demonstration projects and can cover all types of innovation, including commercial, technological and operational. Unlike the NIC, the NIA is not focussed solely on innovative projects with potential low carbon and environmental benefits.

transmission system. ANRE should set clear objectives and qualification criteria for what projects would be subject to innovation incentives. For example, innovation incentives can be provided for a new or unproven technology or operational practice directly related to investments in the transmission network reinforcement and flexibility measures necessary to accommodate the planned penetration of RES. The innovation projects should relate to the development, and research in a field, or technology that could help achieve certain targets related to the penetration of RES.

Innovation incentives can be incorporated into the regulatory framework by using a special allowance. The allowance would be based on a proportion of the allowed revenues. This could be applied for smaller scale research and development projects that qualify for the allowance. Transelectrica would need to apply formally to use the allowance and present their projects and the potential benefits to ANRE. The innovation/decarbonisation allowance can be implemented by allocating a certain budget (e.g. a certain percentage of the allowed revenue) to Transelectrica for investments in innovation type projects subject to regulatory approval and qualification criteria. The regulatory treatment of the assets would enter in the RAB, be subject to depreciation allowance based on the specified asset life and regulatory return under the conditions set out in the overall regulatory framework.

6.2.5 Generic Incentive Schemes

Below we provide two additional approaches that are often applied by regulators to encourage investments.

6.2.5.1 Efficiency Carry-Over Schemes

Towards the end of each regulatory period, the price control will need to be reset for the next regulatory period. The price control may be reset by moving the allowed revenue to the prevailing level of costs in the base year. Thus, the regulated company keeps the profits from efficiency improvements (above the efficiency targets incorporated in the allowed revenue) for up to the length of regulatory period when the gains are transferred to customers through lower prices.

ANRE might consider not to impose an immediate realignment and instead set a revenue path that incorporates the efficiency gains for the duration of the upcoming regulatory period (efficiency carry-over). In this case the TSO will be allowed to enjoy the profits of its efficiency gains for rather longer which will strengthen their incentives to accomplish efficiency savings. On the other hand, the greater the share the TSO is allowed to retain, the longer customers will have to wait before the benefits from efficiency savings are passed through to them.

The term “efficiency carry-over” is used to describe any regulatory mechanism used to carry over all or part of any efficiency gains from one regulatory period to the next. It should strengthen incentives for Transelectrica to pursue efficiency gains.

6.2.5.2 Sliding-Scale Schemes

Sliding scales, or sharing mechanisms as they are also called, set incentives for regulated companies to achieve specific regulatory targets by splitting the benefits and costs of over- or under-achieving these targets between the company and the customers according to a pre-defined rule.

Under such schemes ANRE may set a specific target level for cost items such as investment (and operating) cost reductions. If Transelectrica can achieve this target level within a pre-defined range, benefits or costs of this item are recognised by the regulator to their full extent. If this range is over- or under-achieved, benefits or costs are shared between the company and users. The sharing levels are complemented by a maximum and minimum level (cap or floor) above or below which all costs are covered by the company or its users respectively.

6.3 Key Funding Options

According to the 2021-2030 Integrated National Energy and Climate Plan, Romania should develop additional RES capacities to reach a share of renewable energy of 30.7% by 2030. To achieve this target, the external funding plays also an important role (in addition to the internal funding generated from transmission tariffs and interconnection tariffs) to support the realisation of the investment projects in network reinforcement and flexibility. Below we address several key funding options for transmission investments including *inter alia:*

- Bank loans
- Corporate bonds
- EU-facilities
    - Trans-European Networks for Energy
    - Structural Funds
    - Invest EU Programme
    - Modernisation Fund

6.3.1 Bank Loans

Transelectrica has built strong relationships with local commercial banks and the international financial institutions (IBRD, EBRD, EIB). A substantial part of the investment programs implemented by the company in the last 16 years were financed by loans attracted from the banking system. Currently there is also a considerable interest from credit institutions in participation in financing programs for infrastructure investment projects. Such infrastructure projects in the electricity sector are one of the main areas targeted for financing (see below the excurses of the lending policy of EIB).

Excursus EIB Lending Policy

In November 2019, the European Investment Bank (EIB) adopted a new energy lending policy. The EIB will phase out the financing of traditional fossil fuel energy projects, including natural gas, by the end of 2021. Specifically, the energy lending policy calls for:

- Unlocking energy efficiency investments
- Decarbonising energy supply
- Supporting innovative low-carbon technologies
- Investing in a more secure enabling infrastructure

The EIB will continue to support the investment in national electricity networks, including the interconnection target agreed for 2030 (e.g., 15% of installed capacity for 2030) European Projects of Common Interest. Furthermore, the EIB will look to prioritise investments that increase network flexibility. With regards to the decarbonisation of the energy supply, EIB will undertake to support the integration of renewable energy projects and good regional cooperation.

6.3.2 Corporate Bond Issuance

The issuance of bonds on local or international markets constitutes an alternative to financing the investment program that has a fixed duration and a fixed cost of financing for the whole period.[11] Transelectrica has already been using corporate bonds as part of the external debt in its capital structure. For the future we understand that the company has been considering to launch a Medium-Term Notes (MTM) corporate bond program[12], taking into account the option of borrowing in foreign currency in international markets, such as London and Paris.

6.3.3 EU Funding Facilities

The sections below explain the EU facilities that focusing on the energy infrastructure in the EU. They cover the Trans-European Networks for Energy (TEN-E), Structural Funds and InvestEU Programm.

6.3.3.1 Trans-European Networks for Energy (TEN-E)

The Trans-European Networks for Energy (TEN-E) is a policy that is focused on linking the energy infrastructure of EU countries. As part of the policy, nine priority corridors and three priority thematic areas have been identified.

The EU helps countries in priority corridors and priority thematic areas to work together to develop better connected energy networks and provides funding for new energy infrastructure. In the past ten years, the EU has improved cross-border energy infrastructure with the Trans- European Networks for Energy (TEN-E). 95 energy infrastructure projects – known as Projects of Common Interest – have received €4.7 billion of funding under the EU budget through the Connecting Europe Facility (CEF).

Romania is part of priority electricity corridor no. 3 "North-South electricity interconnections in Central-Eastern Europe and South-Eastern Europe (NSI East electricity): Interconnections and internal lines in North-South and East-West directions to complete the internal market and integrate production from renewable sources. The three priority thematic areas, which relate to the entire EU, include smart grids deployment, electricity highways and a cross-border carbon dioxide network.

6.3.3.2 Structural Funds

The structural funds include the European Regional Development Fund (ERDF) and the Cohesion Fund (CF). The programs related to these funds are shared responsibility between the European Commission and national and regional authorities in Member States.

All regions and Member States should concentrate the support on a more competitive and smarter Europe (Policy Objective 1, PO1), and greener, low-carbon transitioning towards a net zero carbon

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11 The borrower (issuer) issues a bond that includes the terms of the loan, interest payments that will be made, and the time at which the loaned funds (bond principal) must be paid back (maturity date). The interest payment (the coupon) is part of the return that bondholders earn for loaning their funds to the issuer. The interest rate that determines the payment is called the coupon rate.

12 The corporate MTNs represent a debt program that is used by a company to support the establishment of a stable cash flows coming in from its debt issuance. In other words, it allows a company to tailor its debt issuance to meet its financing needs.

economy and resilient Europe (Policy Objective 2, PO2), through the mechanism known as "thematic concentration". Specifically, the mechanism should work as follows:

- All regions and Member States (MSs) should concentrate at least 30% of their allocation to PO2
- More developed regions or MSs should dedicate at least 85% of their allocation to PO1 and PO2
- Transition regions or MSs at least 40% to PO1
- Less developed regions or MSs at least 25% to PO1.

PO2 is the most relevant for the energy sector. This objective promotes a greener low-carbon Europe by promoting non-polluting and fair energy transition, green investments, the circular economy, adaptation to climate change and risk prevention and management. The ERDF/CF specific objectives under the PO2 are:

- to promote energy efficiency and reducing greenhouse gases
- to promote renewable energy generation
- to develop smart energy systems, grids, and storage outside the TEN-E
- to prevent and to address the risks related to climate change and the natural risks (floods, drought, forest fires, landslides, earthquakes) according to the national priorities set and in the framework of the cross-border and transnational coordination and cooperation.

There are several operational programmes proposed, under which the budget allocated to Romania for the period 2021-2027 will be administered. The list of these operational programmes is provided below:

- Operational Programme Sustainable Development
- Operational Programme Smart Growth and Digitalisation
- Regional Operational Programmes (implemented regionally)
- Just Transition Operational Programme.

6.3.3.3 InvestEU Programme

The InvestEU Programme supports sustainable investment, innovation, and job creation in Europe. It aims to trigger more than €372 billion in additional public and private investment over the period 2021-27 through an EU budget guarantee of €26.2 billion. It will bring together the European Fund for Strategic Investments and 13 other EU financial instruments. The InvestEU Programme supports the following four main policy areas:

- Sustainable infrastructure
    - Transport, in particular clean and sustainable transport modes, multimodal transport, road safety, renewal and maintenance of rail and road infrastructure
    - Energy, in particular renewable energy, energy efficiency and building renovation projects focused on energy savings and the integration of buildings into a connected energy source, storage, digital and transport system, improving energy infrastructure interconnection levels
    - Digital connectivity and access including in rural areas

- Supply and processing of raw materials, space, oceans, water, including inland waterways, waste management in line with the waste hierarchy and the circular economy
  - Nature and other environment infrastructure
  - Cultural heritage, tourism
  - Equipment, mobile assets and deployment of innovative technologies that contribute to the environmental climate resilience or social sustainability objectives of the EU, and meet the environmental or social sustainability standards of the EU
  - Research, innovation and digitalisation
- Research, product development and innovation activities
- SMEs
- Social investment and skills

6.3.4 Modernisation Fund (MF)

The Modernisation Fund is a dedicated funding programme to support 10 lower-income EU countries in their transition to climate neutrality by helping to modernise their energy systems and improve energy efficiency. The beneficiary EU countries are Bulgaria, Croatia, Czechia, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, and Slovakia. It includes support investments in energy storage, generation and use of renewable sources and modernisation of energy networks, including pipelines, grids, and district heating, as well as just transition in carbon dependent regions.

The Modernisation Fund envisages two types of investments:

- Priority investments that must fall into at least one priority area as defined by the EU Emission Trading System (EU ETS) Directive, namely:
  - generation and use of electricity from renewable sources
  - improvement of energy efficiency (including in transport, buildings, agriculture, waste, and except in energy efficiency related to energy generation using solid fossil fuels)
  - energy storage
  - modernisation of energy networks (including district heating pipelines, grids for electricity transmission, increase of interconnections among EU countries)
  - support to a just transition in carbon-dependent regions in the beneficiary EU countries (including support to the redeployment, re-skilling and up-skilling of workers, education, job seeking initiatives and start-ups, in dialogue with social partner)
- Non-priority investments that do not fall into a priority area but meet the Modernisation Fund objectives and demonstrate reduction of greenhouse emissions.

Priority investment examples include electricity grids enabling renewable energy investments such as network investments; enhancing flexibility of electricity systems; investments increasing interconnections between the MSs and modernisation of electricity transmission infrastructure.

Most of the resources of the Modernisation Fund (at least 70%) must be invested in priority areas.

At least 9 investment projects in overhead transmission lines, rehabilitation of substations and smart grids have been submitted by Transelectrica to be financed by the Modernisation Fund.

7 CONCLUSION

During the Inception Phase the scope of the project was changes in a way that that DNV especially focusses on an active support of the long-term green VRE scenarios of the ongoing new TYNDP version (2022-2031) instead on a retrospective evaluation respectively review of the latest published Romanian TYNDP release (2020-2029).

The project started with the comparison of VRE scenarios NECP vs. TYNDP. It was shown that for the TYNDP scenario 2031 Transelectrica respected to large extent the installed power stated in the NECP, esp. the installed RES (keeping in mind the slightly different time horizons 2030/2031). However, within the TYNDP 2031 scenario, Transelectrica considered 2,630 MW NPP instead of 1,975 MW (NECP 2030) due to a related concrete grid connection application. And for hydro PPs, Transelectrica considered for the TYNDP 2031 only 6,421 MW instead of 7,593 MW (NECP 2030) lacking a respective grid connection application for the delta power, esp. there was no 1,000 MW application for pumped storage PP like considered in the last release of TYNDP for 2029.

A major focus of the project was dedicated to load flow and contingency analyses. In first step, the TYNDP grid models and reflected generation and load scenarios were checked for the grid models received from Transelectrica. In next step, the PP production was changed in order to reflect a higher RES penetration. While the Transelectrica assumption of simultaneous solar PV feed-in of 65% in maximum was not changed, the simultaneous wind power feed was massively increased from 20% to 85% in maximum.

The assumption to ramp down all conventional generation (except NPP) and hydro PP to zero was indeed taken to reflect a critical, extreme scenario. This assumption was intensively discussed within the DNV project team. Finally, lacking the merit order and market model for the neighbouring countries (which might also have a peaking RES production at the same time) in frame of this study project, the focus was done on reflection of as much as possible green scenarios for Romania.

Regarding reduced inertia in DNV's green scenarios, the increased number of installed NPP units the Romanian inertia contribution won't change significantly. Moreover, wind farms can be expected in future to contribute fast frequency response (FFR) as virtual inertia, depending on respective future Transelectrica's RfG requirements. Regarding FCR provision, in future also BESS could be expected to contribute significantly like in Germany, since the NECP states for Romania up to 400 MW BESS by 2030.

As another important assumption taken for these simulations, all RES farms were considered to actively contribute to voltage stabilization via Q control responding any Transelectrica target voltage values for busbars set by the Transelectrica control room dispatchers. Related to the identified voltage problems, slight violations are expected to be solved by manual measures, some violations could be caused by imprecise modelling, too, esp. regarding the reflection of tap changers.

Based on the preparations, comprehensive load flow and contingency simulations were conducted in order to identify any needs for measures enabling these green scenarios. In the final report meeting, Transelectrica confirmed that the DNV simulation results are reasonable and not that different to other studies of green scenario analyses. Only the conventional production (except NPP) and hydro production ramped down to zero are less realistic assumptions, hence Transelectrica assumed more export while the base case shows import.

Regarding the OHL simulation results, the voltage levels 380, 220 and 110 kV was monitored while the identification measures was limited to the EHV level (i.e. 380 and 220 kV). Transelectrica confirmed in the final report meeting that these are like expected, therefore Transelectrica considered already a number of reinforcements and informed DNV accordingly so that this input information was available in the course of grid simulations. Regarding the transformer related simulation results, DNV monitored loading violations of ten 380/110 kV transformers. These violations are all below the permissible overload of 20% and therefore no action was suggested by DNV. However, some inaccuracies could be caused e.g. by an imprecise transformer reflection in the provided grid models, to be further checked by Transelectrica.

DNV conducted a simplified Cost-Benefit Analysis (CBA) of the identified investment measures, limited to the related costs and impact on VRE contribution to the green penetration for Romania. As result, the CBA shows a limited CapEX of 15.7 m€ with yearly OpEX of 310 k€ for all identified EHV related measures. While the required CapEx for the transmission grid reinforcement appears low, significant investments need to be done in the distribution grid infrastructure incl. 110 kV which was not in the scope of this study. However, the benefits would be a total wind energy of up to 9.9 TWh/a and solar PV infeed up to 3.5 THW/a, provided that the required investments into VRE farms as well as in the electricity grid (transmission and distribution level) will be realized.

In subsequent step, DNV analysed the flexibility potential and identified respective options. Apart from the nine Special Protection Schemes (SPS) already identified and grid model wise considered as voltage related solutions in the course of load flow and contingency simulations, no further flexibility options have turned out to be beneficial. On the one hand, no required EHV OHL reinforcement needs were identified not yet reflected by the already planned set of Transelectrica reinforcement measures, and thus no opportunity for installing a Dynamic Line Rating (DLR) system or load flow controlling assets. On the other hand, the monitored loading violations for 10 transformers are evaluated as non-critical ones.

In last step, DNV analysed financial options and the regulatory policy framework for Romania, starting with an overview on the status quo of the Romanian regulatory framework and policy measures. The different investment financing possibilities were explained for the regulatory schemes, it was elaborated on how exemption from efficiency analysis, investment in innovations and generic incentive schemes can work for Transelectrica. As key EU funding options, DNV underlined bank loans, corporate bond issuance, EU funding facilities line, namely Trans-European Networks for Energy (TEN-E), Structural Funds and InvestEU Programme. Furthermore the principle of EU Modernisation Funds was described.

In the light of the DNV results, Transelectrica confirmed that DNV’s findings provide valuable input especially for the final preparation of the TYNDP 2022 – 2031.

ANNEX: REFERENCES

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