THE IMPACTS ON THE HIGH-VOLTAGE NETWORK OF LARGE-SCALE RES INTEGRATION IN BOSNIA AND HERZEGOVINA

– Final Report –

September 15, 2022

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[Category]

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1 EXECUTIVE SUMMARY

The main motivation for this study of the Electricity Market Initiative (EMI) was to effectively address the substantial grid impacts of growing requests for RES grid connection and operation in Bosnia and Herzegovina (BiH), along with expected similar massive changes in the neighboring well-interconnected systems, primarily Croatia. Transmission (and distribution) networks need to adjust to future circumstances, since they were not initially designed for new, more dispersed network users like RES, which are often located in remote areas.

The main scope of work was to develop, coordinate and analyze the 400 kV and lower voltage network development needs in the BiH system, coordinated with activities in Croatia, to ensure that network development would support the significant expected changes in the BiH generation portfolio, primarily from RES integration. These factors are of utmost importance in BiH due to the proximity and high interconnectedness with Croatia (21 interconnection lines), and the high RES potential and investors' interest in BiH and Croatia.

In addition, this analysis was designed to demonstrate the value of coordinated grid planning across borders with substantial power flows. While this study was not a joint study between BiH and Croatia, this work needed to take Croatia's latest transmission plans into account to identify the optimal grid upgrades in BiH.

The study evaluated the need for BiH transmission network reinforcement at all three transmission network voltage levels: 400, 220 and 110 kV. We used the PSS/E software package and regional power system model for 2025 and 2030 verified by the 11 neighboring TSOs in the EMI. This robust and reliable model consists of more than 8000 buses and 1400 power plants. We updated the model with HOPS input data for Croatia and NOS BIH input data for BiH.

For this analysis we defined 62 different scenarios in the ToR (12 basic scenarios for 2025 and 16 basic scenarios for 2030, plus 34 reinforcement scenarios for the max reference case with two options for the HVDC submarine link from Montenegro – Italy (500 MW and 1000 MW).

Based on NOS BiH inputs, we included a total installed generation capacity in BiH for 2030 of 5,936 MW, a significant increase of about 1,330 MW compared to existing capacity. We projected the largest share of generation capacity in 2030 to go to thermal power units (2837 MW or 47,8%); hydro plant capacity remains the same as today (1998 MW or 33,7% of total installed generation capacity); while RES (wind and solar power units) will grow significantly to 1100 MW or 18,5%, divided into different areas. Most of the existing coal and lignite generation will stay on line, with up to 466 MW being retired, leaving about 900 MW in place.

In terms of the demand for power, total system peak load in BiH is expected to increase, though quite slowly. In 2030 it is expected to be 2000 MW, which is just 100 MW higher than in 2025, and about the same as in 2021 (1909 MW). In other words, the total planned generation capacity in 2030 (5936 MW) will be almost three times higher than the peak load (2000 MW). Overall, BiH will remain a net exporter of power.

The key outcome of this study was to identify – under alternative conditions - the optimal network topology required for the BiH power system to accommodate the expected significant changes in generation capacities in 2025 and 2030, taking the Šuica 400/110 kV substation as a given input.

This study found that to accommodate existing and planned generation capacities in all analyzed scenarios, combined with planned transmission development in Croatia, it would be optimal to develop the following grid reinforcements in BiH by 2030:

1. Construct a new single 400 kV OHL Konjsko – Mostar 4 (fully in line with the HOPS 400 kV development study [2])
2. Place conductor replacements on five 110 kV lines:
    a. OHL 110 kV Komolac - Trebinje (~18 km) ACCC Lisbon 230 MVA
    b. OHL 110 kV Buško Blato - Livno (~13 km) ACCC Lisbon 230 MVA
    c. OHL 110 kV Livno - Šuica (~18 km) ACCC Lisbon 230 MVA
    d. OHL 110 kV Trebinje – Herceg Novi(~31 km) ACCC Rovinj 165 MVA
    e. OHL 110 kV Šuica – Baljci (~4 km) ACCC Lisbon 230 MVA

If the construction of this 400 kV line is not feasible in the given timeframe for any reason (e.g., different time dynamics with the neighboring TSO, cross-border issues, permitting and spatial details, financial issues, etc.), the second option would be to construct a new 400 kV OHL Banja Luka – Šuica, and add the same reinforcements on the 110 kV grid.

We estimate the total costs for the first recommended 400 kV OHL and the 110 kV grid reinforcements at 107 - 117 million BAM (about 54 - 59 million €), based on the unit prices recently updated by Elektroprenos. When we include an additional 62,5 million BAM of SS Šuica construction costs and the OHL 110 kV and 400 kV upgrade Konjsko – Šuica - Mostar, the total costs of needed network reinforcements would be about 300 million BAM. These costs could vary based on the factors just mentioned, and the next phase of work should develop more granular, site-specific costs based on the design for each element. **While this is a significant expenditure to absorb RES generation, it would avoid significant congestion, line losses and reliability issues that could arise without such investments.**

In the study we also analyzed voltage profiles. The violations (voltages on the transmission nodes outside allowed limits) depends on the scenario. With the proposed 400 kV network reinforcements, the number of voltage violations slightly grows to 19 to 21. However, most of these are in the 400 kV network, with quite low overvoltage levels, close to the upper limit, so they are not critical. **Thus we surmise that voltage issues will not pose a challenge to the absorption of RES if BiH makes the grid upgrades described above.** Further voltage profile analysis and reactive power compensation could be the subject of another study.

We also analyzed the impact on BiH transmission network losses, and determined that reinforcement of the 400 kV grid will reduce transmission losses, and that conductor replacement on the five existing 110 kV does so as well. In the reinforcement scenario (400 kV OHL Konjsko – Mostar 4 along with proposed 110 kV conductors reinforcements), losses would drop about 18% compared to the initial 2025 total scenario value, and 9% compared to the initial 2030 total scenario. In the alternative reinforcement scenario (400 kV OHL Banja Luka – Šuica along with the same 110 kV conductors reinforcements), the network losses drop about 12% compared to the initial 2025 total scenario, or 3% compared to initial 2030 scenario.

These significant reductions in losses result in real customer savings, and are another basis for a serious comparison between the two recommended new potential 400 kV grid reinforcements.

Finally, the two systems (Croatia and BiH) are currently planned separately, with one country synchronizing their plan after the other country issues its plan. **We strongly recommended here that network planners in both countries establish firm and continuous cooperation to exchange all inputs and details when preparing future network development plans.**

Such coordinated transmission planning will become increasingly important in both countries as RES projects become more dominant in the generation mix, especially near the border area.

Indeed, regional transmission planning would benefit customers throughout Southeast Europe, and we recommend such coordination and joint development as power markets consolidate throughout the EMI region.

2 SCOPE OF WORK

This work develops and analyzes the implications for potential upgrades to the 400 kV network development on both sides of the Croatia - BiH border to support larger scale RES integration in this sub-region. Both sides (NOS BiH and Elektroprenos BiH on the BiH side, and HOPS on the Croatian side) have expressed their interest and support for this common approach. This study is prepared for BiH stakeholders, and is focused on both EU and non-EU EMI members, as it deals with both RES integration and cross-border transmission planning, which are both core elements of the USAID/USEA Electricity Market Initiative (EMI).

The electricity market and network conditions in Southeast Europe (SEE) are quite unique. There are more than 10 countries, mostly small power systems that are very well connected, with strong mutual impact, of which BiH and Croatia are the best example. Accordingly, new projects, especially fundamental network projects such as the 400 kV backbones, require a regional perspective, for which the USAID/USEA EMI modelling and analysis platform is highly suitable.

This analysis also evaluates the 220 kV and 110 kV elements in the BiH grid, and reports the extent of their potential overloads. We identify the 220 kV and 110 kV network reinforcements needed to accommodate expected RES additions, though the main focus is on needed upgrades at the 400 kV level. This approach thus projects the impact of RES integration on the full spectrum of high voltage components, so that NOS BiH and Elektroprenos BiH may plan for and request approval from regulators for investments in their entire network.

We have used the Power System Simulator for Engineering (PSS/E), with the EMI's regional verified network model, for our calculations. Given the time required for 400 kV line preparation and construction, and NOS BiH's interest, this study assesses the target years 2025 and 2030.

We used input data on Croatia from HOPS and other EIHP studies, along with BiH inputs. in order to assess the scenarios of most interest to NOS BiH, the BiH inputs included: electricity load per each transmission node; installed and engaged generation capacities; RES locations; and WPP and SPP simultaneity rates. Elektroprenos did not participate in the preparation of this Study.

To define the most relevant scenarios for decisions regarding the development of the 400 kV network of this subregion, we used these six criteria:

1. Time horizon
2. Load regime
3. Hydrological conditions
4. RES development level
5. Level of decarbonization
6. New 400 kV corridors

We selected scenarios designed to focus on the operational aspects most relevant for making strategic decisions about the 400 kV network development, rather than to a wide range of uncertain future system conditions. In close cooperation with NOS BiH, we defined the following set of conditions:

- Two time-horizons (2025 and 2030)
- Two system load regimes (annual peak (max) and off-peak (min))
- A single group of hydrological and wind conditions (extremely wet and extremely windy)
- A single RES development level (based on the current list of RES applications, provided by NOS BiH)
- For the region we used the EMI moderate decarbonization scenario, which removes approximately two-thirds of coal and lignite generation in SEE by 2030, while we used two BiH levels of decarbonization (existing TPP units that NOS BiH indicated will be out of operation in the moderate and extreme decarbonization scenarios):
    - The **moderate** decarbonization scenario assumes additional decommissioning of thermal units beyond the referent one based on the commissioning year, efficiency, and other factors. It includes, in most cases, decommissioning the units that are more than 40 years old; in NOS BiH's case, the 190 MW Tuzla 6 plant.
    - The **extreme** decarbonization scenario assumes additional decommissioning of thermal units that are "younger" and more efficient, and which were commissioned more than 30 years ago; in this case, the 276 MW Gacko 1 plant.
    - The remaining 885 MW of TPPs continues to operate in BiH through 2030 under all scenarios.

Table 1: BiH Decarbonization scenarios (2030)

TPP	**Unit**	**Installed capacity [MW]**	**Decarbonization scenario**	
			Moderate [MW]	**Extreme [MW]**
TPP Gacko	1	276	-	276
TPP Tuzla	3	85	-	-
	4	175	-	-
	5	180	-	-
	6	190	190	190
TPP Kakanj	5	103	-	-
	6	85	-	-
	7	230	-	-
TOTAL		**1,351**	**190**	**466**

Table 1 refers to the BiH decarbonization scenarios starting with 1351 MW of TPPs, which NOS BiH defined at the outset of this study in 2021. Since then, there have been considerable updates to BiH's generation plan, so NOS BiH revised these inputs and provided the updated value of 2837 MW of TPPs in 2030 (see Table 2 and Figure 3 below), which we used in our analysis.

These conditions initially define 16 (2025) + 16 (2030) study scenarios, as shown below:

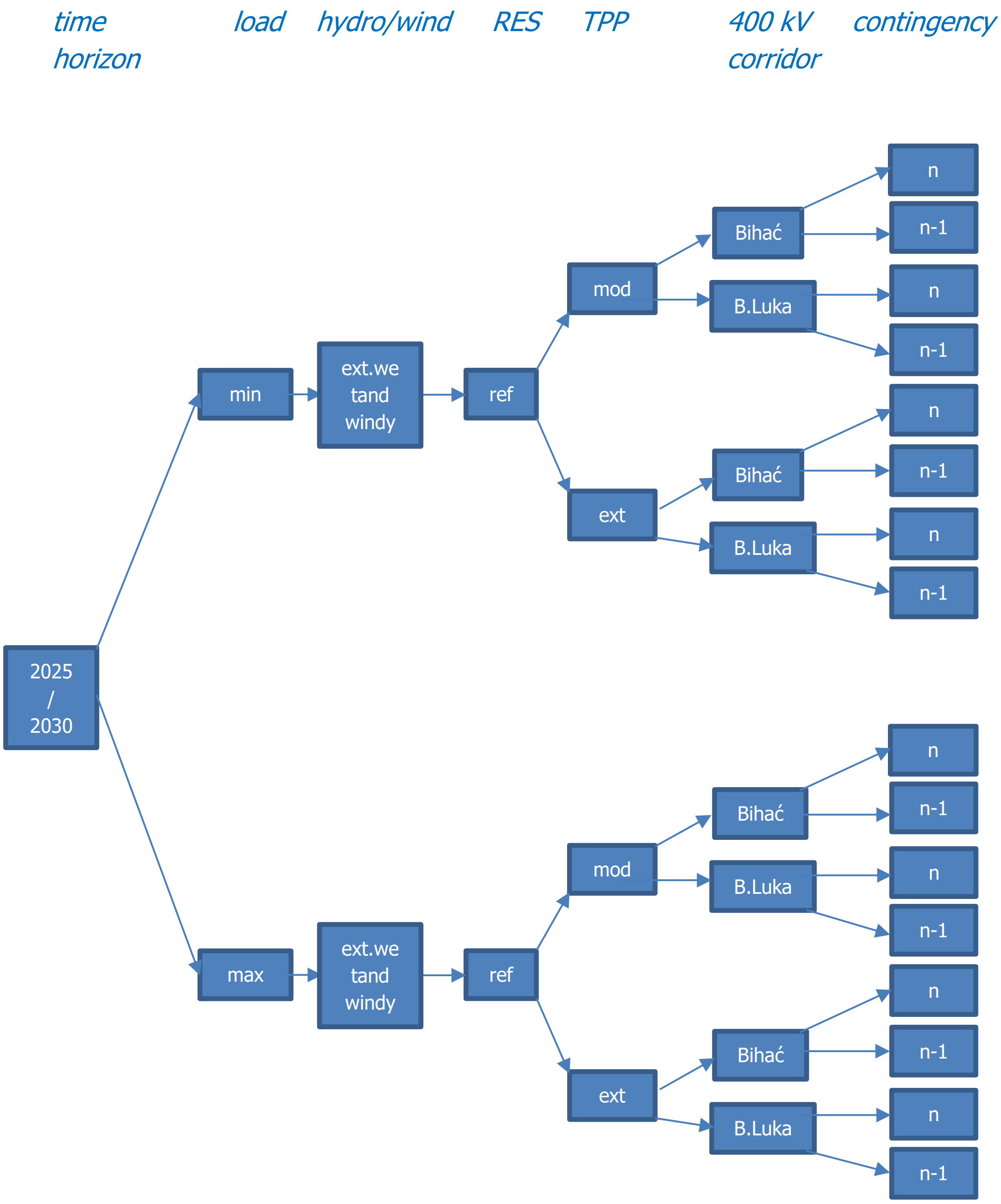

Figure 1: Chart of given scenarios for PSS/E analysis

Note: *While it is not realistic to construct new 400 kV lines by 2025, the construction of the 400 kV substation Lika is conditionally related to the new OHL 400 kV Konjsko – Lika – Melina. In addition, the construction and connection of SS 400/x kV Bihać, and its connection to new OHL 400 kV B. Luka – Lika within the given time frame (2030) - is linked to these other projects.*

We provide the outputs of this study for all scenarios in five main categories:

- Countries' electricity balance – This output shows the electricity import/export balance for both Croatia and BiH (and neighboring countries) in all analyzed scenarios. This is important to show the clear link between the country balance and the 400 kV line loadings

- Selected line loadings (MVA, In%) – We present the most relevant transmission lines in terms of their absolute (MVA) and relative (% of nominal current) values, to follow the possible overloadings in each scenario.
- List of contingencies (elements, In%) – This important output identifies all critical outages and consequent overloads for each analyzed scenario on all three voltage levels in the transmission network (400, 220 and 110 kV)
- Network voltage profiles (kV, Un%) – This output monitors the voltage profiles in all the BiH network nodes, and checks the reasons for the voltage being outside allowed limits
- Network losses (MW) – This characterizes each scenario with the level of transmission network losses, to evaluate the network losses associated with each solution.

The main outcome of this study is to identify the changes in the high-voltage network topology for the BiH power system that will best accommodate expected RES capacities in 2025 and 2030, and to compare the results of all scenarios. We also focused on drawing lessons for future transmission planning.

3 BACKGROUND

Bosnia and Herzegovina (BiH) is a country located at Balkan peninsula, Southeast Europe, with around 3.8 million people, and surrounded by Croatia, Serbia and Montenegro. Historically, they were part of one country, and their transmission systems were developed together, which resulted in strong interconnections after independence.

Around half of BiH electricity generation capacity is installed in hydro plants, and the remainder in large lignite plants. Currently, BiH has around 4600 MW of installed generation capacity:

- around 2000 MW of net installed capacity in 16 hydro plants larger than 10 MW,
- around 2000 MW of net capacity in 5 lignite plants, all connected to transmission network,
- the remaining capacity is installed in wind plants, solar plants, distributed generation units and industrial generation.

On average, BiH generates over 60% of its electricity from TPPs, and is a net exporter. Existing TPPs are mostly old lignite-fired units with large amounts of CO2 and other pollutant emissions. Most of them are not equipped with modern filters necessary to reduce emissions. Some existing TPPs are planned to be decommissioned by 2025 and 2030 and replaced with new lignite units, despite opposition. While recent high market prices and the energy crisis will probably postpone decarbonization plans in Europe and this region, that is not our focus. Rather we use inputs from NOS BIH to check the network's capability to absorb new generation changes through 2030.

BiH's peak system load in 2021 was around 1900 MW (the historical maximum was 2200 MW in 2014), while the minimum load in 2020 (and in the last several decades) was around 600 MW. It is important to note that the Aluminij Mostar company had a constant load (0-24h) of around 190 MW (annual electricity consumption 1,25 – 2 TWh). In mid-2019, the company stopped production, which resulted in a significant drop in the minimum system load in BiH. It is expected that total system demand will slowly grow (0,3 – 0,6% per year). The highest consumption is typically in the Winter, while in the Spring and Autumn electricity consumption is at the lowest levels. Distributed generation will have a growing impact on the transmission system, which will offset demand growth due to electrification, leading to small increases in the impact of demand on the transmission level through 2030.

The RES potential in BiH is quite promising even without financial incentives, but RES integration is still in its early stage, and developing slowly.

Currently, RES project development in BiH is far above the level expected 5 or 10 years ago. NOS BiH planned for around 800 MW of wind power plants to be online in 2030, while currently there are more than 1500 MW of SPP and WPP projects under development, as shown in Figure 2.

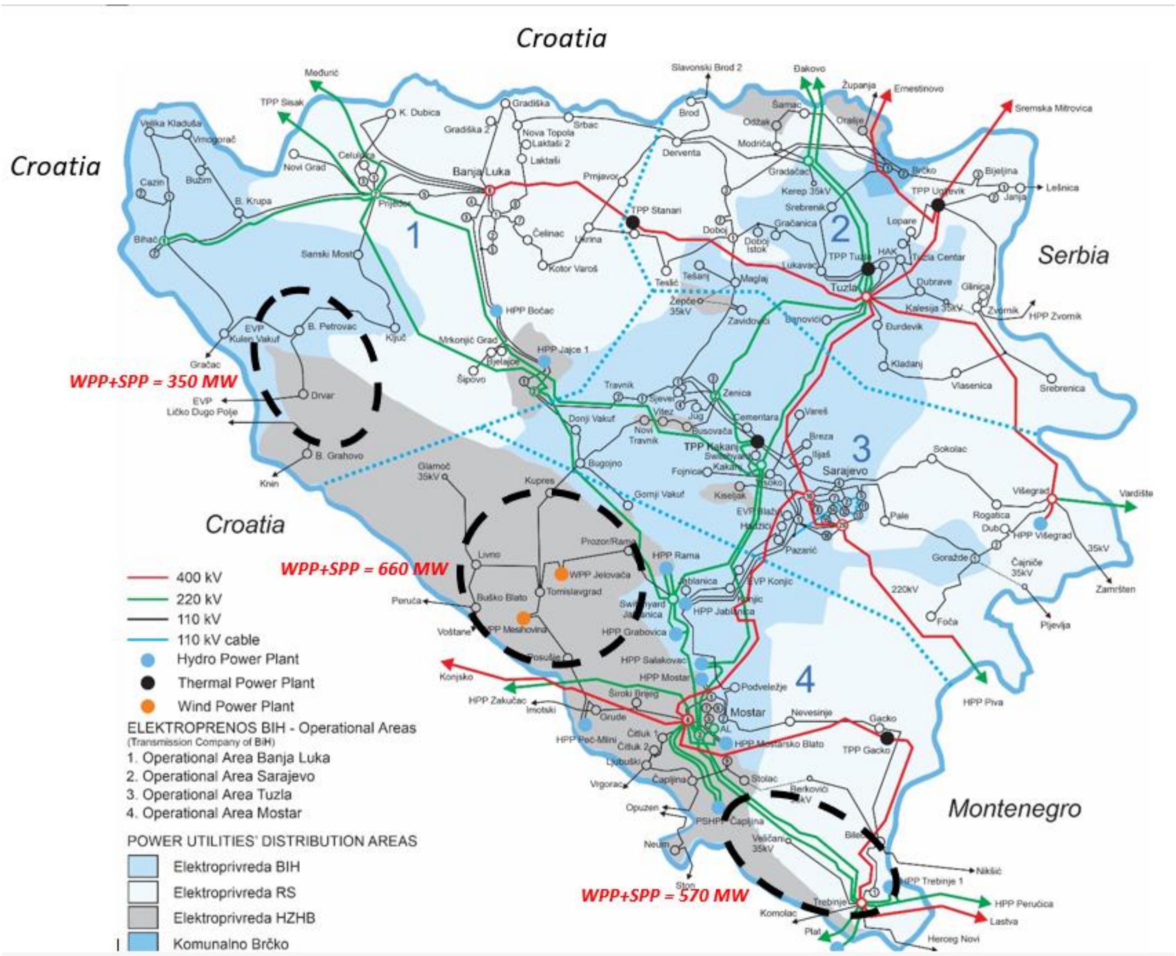

Figure 2: BIH transmission system with the most active RES development areas

According to the latest updated information, NOS BiH evaluates connection of more than 38 WPPs with an installed capacity of 2126.1 MW and 39 SPP with an installed capacity of 3047.9 MW, in the locations of Western Herzegovina, Eastern and Western Bosnia.

Around 2/3 of the total BiH border length is with Croatia, and these two systems are extremely well connected. There are 21 interconnection lines between these two systems on the 400, 220 and 110 kV voltage level, especially in the southern part of the system, where there is the largest RES potential, with strong RES developers' interest on both sides of the border, as shown in Figure 2. Since the mutual impact of these two systems is extremely high, it is of the utmost importance to coordinate transmission network development, especially under conditions of great uncertainty, such as recent RES development in the region.

In April 2021, the Croatian TSO HOPS initiated a 400 kV network development study to support expected RES integration in Croatia. Currently, HOPS is evaluating more than 13,000 MW of RES grid connection applications submitted in the last 1-2 years, and most of them are in the southern part of Croatia, right across the border from the largest RES development interest area in BiH. HOPS finalized its study in March 2022 [2], and its completion was the right moment to initiate a similar analysis on the BiH system, to coordinate these studies.

The large-scale RES development expected in these two countries will require large network investments. This coordinated analysis using regional verified models provides insights and saves time for both sides in the challenging process of network reinforcement and operational preparation for the green transition.

Since the RES projects in Serbia are not in the cross-border area of BiH, and there is much lower connectivity on this border, the mutual impact or RES development on the transmission network is much lower, and we did not analyze the BiH-Serbia border here.

The cross-border influence of Montenegro grid on the BiH transmission grid is primarily related to the construction and operation of the MONITA HVDC submarine cable (±500/1000 MW). Since the commissioning of the HVDC cable, Montenegro has become a major importer of electricity from BIH, which is then exported to Italy. Imports from Italy to Montenegro and BiH is possible, but for market reasons, it occurs much less often than in the opposite direction.

The MONITA HVDC cable capacity is currently ±500 MW, and it is planned to increase to ±1000 MW by 2030.

4 INPUT DATA AND ASSUMPTIONS

This Chapter describes the input data and assumptions used in this study, primarily for generation capacities, loading at transmission network nodes, and data from the ten-year network development plans (TYNDP) in BiH, Croatia and Montenegro.

4.1 Generation capacities and peak loads

The total existing installed generation capacity in BiH today is 4608 MW [1], with about the same share of local coal plants (2076 MW) and hydro plants (1998 MW). The remaining capacity is in new RES (small hydro (180 MW), wind power (135 MW), solar power (56 MW), biogas and biomass power plants (2 MW) and industrial power plants (93 MW)).

Total installed generation capacity in BiH included in PSS/E model for 2030 is given in the following table and Figure 3 as defined by NOS BIH, and it is equal to 5936 MW. It represents an increase of about 1330 MW or 29% compared to the existing installed capacity. Largest share in 2030 still goes to thermal power units (2837 MW or 47.8%), hydro power plant capacity remains the same (1998 MW or 33.7% of total installed generation capacity), while RES (wind and solar power units) has 18.5%. RES capacity is expected to grow significantly, by almost 1000 MW, to 1100 MW connected to the transmission network in 2030.

Along with decommissioning of the old units in BiH, there are plans to commission two new TPP units by 2030: TPP Tuzla 7 (450 MW) and TPP Kakanj 8 (300 MW). Unit 8 in TPP Kakanj would replace Units 1, 2, 3 and 4, which are already closed. However, even though these new units are planned to be commissioned by 2030, these units are not engaged in our scenarios and their status is still questionable.

Clearly, the total TPP installed capacities in BiH in this study for 2030 are significantly higher (by ~1200 MW) than foreseen in the same timeframe in the EMI 2021 Decarbonization study [4] where the input data were collected two years ago. Several units foreseen for decommissioning two years ago now remain operational. However, even though there are lot of TPP installed capacities kept as operational in the model, a large portion of it is not engaged in the study scenarios, as we describe below. That is, these old TPP units are now treated as operational in the planning input data for 2025 and 2030, even though their lifetime has ended. This reflects the current situation with the extremely high electricity prices and the energy crisis in Europe.

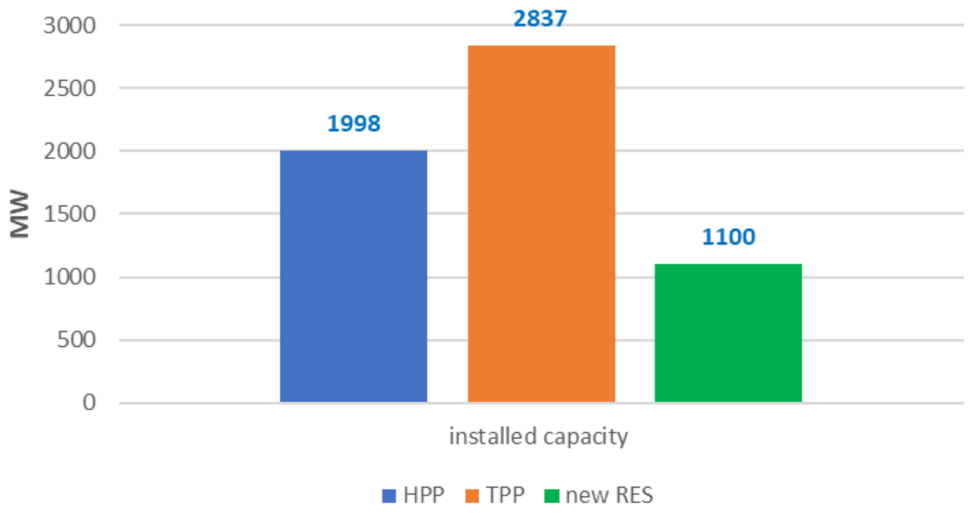

Figure 3: Total installed generation capacity in 2030 in BiH in this study

The total TPP capacity of 2837 MW includes all units in the PSS/E model (i.e., all existing units plus the potential new Kakanj 8 and Tuzla 7 in 2030)

We provide the installed capacity for each generation unit in the PSS/E model in Table 2 below.

Table 2:Total installed generation capacity in BiH in 2030

Generation unit	**Installed capacity (MW)**				
	Total	WPP	SPP	HPP	TPP
VE Grebak	49,50	49,50	-	-	-
VE Hrgud	50,00	50,00	-	-	-
SE Trebinje 1	61,74	-	61,74	-	-
SE Trebinje 2	53,63	-	53,63	-	-
SE Trebinje 3	53,27	-	53,27	-	-
SE Bileća	55,00	-	55,00	-	-
HE Bočac G1	55,00	-	-	55,00	-
HE Bočac G2	55,00	-	-	55,00	-
HE Trebinje G1	54,00	-	-	54,00	-
HE Trebinje G2	54,00	-	-	54,00	-
HE Trebinje G3	63,00	-	-	63,00	-
HE Višegrad G1	105,00	-	-	105,00	-
HE Višegrad G2	105,00	-	-	105,00	-
HE Višegrad G3	105,00	-	-	105,00	-
TE Gacko	300,00	-	-	-	300,00
TE Ugljevik	300,00	-	-	-	300,00
HE Ulog G1	17,00	-	-	17,00	-
HE Ulog G2	17,00	-	-	17,00	-
HE Dub G1	7,20	-	-	7,20	-
HE Dub G2	9,20	-	-	9,20	-
TE Stanari	300,00	-	-	-	300,00
VE Trusina	51,00	51,00	-	-	-
VE Podveležje	48,00	48,00	-	-	-
HE Grabovica G1	58,00	-	-	58,00	-
HE Grabovica G2	58,00	-	-	58,00	-
HE Jablanica G1	30,50	-	-	30,50	-
HE Jablanica G2	30,50	-	-	30,50	-
HE Jablanica G3	30,50	-	-	30,50	-
HE Jablanica G4	30,50	-	-	30,50	-
HE Jablanica G5	30,50	-	-	30,50	-
HE Jablanica G6	30,50	-	-	30,50	-
HE Salakovac G1	67,50	-	-	67,50	-
HE Salakovac G2	67,50	-	-	67,50	-
HE Salakovac G3	67,50	-	-	67,50	-
TE Kakanj G5	118,00	-	-	-	118,00
TE Kakanj G6	110,00	-	-	-	110,00
TE Kakanj G7	230,00	-	-	-	230,00
TE Kakanj G8	300,00	-	-	-	300,00
TE Tuzla G3	100,00	-	-	-	100,00
TE Tuzla G4	200,00	-	-	-	200,00
TE Tuzla G5	200,00	-	-	-	200,00

Generation unit	**Installed capacity (MW)**				
	Total	WPP	SPP	HPP	TPP
TE Tuzla G6	215,00	-	-	-	215,00
TE Tuzla G7	450,00	-	-	-	450,00
HE Vranduk G1	9,30	-	-	9,30	-
HE Vranduk G2	9,30	-	-	9,30	-
HE Janjići G1	8,11	-	-	8,11	-
HE Janjići G2	8,11	-	-	8,11	-
HE Ljuta	8,70	-	-	8,70	-
VE Vlašić	50,00	50,00	-	-	-
VE Ivan sedlo	25,00	25,00	-	-	-
SE Bjelajski vaganac 1	29,50	-	29,50	-	-
SE Bjelajski vaganac 2	29,50	-	29,50	-	-
SE Bjelajski vaganac 3	29,50	-	29,50	-	-
PHE Čapljina G1	220,00	-	-	220,00	-
PHE Čapljina G2	-180,00	-	-	- 180,00	-
PHE Čapljina G1	220,00	-	-	220,00	-
PHE Čapljina G2	-180,00	-	-	- 180,00	-
HE Jajce 1 G1	30,00	-	-	30,00	-
HE Jajce 1 G2	30,00	-	-	30,00	-
HE Jajce 2 G1	9,00	-	-	9,00	-
HE Jajce 2 G2	9,00	-	-	9,00	-
HE Jajce 2 G3	9,00	-	-	9,00	-
TE TO Zenica	14,45	-	-	-	14,45
HE Mostarsko blato G1	31,50	-	-	31,50	-
HE Mostarsko blato G2	31,50	-	-	31,50	-
HE Peć Mlini G1	15,30	-	-	15,30	-
HE Peć Mlini G2	15,30	-	-	15,30	-
HE Mostar G1	24,00	-	-	24,00	-
HE Mostar G2	24,00	-	-	24,00	-
HE Mostar G3	24,00	-	-	24,00	-
HE Rama G1	86,00	-	-	86,00	-
HE Rama G2	86,00	-	-	86,00	-
VE Mesihovina	50,60	50,60	-	-	-
VE Baljci	48,00	48,00	-	-	-
VE Debelo Brdo	54,00	54,00	-	-	-
VE Oštrc	29,80	29,80	-	-	-
VE Ivovik	84,00	84,00	-	-	-
VE Tušnica	72,60	72,60	-	-	-
VE Slovinj	139,65	139,65	-	-	-
VE Jelovača	36,00	36,00	-	-	-
HE Dabar G1	58,80	-	-	58,80	-
HE Dabar G2	58,80	-	-	58,80	-
HE Dabar G3	58,80	-	-	58,80	-
HE DU G2	126,00	-	-	126,00	-
Total	**5936,17**	**788,15**	**312,14**	**1.998,43**	**2.837,45**

Table 3: Total installed generation capacity in 2030 in BiH in this study

Generation output (MW)	installed capacity	share (%)
HPP	1998	33,7
TPP	2837	47,8
new RES	1100	18,5
TOTAL	**5936**	

Total system peak load in BiH in 2030 is 2000 MW, or just 100 MW higher than in 2025. By comparison, in 2021 the system peak load was 1909 MW [1]. However, **total planned generation capacity in 2030 is expected to be almost three times higher than the peak load**. Clearly, BiH will have a good basis for significant electricity exports. just as today, when electricity is a major BiH export product. There is high potential in widely uninhabited areas that is suitable to develop new commercial RES projects. New generation capacities around Europe are mainly built for the integrated, open European electricity market rather than for domestic consumption, and as such, BiH is very attractive area for RES developers.

Table 4: Total installed BiH generation capacity vs peak load in 2030

BiH	Installed generation capacity (MW)	System peak load (MW)	Inst.gen.capacity / peak load
2030	5936	2000	2,97

In addition to installed capacities for each generation unit, NOS BiH also provided us with the expected engagement of each unit in the four basic scenarios (max and min load scenarios in 2025 and 2030), as shown in the following figure and table. These values are the typical outputs in given snapshots, and represent the characteristic generation levels in the planning studies. It is usually significantly above the average annual generation level.

Figure 4: BiH generation level of engagement per technology across basic scenarios

This level of engagement is based on the local operational experience during peak and minimum system load regimes.

Table 5: Engagement of BiH generation units in the basic analyzed scenarios

Power Plant	2025 MAX	2025 MIN	2030 MAX	2030 MIN
	MW	MW	MW	MW
VE Grebak	37,13	29,70	37,13	29,70
VE Hrgud	37,50	30,00	37,50	30,00
SE Trebinje 1	18,52	12,35	18,52	12,35
SE Trebinje 2	16,09	10,73	16,09	10,73
SE Trebinje 3	0,00	0,00	15,98	10,65
SE Bileća	16,50	11,00	16,50	11,00
HE Bočac G1	35,75	11,00	35,75	11,00
HE Bočac G2	35,75	11,00	35,75	11,00
HE Trebinje G1	35,10	10,80	35,10	10,80
HE Trebinje G2	35,10	10,80	35,10	10,80
HE Trebinje G3	40,95	12,60	40,95	12,60
HE Višegrad G1	68,38	20,95	68,32	21,02
HE Višegrad G2	68,38	20,95	68,32	21,02
HE Višegrad G3	68,38	20,95	68,32	21,02
TE Gacko	200,00	250,00	200,00	0,00
TE Ugljevik	220,00	220,00	240,34	228,26
HE Ulog G1	11,05	3,40	11,05	3,40
HE Ulog G2	11,05	3,40	11,05	3,40
HE Dub G1	4,68	1,44	4,68	1,44
HE Dub G2	5,98	1,84	5,98	1,84
TE Stanari	275,00	0,00	275,00	0,00
VE Trusina	0,00	0,00	38,25	30,60
VE Podveležje	36,00	28,80	36,00	28,80
HE Grabovica G1	37,70	11,60	37,70	11,60
HE Grabovica G2	37,70	11,60	37,70	11,60
HE Jablanica G1	19,83	6,10	19,83	6,10
HE Jablanica G2	19,83	6,10	19,83	6,10
HE Jablanica G3	19,83	6,10	19,83	6,10
HE Jablanica G4	19,83	6,10	19,83	6,10
HE Jablanica G5	19,83	6,10	19,83	6,10
HE Jablanica G6	19,83	6,10	19,83	6,10
HE Salakovac G1	43,88	13,50	43,88	13,50
HE Salakovac G2	43,88	13,50	43,88	13,50
HE Salakovac G3	43,88	13,50	43,88	13,50
TE Kakanj G5	0,00	0,00	0,00	0,00
TE Kakanj G6	100,00	0,00	100,00	0,00
TE Kakanj G7	200,00	180,00	200,00	180,00
TE Kakanj G8	0,00	0,00	0,00	0,00
TE Tuzla G3	0,00	0,00	0,00	0,00
TE Tuzla G4	0,00	0,00	0,00	0,00
TE Tuzla G5	200,00	150,00	200,00	150,00
TE Tuzla G6	200,00	150,00	200,00	150,00
TE Tuzla G7	0,00	0,00	0,00	0,00

Power Plant	2025 MAX	2025 MIN	2030 MAX	2030 MIN
	MW	MW	MW	MW
HE Vranduk G1	0,00	0,00	6,05	1,86
HE Vranduk G2	0,00	0,00	6,05	1,86
HE Janjići G1	0,00	0,00	5,27	1,62
HE Janjići G2	0,00	0,00	5,27	1,62
HE Ljuta	5,66	1,74	5,66	1,74
VE Vlašić	0,00	0,00	37,50	30,00
VE Ivan sedlo	18,75	15,00	18,75	15,00
SE Bjelajski vaganac 1	0,00	0,00	8,85	5,90
SE Bjelajski vaganac 2	0,00	0,00	8,85	5,90
SE Bjelajski vaganac 3	0,00	0,00	8,85	5,90
PHE Čapljina G1	143,00	44,00	143,00	44,00
PHE Čapljina G2	0,00	0,00	0,00	0,00
PHE Čapljina G1	143,00	44,00	143,00	44,00
PHE Čapljina G2	0,00	0,00	0,00	0,00
HE Jajce 1 G1	19,50	6,00	19,50	6,00
HE Jajce 1 G2	19,50	6,00	19,50	6,00
HE Jajce 2 G1	5,85	1,80	5,85	1,80
HE Jajce 2 G2	5,85	1,80	5,85	1,80
HE Jajce 2 G3	5,85	1,80	5,85	1,80
TE TO Zenica	0,00	0,00	0,00	0,00
HE Mostarsko blato G1	20,48	6,30	20,48	6,30
HE Mostarsko blato G2	20,48	6,30	20,48	6,30
HE Peć Mlini G1	9,95	3,06	9,95	3,06
HE Peć Mlini G2	9,95	3,06	9,95	3,06
HE Mostar G1	15,60	4,80	15,60	4,80
HE Mostar G2	15,60	4,80	15,60	4,80
HE Mostar G3	15,60	4,80	15,60	4,80
HE Rama G1	55,90	17,20	55,90	17,20
HE Rama G2	55,90	17,20	55,90	17,20
VE Mesihovina	37,95	30,36	37,95	30,36
VE Baljci	36,00	28,80	36,00	28,80
VE Debelo Brdo	0,00	0,00	40,50	32,40
VE Oštrc	22,35	17,88	22,35	17,88
VE Ivovik	0,00	0,00	63,00	50,40
VE Tušnica	54,45	43,56	54,45	43,56
VE Slovinj	104,74	83,79	104,74	83,79
VE Jelovača	27,00	21,60	27,00	21,60
HE Dabar G1	38,22	11,76	38,22	11,76
HE Dabar G2	38,22	11,76	38,22	11,76
HE Dabar G3	38,22	11,76	38,22	11,76
HE DU G2	81,90	25,20	81,90	25,20
Total	**3368,78**	**1778,14**	**3633,36**	**1715,30**

Table 5 shows the Engagement of BiH generation units, referring to the units actually operating in the four basic scenarios. A gray background field with a zero MW value means that these units are either not yet built or planned for decommissioning by 2025 or 2030). A white background field with zero MW means that such units exist, but they are not engaged in the basic scenarios.

We provided the TPP candidates for decommissioning in Chapter 1. To get a closer look at the candidates for decommissioning among the existing BiH generation fleet, both coal-fired TPPs and HPPs, and select the best options, we show below each plant's initial year of commissioning along with its average annual generation and expected off-line date (EOL). In addition, we also list the largest new candidates for commissioning through 2030, as given in the latest BiH Ten-Year Network Development Plan (see details in the following subchapter).

- Coal-fired thermal power plants (TPP):
    - TPP Gacko (300 MW, ~1150 GWh/Year) since 1983
    - TPP Ugljevik (300 MW, ~1460 GWh/Year) since 1985
    - TPP Stanari[1] (300 MW, ~2000 GWh/Year) since 2016
    - TPP Tuzla 3 (100 MW, ~300 GWh/Year) since 1967 – EOL 2024
    - TPP Tuzla 4 (200 MW, ~1020 GWh/Year) since 1971 – EOL 2024
    - TPP Tuzla 5 (200 MW, ~1030 GWh/Year) since 1974 – EOL 2027
    - TPP Tuzla 6 (223 MW, ~1150 GWh/Year) since 1978
    - TPP Kakanj 5 (110 MW, ~500 GWh/Year) since 1969 - EOL 2024
    - TPP Kakanj 6 (110 MW, ~500 GWh/Year) since 1977
    - TPP Kakanj 7 (230 MW, ~1200 GWh/Year) since 1988
    - TPP Tuzla 7 (450 MW, ~2630 GWh/Year) expected in 2025
    - TPP Kakanj 8 (300 MW, ~1755 GWh/Year) expected in 2028

- Hydro power plants (HPP):
    - HPP Bočac (2x55 MW, ~278 GWh/Year) since 1981 @Vrbas (river)
    - HPP Trebinje (2x54 + 63 MW, ~395 GWh/Year) since 1968/75 @Trebišnjica
    - HPP Višegrad (3x105 MW, ~922 GWh/Year) since 1989 @Drina
    - HPP Ulog (2x35 MW, ~81 GWh/Year) expected in 2023 @Neretva
    - HPP Ustiprača (2x3,74 MW, ~35 GWh/Year) since 2017 @Prača
    - HPP Dub (2x4,7 MW, ~44 GWh/Year) since 2019 @Prača
    - HPP Grabovica (2x58 MW, ~169 GWh/Year) since 1982 @Neretva
    - HPP Jablanica (6x30,5 MW, ~715 GWh/Year) since 1955 @Neretva
    - HPP Salakovac (3x67,5 MW, ~394 GWh/Year) since 1981 @Neretva
    - Pump storage HPP Čapljina (2x 220/-180 MW, ~200 GWh/Year) since 1979 @Trebišnjica
    - HPP Jajce 1 (2x30 MW, ~220 GWh/Year) since 1957 @Vrbas
    - HPP Jajce 2 (3x10 MW, ~81 GWh/Year) since 1954 @Vrbas
    - HPP Vranduk (2x9,3 MW, ~96 GWh/Year) expected in 2027 @Bosna
    - HPP Janjići (2x8,1 MW, ~77 GWh/Year) expected in 2027 @Bosna
    - HPP Ljuta (0,4365 MW, ~35 GWh/Year) expected in 2024 @Ljuta

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[1] Construction of TPP Stanari (550 M€) was financed by Chinese development Bank load (350 M€), with Republika Srpska loan warranty.

As indicated in Chapter 1, the main motivation for this study arises from the need for NOS BiH to effectively address sharply growing requests for RES grid connection and operation in BiH, in addition to the expected massive RES additions and grid changes in the neighboring well-interconnected systems, primarily Croatia. Therefore, it is critical for this analysis to incorporate the current and expected generation mix and country balance in Croatia.

Total generation capacity in Croatia in 2020 was 4,661,8 MW: 2199,4 MW in HPP, 1552,6 MW in TPP, 801,3 MW in WPP and 108,5 MW in SPP.

Among current TPPs, 145,3 MW are Biomass, Geothermal and Biogas power units.

Total 2020, Croatia's yearly electricity production was 13.385,3 GWh. HPPs produced 5,810.4 GWh, TPPs 5,758.7 GWh, WPPs 1,720.7 and SPPs 95,5 GWh. As in BiH, the Croatian country balance is strongly dependent on hydrological conditions. Depending on the hydrological season, HPPs generation in Croatia can vary between 4 and 8 TWh/year.

The nuclear power plant (NPP) Krško in Slovenia is 50% in Croatian and 50% in Slovenian ownership. The Croatian share of its production in 2020 was 3,020.4 GWh. Since NPP Krško is located in Slovenia, in the country balance this generation is treated as an electricity import.

Accordingly, total supplied energy for Croatia in 2020 was 18,024.6 GWh, with net imports of 4,639.0 GWh. In contrast to BiH, Croatia is most of the time an importer of electricity.

The following tables and figures give total engaged generation capacity, system loads and country balances in BiH and Croatia in the four basic scenarios in 2025 and 2030.

Table 6: Total engaged Croatian and BiH generation capacity in the basic scenarios in 2025 and 2030

Generation (MW)	Croatia	BiH	Total
2025 MAX	3618	3368	6986
2025 MIN	3619	1779	5398
2030 MAX	4433	3632	8065
2030 MIN	4365	1708	6073

Clearly, from 2025 to 2030, it is expected that the maximum generation output at the time of peak load in BiH will be about the same (changing by less than 300 MW, from 3368 MW in 2025 to 3632 MW in 2030), and will be around 1700 MW during the minimum load regime in both years). However, HOPS in Croatia plans for generation output during the peak load regime in 2030 to be 4365 MW, or 800 MW higher than the peak load in 2025. Moreover, in Croatia a similar generation output is planned both for the maximum and minimum regime in 2025 and 2030, which is a consequence of substantial amounts of large-scale intermittent generation.

The sum of generation outputs in both countries ranges from ~5400 MW to ~8000 MW, based on the year and the load level, as Figure 5 shows.

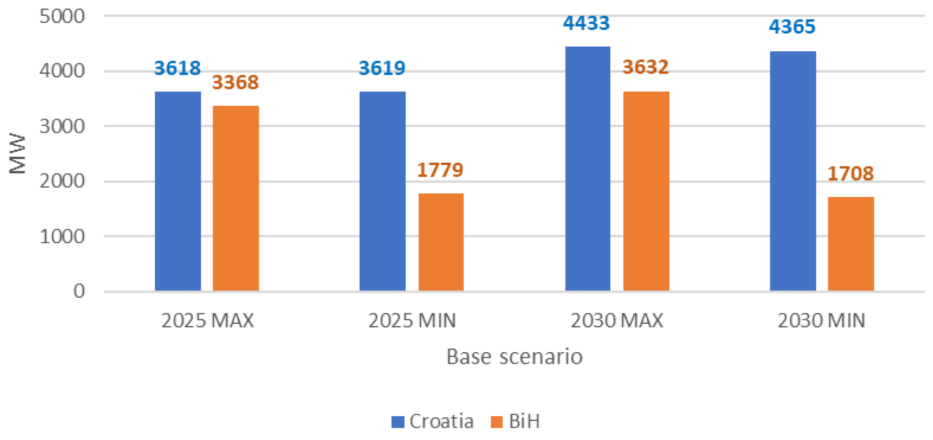

Figure 5: Engagement of BiH and Croatian generation in the four analyzed basic scenarios

Due to the extremely high level of system interconnectivity between BiH and Croatia, besides the generation output, it is important to compare the level of the system load in both countries in the basic scenarios in 2025 and 2030 as defined by the system operators. The sum of system loads in both countries is between ~2000 MW and ~4700 MW, as shown on the following figure and table.

Table 7: Total Croatian and BiH system load in the basic scenarios in 2025 and 2030

Load (MW)	Croatia	BiH	Total
2025 MAX	2828	1900	**4728**
2025 MIN	1280	750	**2030**
2030 MAX	3250	2000	**5250**
2030 MIN	1350	800	**2150**

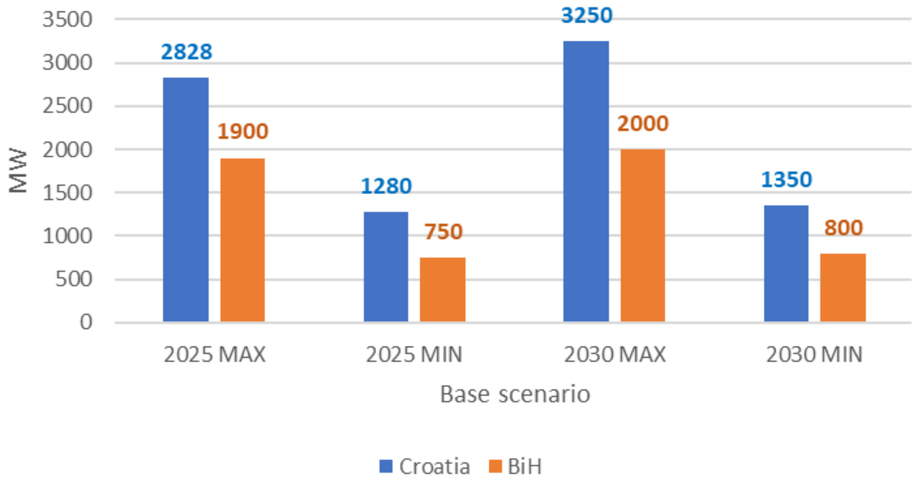

Figure 6: Total Croatian and BiH system load in basic scenarios in 2025 and 2030

As usual, there are two important aspects to be followed in the network development studies: total system generation over total system consumption (GWh) and installed generation capacity over system peak load (MW). Here we'll focus for the moment on the latter to provide basic information on the existing generation capacity and its theoretical capability to cover domestic peak load.

The following table and figure provide the total system balances for both countries in terms of installed generation capacities versus peak system load. In that sense both countries have preconditions to be net exporters in all analyzed basic scenarios. We expect BiH to be able to export between ~900 MW (2030 min) and ~1600 MW (2025 max), while Croatia will be able to export between ~800 MW (2025 max) and ~3000 MW (2030 min). These figures are a consequence of massive RES integration expected in both countries, and the operation of existing generation. The transmission network has to sustain all market activities, even those that are quite unlikely. Since these values represent the maximum possible exchange to the neighboring systems, they are important in this network development analysis.

Table 8: Total Croatian and BiH system balance in basic scenarios in 2025 and 2030

Balance (MW)	Croatia	BiH	Total
2025 MAX	790	1468	**2258**
2025 MIN	2339	1029	**3368**
2030 MAX	1183	1632	**2815**
2030 MIN	3015	908	**3923**

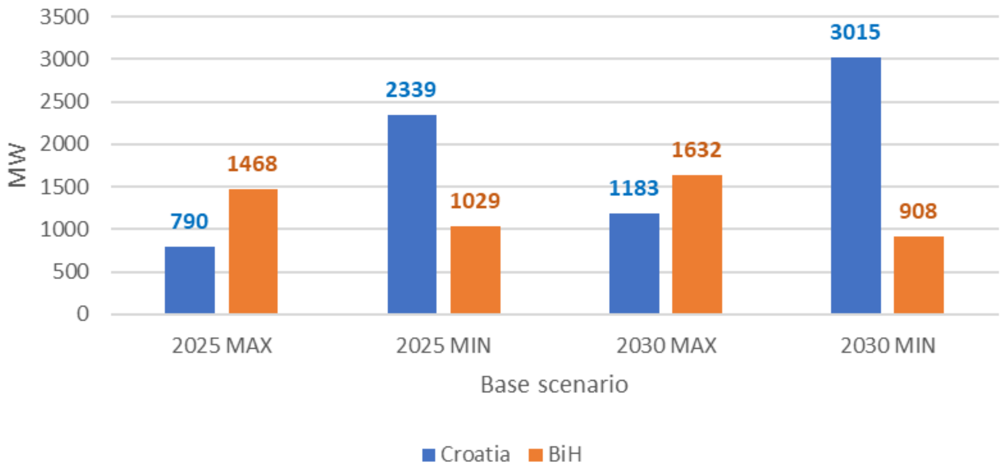

Figure 7: Total Croatian and BiH system balance in basic scenarios in 2025 and 2030

Based on the system operators' expectations in these scenarios, these two countries together are expected to be able to export between ~2200 MW and ~3900 MW.

4.2 Ten-Year Network Development Plan of the Bosnia and Herzegovina Transmission Network

We describe the generation capacities of BiH power and other relevant input data in this subchapter. It provides the foundation and starting point for our analysis of the need for new transmission and upgrades there. It also enables us to compare this work's findings to the current TYNDP, which may require updates based on these results, if Elektroprenos BiH agrees.

The transmission grid of BiH also includes 400 kV, 220 kV, 110 kV lines and substations, and it is organized in four operative areas: Banja Luka, Mostar, Sarajevo and Tuzla. The TYNDP of Elektroprenos BiH covers the period of 2021 – 2030.

The basic inputs for the TYNDP are:

- Generation Indicative Development Plan (actual 2022 – 2031) [9]
- Realized and planned system loadings on the TSO level
- Realized and planned maximum loadings of individual 110/x kV SS
- Input data from the electricity companies in BiH and the Brčko District, as well as customers directly connected to the transmission network

4.2.1 Planned Transmission System Loadings

The Generation Indicative Development Plan [9] defines three basic scenarios of load growth:

- Pessimistic scenario – low load growth at an average of 0,4%
- Realistic scenario – basic load growth at an average of 1,1%
- Optimistic scenario – high load growth at an average of 2,2%

These scenarios are based on an analysis of historical load data between 2001 and 2019 together with BiH's GDP growth forecast. This table shows the planned maximum BiH transmission system loadings using the realistic scenario.

Table 9: Planned maximum power system loadings in BiH, 2021-2030

Year	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Pmax [MW]	1.909	1.888	1.909	1.930	1.951	1.972	1.994	2.016	2.038	2.061

Clearly, these loadings are not expected to pose any challenges to NOS BiH and transmission network development, Therefore, the much greater challenge is the one posed by RES development, in both BiH and Croatia.

4.2.2 Existing and planned transmission network topology

The following tables list the current transmission system's tie lines, transformers and substations for all transmission system voltage levels. It clearly shows that adding a new 400/110 kV substation Šuica with two 400/110 kV transformers with 100-200 km of 400 kV OHL would be a significant change in the 400 kV grid topology formed more than 40 years ago. These tables show the grid topology in BiH in 2019, and there have been no changes since that time.

Table 10: 400, 220 and 110 kV tie lines in the BiH transmission system in 2019

Rated voltage	Nr. Of tie lines	Nr. Of Interconnectors	Length [km]
400 kV	10	4	804,83
220 kV	32	10	1535,19
110 kV	212	13	3534,92
Total	**254**	**27**	**5,875**

Table 11: 400, 220 and 110 kV SS in the BiH transmission system in 2019

Rated Voltage	Number
SS 400/x kV	10
SS 220/x kV	9
SS 110/x kV	135
Total	**154**

Table 12: 400, 220 and 110 kV transformers in BiH transmission system in 2019

Transformer ratio	Number	Installed capacity [MW]
400/231 kV	7	2800
400/115 kV	6	1800
220/115 kV	13	1950
110/x kV	251	5877
Total	**277**	**12427**

The BiH transmission system's network topology in 2019 is given in the figure below.

It is important to note that the areas in BiH close to the Croatian border are the most attractive for RES grid development, However, most of these areas have a relatively low level of existing internal network topology development to enable them to absorb a high level of RES. So, on one side we have high interconnectivity with the neighboring system, and high RES potential, while on the other side we have a low level of internal network development to absorb this high RES capacity. That is the main challenge for the network planners in BiH.

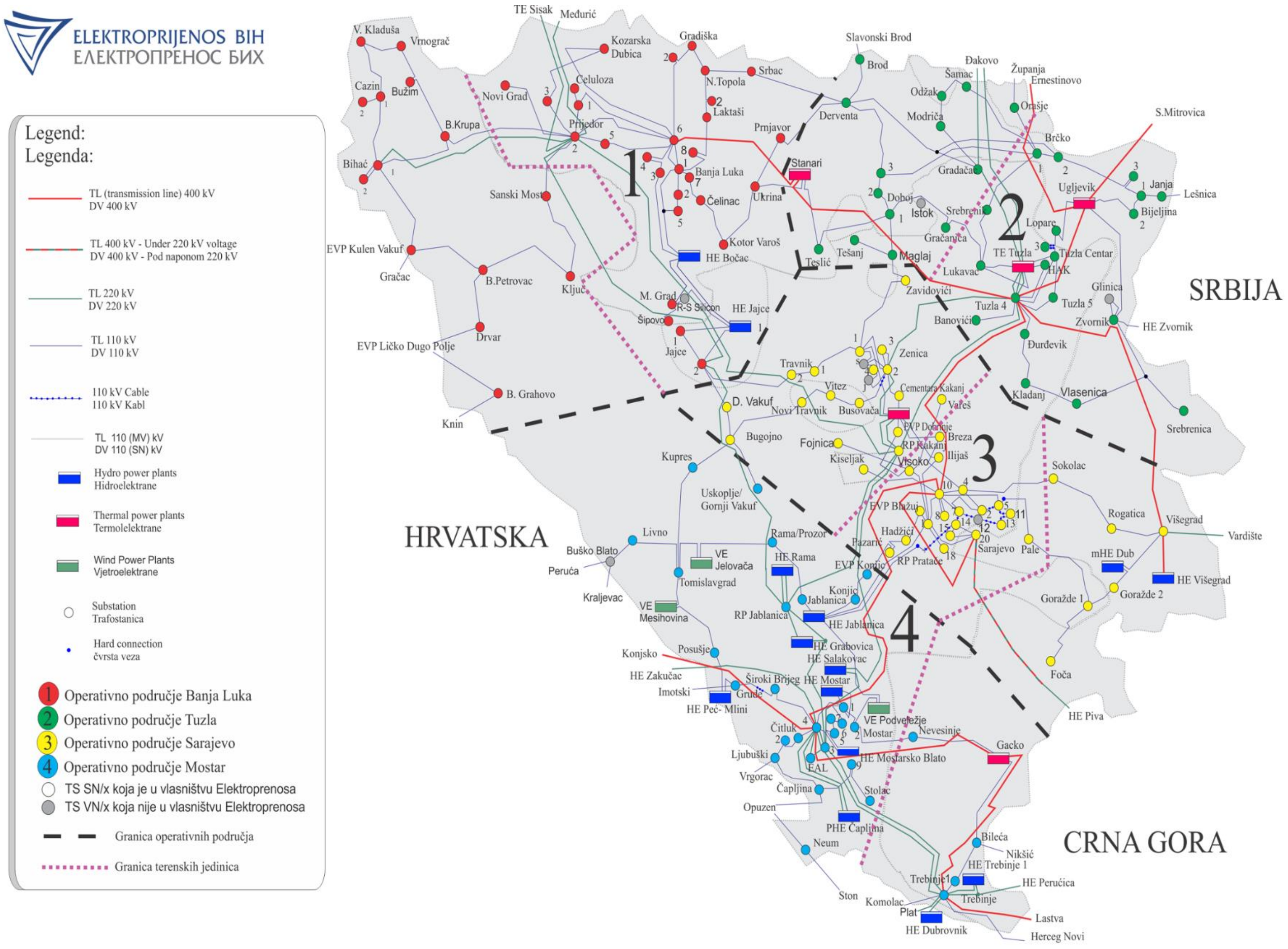

Figure 8: BiH's 400 kV, 220 kV and 110 kV transmission system at the end of 2021

The table below shows the high voltage tie lines that the current TYNDP expects will be built in the next ten years, followed by a brief explanation of the status of each project.

Table 13: New high voltage tie lines between BiH and neighboring systems planned for the next ten years

OHL Name	Year of Commission
400 kV Višegrad (BA) - Bajina Bašta (RS)	2025
400 kV Banja Luka (BA) – Lika (HR)	2031
400 kV TE Tuzla (BA) – Đakovo (HR)	2032
400 kV Gradačac (BA) – Đakovo (HR)	2032

The need to build a new OHL Višegrad – Bajina Bašta (RS) and OHL 400 kV Višegrad – RHE Bistrica (RS) – Plevlja (MNE) is a conclusion drawn from the study "*400 kV Interconnection from Serbia into both Montenegro and BiH, EMS, 2019*". The end goal of that project was to expand regional interconnection capacities. This tie line will be built in the first phase of the project using the route of the existing OHL 220 kV Višegrad – Vardište, which will cease to exist after construction of the new line. The figure below shows the topology of this project.

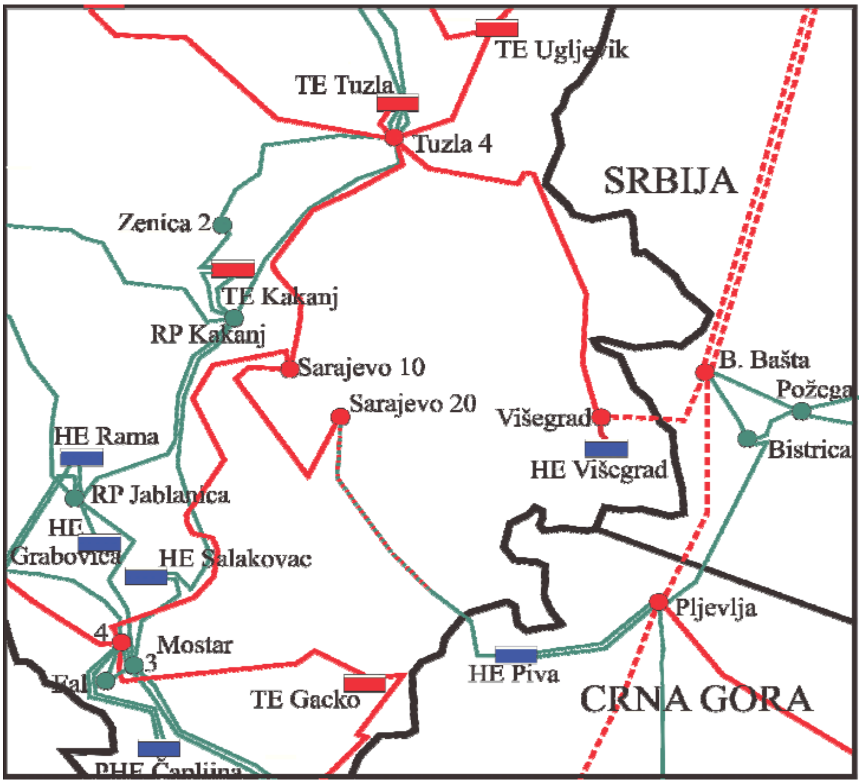

Figure 9: The topology of the project OHL 400 kV Višegrad – Bajina Bašta

A feasibility study in 2019 also analyzed the new 400 kV Banja Luka – Lika (HR) OHL, which would enlarge interconnection capacities between BiH and Croatia to enable more power flows and more RES integration in both countries. This study assessed total investment costs at 160 million €; however, since then, there have been no further steps on this project on either side.

The plan is to develop the new OHLs 400 kV TE Tuzla (BA) – Đakovo (HR) and Gradačac (BA) – Đakovo (HR) by upgrading the existing OHL 220 kV TE Tuzla (BA) – Đakovo (HR) and Gradačac

(BA) – Đakovo (HR), along with their respective substations. This project – anticipated for 2032 - is at an early development stage, and the next step would be to initiate a prefeasibility study.

4.2.3 Transmission System Balance and Losses

This chapter shows the BiH transmission system balance in 2019, with losses in the past decade.

Table 14: BiH transmission system energy balance in 2019 (GWh)

Nr.	Month/GWh	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Total
1	Generation	1355	1339	1.320	994	1168	1.203	1303	1329	1.129	1081	1429	1.672	15322
2	Energy from DSO	5	16	26	30	34	18	6	8	4	4	13	16	180
3	Imports	321	166	363	293	211	179	176	214	251	196	181	173	2724
4	Total Avaliable energy (1+2+3)	1681	1521	1710	1317	1413,3	1400	1486	1550,5	1384	1381	1623,3	1862	18327
5	Total Energy delivered	1162	996	1.000	937	950	889	872	874	815	887	897	1.031	11310
6	Exports	462	492	646	343	430	475	574	644	545	459	698	797	6565
7	Pumping	16	4	30	7	5	10	14	5	0	6	0	0	97
8	Total required energy (5+6+7)	1639,4	1491,1	1675,8	1287,5	1385	1374	1460,1	1522,4	1360,4	1352,5	1595,1	1827,2	17970,5
9	Transmission system losses (4-8)	41	30	34	30	28	26	26	28	24	28	28	34	357
10	Transmission system losses (%)	2	1,97	2	2	1,98	2	2	1,81	2	2	1,72	2	23

If we plot the monthly available energy and monthly required energy BiH is clearly a net energy exporter in 2019 (Figure below).

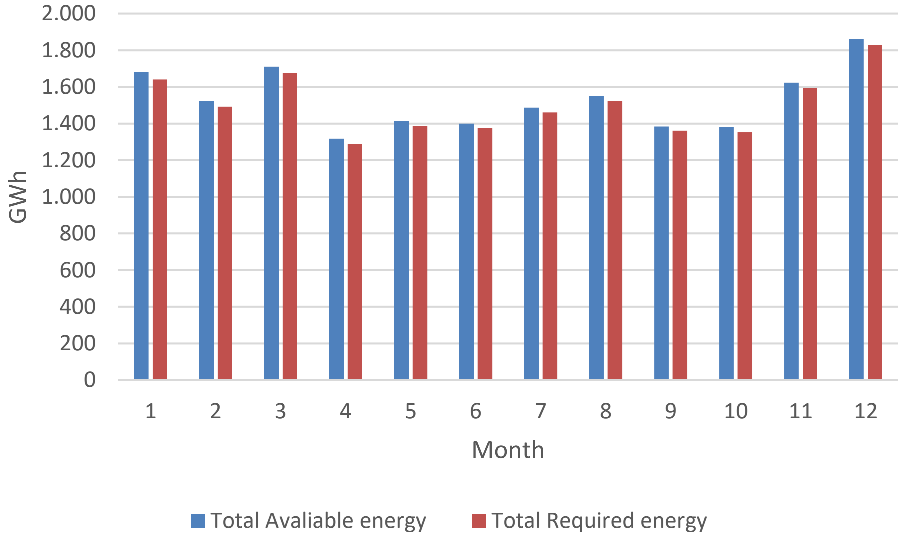

Figure 10: Total available and required energy in 2019

Table 15: Total transmission system losses in the period 2009-2019

Year/GWh	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Yearly consumption on transmission system	10.787	11468,9	11879,7	11.853	11732	11345,6	11.719	12015,4	12273,9	12.193	11309,4
Pumping	0	2,2	21,4	66	0	0	13,9	46,2	266,1	137,4	96,3
Transmission system losses	306,1	337,9	324,2	308,1	343,1	304,2	359,4	333,3	341,5	398	357
Total generation	14.083	15.638	13714,7	12.271	15.770	14519,9	14.228	16.152	14722,7	17.335	15.502
Transmission system losses [%]	2	2,16	2,36	3	2,18	2,09	3	2,06	2,32	2	2,3

The losses in the transmission system are somewhat above 2%, which is quite low and an acceptable level of network losses. However, these values are used just for illustration purposes in the selected snapshots of given scenarios. Detailed analysis of the transmission network yearly losses is a much more robust and complex analysis and goes beyond the scope of this study.

4.3 Ten-Year Network Development Plan for Croatian Network

Given the high interconnectedness and interdependence of the Croatian and BiH networks, as described above, and the need to jointly absorb large renewable additions, this subchapter describes transmission power system development in Croatia. It includes the 400 kV, 220 kV, 110 kV lines and substations, and it is organized in four operative areas: Zagreb, Rijeka, Osijek and Split. The latest TYNDP covers the timeframe from 2022 – 2031.

The two key elements in each power system plan are the power system loading and the planned production capacities.

4.3.1 Transmission System Realized and Planned Loadings in Croatia

Transmission system loading is the fundamental parameter in every power system plan. The yearly power curve shows the power system loadings throughout the year. Usually, the most important power system operating points are the maximum and minimum system loading. Those numbers then must be distributed to individual load centers i.e., substations, using historical participation factors.

To provide further insights, the number of scenarios can be further expanded to include seasonal maximums (e.g., not just winter maximums but also summer maximums). This is important today, since historically, the winter maximum was by far the highest, but with higher temperatures and more air conditioning, the summer and winter maximums are quite close. The system minimum is usually in the spring.

The tables below show the minimum and maximum transmission system loadings in the past ten years in Croatia, and the relation between winter and summer maximums. Clearly, there were no big changes in the last decade, mainly due to the economic crisis, but also due to the impact of energy efficiency measures and distributed generation.

Table 16: Maximum and minimum loadings in the Croatian power grid (2011.-2020.)

Year	P_{max} [MW]	Month	P_{min}[MW]	Month	P_{min}/P_{max}
2011.	2970	1.	1185	4.	0,4
2012.	3193	2.	1132	5.	0,35
2013.	2813	2.	1105	3.	0,39
2014.	2974	12.	1166	5.	0,39
2015.	3009	7.	1188	6.	0,39
2016.	2869	7.	1155	5.	0,4
2017.	3079	8.	1305	9.	0,42
2018.	3168	2-	1249	5.	0,39
2019.	3038	7.	1226	4.	0,4
2020.	2872	7.	1067	4.	0,37

Table 17: Maximum winter loadings and maximum summer loadings in Croatia

Year	$P_{max-win}$ [MW]	Month	$P_{max-sum}$ [MW]	Month	$P_{max-sum}/P_{max-win}$
2011.	2970	1.	2833	7.	0,95
2012.	3193	2.	2778	7.	0,87
2013.	2813	2.	2812	7.	1
2014.	2974	12.	2541	8.	0,85
2015.	3009	7.	3009	7.	1,05
2016.	2869	7.	2867	7.	1,01
2017.	3079	8.	3079	8.	1
2018.	3168	2-	2991	8.	0,94
2019.	3038	7.	3038	7.	1,07
2020.	2872	7.	2872	7.	1,01

The realized loadings and these four factors determine the planned future transmission load:

- Demographics
- Economic activity
- Distributed generation
- Measures for energy efficiency

Taking all these factors into consideration, Croatia expects the maximum transmission system loading to grow at an average annual rate of 0.5%.

Larger loading growth is not expected due to the following factors:

- Insufficient energy intensive industry
- Growth of distributed generation (primarily RES)
- Switching from electric heating to gas heating in some areas
- Introduction of new energy efficiency measures

4.3.2 Transmission System Realized and Planned Production Capacities in Croatia

The second important variable in power system planning are the production capacities. In Croatia most of the existing capacities are thermal or hydro. However, in the last decade there has been an intensive integration of renewable energy, mostly wind. Total installed wind capacity connected to the transmission and distribution network is now 950.95 MW. The following tables show the existing installed capacities per technology.

Table 18: PPs connected to the Croatian transmission network

HPP Name	Approved connection capacity [MW]	Nr. Of generators	POC[2] Voltage level [kV]
Varaždin	95	2	110
Čakovec	79	2	110
Dubrava	80	2	110
Rijeka	38	2	110
Kraljevac	45	2	110
Run of River HPPs	**337**		
Vinodol	91	3	110
Senj	219	3	220 & 110
Sklope	24	1	110
Lešće	45	2	110
Gojak	60	3	110
Orlovac	24	3	220
Peruća	61,2	2	110
Đale	42	2	110
Zakučac	538	4	220 & 110
Dubrovnik	126	1	110
Storage HPPs	1230,2		
Velebit	276/-254	2	400
Buško Blato	10,5/-10,2	3	110
Pump Storage HPPs	286,5/-264,2		
Condensation TPPs	743	5	220 & 110
Combined cycle TPPs	880	6	220 & 110
TPPs	1523	11	
WPPs	951		220 & 110 & DSO

The following figure shows shares in total generation in percentages of each technology (hydro, thermal and wind). The figure shows the steady growth of wind generation from 2012-2020.

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[2] Point of connection to the transmission grid

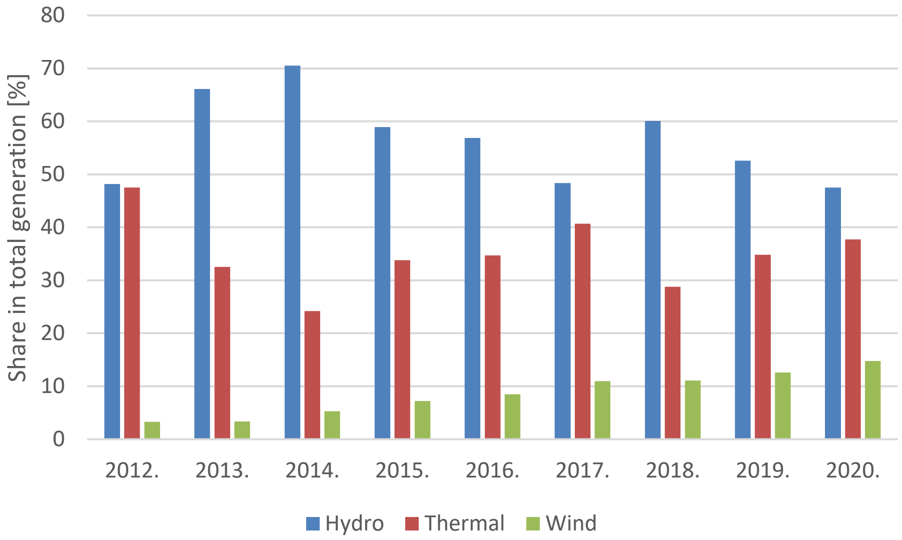

Figure 11: Shares of total generation per technology in Croatia, 2012-2020

The following power projects, totaling over 1 GW, have signed Grid connection contracts, and are expected to be built in the next five years.

Table 19: Projects with signed Grid Connection Contracts in Croatia Expected to Come on Line in Five Years

WPP Name	Technology	Approved connection capcity [MW]	POC Voltage level [kV]	Year of commission
EL-TO Zagreb	TPP-gas	150	110	2022
ST 3-1/2 Visoka Zelovo	WPP	53	110	2022
Konavoska Brda	WPP	120	220	2022
ZD2P	WPP	68	110	2022
ZD3P	WPP	43	110	2022
Obrovac-Zelengrad	WPP	12,4	110	2023
Bruvno	WPP	45	110	2023
Drava International	Storage	12,4	110	2023
Zagocha	TPP-geo	20	110	2024
Rust	WPP	120	110	2026
Benkovac	SPP	60	110	2026
Sukošan	SPP	45	110	2026
Kolarina	SPP	38	110	2026
Raštević	SPP	41	110	2026
Korlat	SPP	75	110	2026
Kruševo	SPP	17	110	2026
Rasinja	SPP	50	110	2026
Zona Pometno Brdo	SPP	84,7	110	2026
Total		**1054,5**		

As shown, Croatia expects 461 MW more of wind generation, and 411 MW of solar by 2026, with the SPPs expected especially in Dalmatia, very close and well connected to the BiH system.

However, on top of these projects totaling 1054 MW, there are additional more than 13000 MW of projects under development. This is a massive queue. The Energy Strategy of Croatia [7] expects a significant share of these candidates will be commissioned by 2030. In the referent development case of the Energy Strategy [7], in 2030 the RES share in total generation will be 36.7%, assuming total installed WPP capacity of 1634 MW, solar power plants 1039 MW and hydro power plants of 2686 MW, or 5359 MW in total RES (this is not to be confused with the figures and values given above describing historical generation installed capacity).

4.3.3 Existing and planned 400 kV and 220 kV transmission topology in Croatia

The actual HOPS TYNDP covers from 2022 to 2031. It is divided into 2-time frames covering the short (2025) and longer term (2031).

Croatia has the most interconnections with BiH (with many 110 kV interconnections), which underscores the importance of considering the neighboring system when planning. The 400 kV and 220 kV network of Croatia is longitudinal due to the country's shape. This makes it harder to mesh (loop) the network exclusively in Croatia. Most RES is in the south, roughly between SS Velebit and SS Konjsko. Most of the TPPs are in the central part of the country except for TPP Plomin, which is located at sea in the Istra region.

Generally, the power flows are bidirectional:

- South – East to North – West in conditions of extreme hydrology and wind
- North – West to South – East in conditions of dry hydrology and less wind

The Figure below shows the planned topology of Croatia's 400 kV and 220 kV grid in 2025.

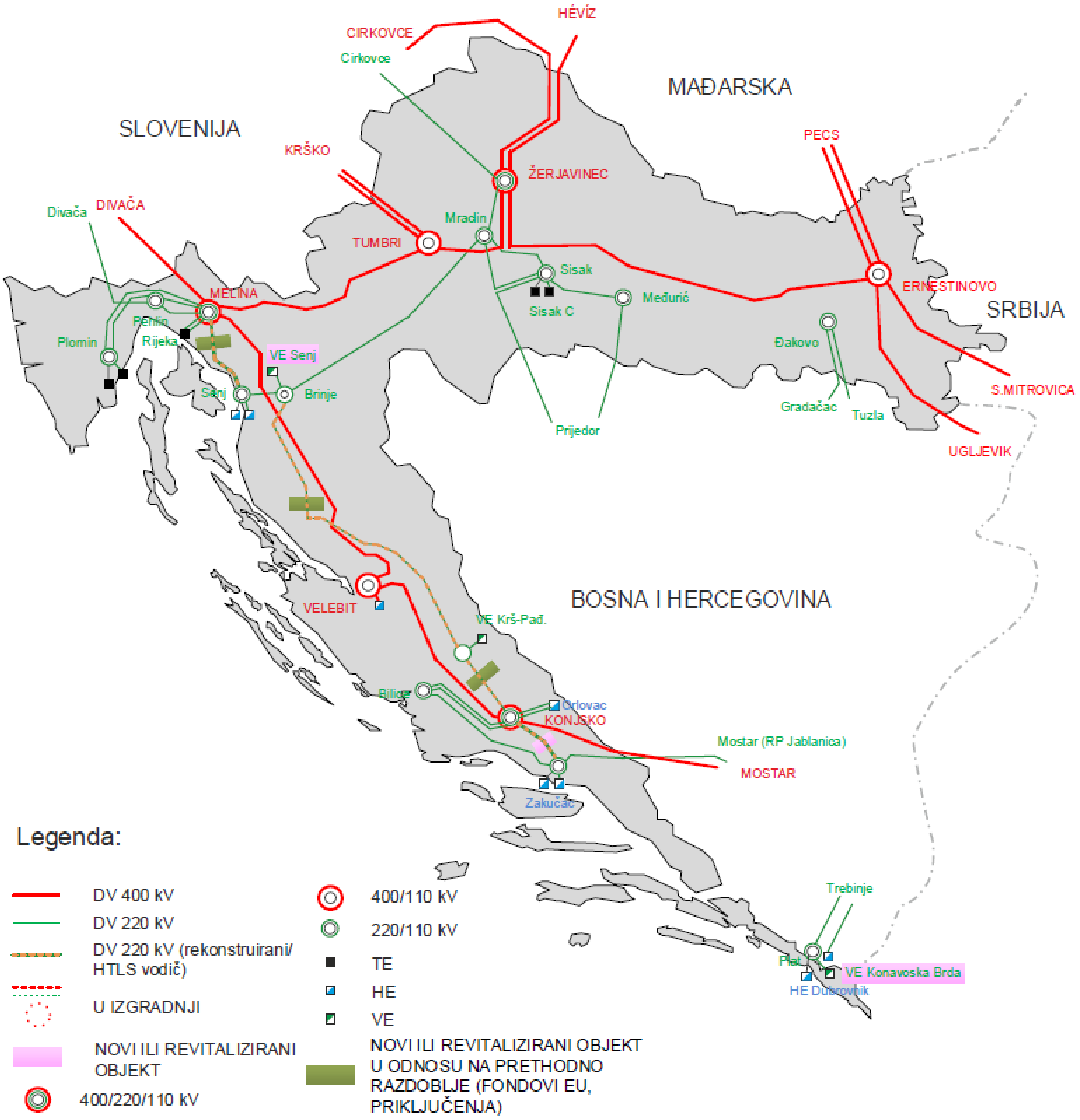

Figure 12: Topology of Croatia's 400 kV and 220 kV grid – Year 2025.

As expected, this topology is mostly unchanged compared to the present. There is strengthening of the 220 kV south – northwest axis by installing 585 MVA high-temperature low sag (HTLS) conductors with higher capacity rate on the existing pylons (dotted orange – green line). This is due to planned new renewables in Croatia, coupled with flows from BiH to Slovenia over the Croatian 400 kV and 220 kV network. These flows can appear in springtime during high hydrology and strong wind conditions. Since the region, and especially Croatia and BiH, is strongly wind and hydro coupled, high flows will come from the south (BiH) over Croatia and Slovenia towards Italy and Austria.

Besides network reinforcements, several projects are under consideration in the TYNDP by 2025:

- Construction of OHL 2x400 kV Cirkovce - Pince (SI) with connection I/O to existing OHL Žerjavinec – Heviz (finalization any day now)
- Replacement of 220/110 kV 150 MVA transformer in SS Sisak (2022.)

Conditional projects – financed by 3rd party (Grid connection fee / EU Funds):

- Reconstruction of OHL 220 kV Konjsko – Krš Pađene - Brinje with HTLS conductor (2024.)
- New 400/220 kV 400 MVA & 2x 220/110 kV 150 MVA transformers at SS Konjsko (2024.)
- Reconstruction of SS 400/110 Velebit with GIS 110 kV switchyard (2025.)

The following figure shows only existing substations (SS). This could change if there are lot of new renewables applying for the connections. From other existing projects we are sure that one SS is needed, while others will depend on the realization of additional projects.

So, at least one new 400 kV substation would be required to absorb the energy (mostly WPPs and SPPs). There are a few viable locations (all in the region of Dalmatia) for these substations and due to RES uncertainty (regarding the number, size and micro-locations of individual projects), these substations and their connections to the existing grid are not drawn in the figure nor in HOPS's other formal documents. More precisely, the RES project development process in Croatia is quite long and exhausting, with developers sometimes targeting the same sites, the same connection points, and the same off-takers etc., so it is impossible to clearly define which RES candidates are viable until construction starts.

Many of these network reinforcements and new substations can be sped up or prolonged depending on the speed of new renewables integration.

The Croatian National Recovery and Resilience Plan for 1/2021 to 6/2026[3] [8] includes Investment program for "*Revitalization, construction and digitization of the energy system and related infrastructure for the decarbonisation of the energy sector*", which is partly financed by the EU Recovery and Resilience Facility. The budget for this TSO and DSO investment program is about 3,510.0 Million HRK (about 466 Million €). The Plan's investment goal is to speed up grid development until 2026 through transmission capacity increases (primarily north-south) in revitalization and digitalization to ensure the integration of new RES, and strengthen the decarbonization of the energy sector.

The following figure shows the 400 kV and 220 kV network topology in the longer term (2031), including the new 400 kV network reinforcements (dotted red lines) foreseen in the HOPS 400 kV network development study [2]. New substations comparing to 2025 are marked with a pink or green color.

The following relevant projects are under consideration in the current TYNDP (2032):

- New OHL 2x400 kV Tumbri – Veleševec (2030.) with following changes in topology:
    - Formation of OHL 400 kV Tumbri – Žerjavinec 2
    - Formation of OHL 400 kV Tumbri - Ernestinovo
- Reconstruction of 220 kV switchyard at SS 220/110 kV Zakučac (2027.)
- New/replacement of 220/110 kV 150 MVA transformer in SS Bilice (2026. & 2027.), Međurić (2027.), Mraclin (2029.)

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[3] Plan oporavka i otpornosti, srpanj 2021..pdf (gov.hr)

- New/replacement of two 400/220 kV 400 MVA transformer in SS Melina (2031.),
- Reconstruction of OHL 220 kV Đakovo (HR) – Tuzla (BA) & Đakovo (HR) – Gradačac (BA) (2031.)
- Reconstruction of OHL 220 kV Zakučac (HR) – Mostar (BA) (2032.)
- Construction of SS 220/110 kV Vodnjan (2032.)

Conditional projects – financed by the 3rd party (network users through the grid connection fee / EU funds):

- New 400/110 kV 400 MVA transformer at SS Velebit (2026)
- Construction of SS 400/220 kV Lika (2030)
- Extension of SS 400/220/110 kV Konjsko (1 line bay) (2028)
- Extension of SS 400/220/110 kV Melina (1 line bay) (2029)
- Construction of OHL 400 kV Lika – Konjsko (2030)
- Reconstruction of OHL 220 kV Orlovac – Konjsko with HTLS conductor (2028)

It is important that in this Plan, substation Lika is connected only with Konjsko and Melina on the 400 kV voltage level. There is no connection to substation Banja Luka (BA) or any other new interconnection until 2031. This affects the possible reinforcement options in BiH's 400 kV network later in this analysis.

Besides the TYNDP, this study also took into consideration the recently completed study on the development of the Croatian 400 kV grid [2]. The study conclusions, together with the actual TYNDP, were included in the model to form a more realistic picture of the grid. In comparison with the TYNDP, this study shows new potential grid reinforcements (dotted red lines on the previous figure):

- Strengthening of the 400 axis all the way from Mostar (BiH) to Divača (Slo) across the Croatian territory (this is dependent on the number of GW of integrated RES)
- New OHL 400 kV Lika – Tumbri (or Veleševec) to divert some of the energy to the central part of the country

Altogether, we merge the TYNDP and 400 kV development study in the following figure. The new 400/x kV SS depends on the realized RES projects, and the new TYNDP will be updated accordingly. These RES projects are mostly in the Dalmatia and Lika regions, and would be connected to the new OHL 400 kV Konjsko – Melina. The new 400 kV link to BiH (Lika – Banja Luka) would not resolve the bottlenecks in the Croatian system caused by large scale RES integration due to micro-locations and sizes of RES projects under development in this region.

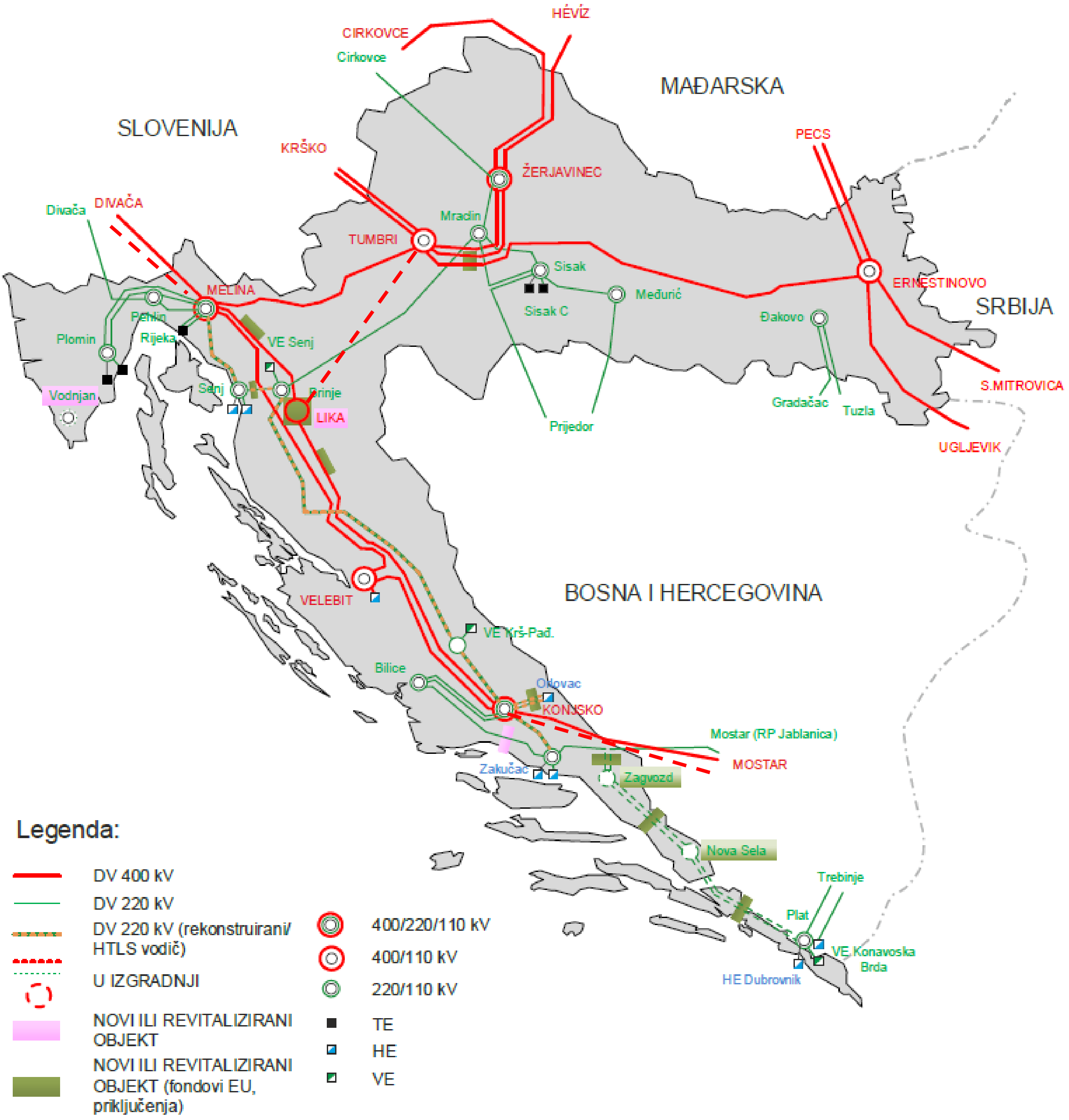


Figure 13: Configuration of Croatia's 400 kV and 220 kV grid – Year 2031.

4.3.4 Transmission System Balance and Losses

This subchapter shows the power balance for 2020, together with total consumption and losses in the past decade.

Table 20: Croatian transmission system power balance in 2020

Nr	Power balance	Energy [GWh]
1	Power plant flows into the transmission grid	10801
2	Imports in HR	10490
3(1+2)	Total energy flows into the transmission grid	21291
4	Exports from HR	5434
5(3-4)	Total consumption on transmission network	15857
6	Energy delivered to buyers on transmission network	1057
7	Pumping	231
8	Power plant self-consumption	81
9	Transmission system losses	373
10	Energy delivered to the distribution network	14428
11(min(2,4))	Transit	5434

Table 21 Total consumption and losses in the Croatian transmission system from 2008-2020

Year	Total Consumption [GWh]	Transits [GWh]	Losses [GWh]	Losses [%]
2008	17117	5667	484	2,08
2009	17307	5682	511	2,10
2010	16832	7683	598	2,38
2011	17703	6308	514	2,17
2012	17518	5568	563	2,04
2013	16624	6762	483	2,07
2014	16196	6227	430	1,92
2015	16831	5532	507	2,23
2016	16773	6054	510	2,23
2017	17320	4778	417	1,89
2018	17298	6532	534	2,24
2019	16821	5237	388	1,75
2020	15857	5434	373	1,74

Croatia has usually been a net energy importer, especially in times of dry hydrology. The losses in the system vary around 2%, and even lower in the last few years. If the Croatian Energy Strategy and power system development plan become true, it will dramatically change the existing power system balance, from being a significant importer (up to ~30% of its needs) to one that is a heavily exporting country in just 10 years. This rapid shift has significant implications for NOS BiH and BiH, as well as for retail customers there.

Finally, we note that the two systems (Croatia and BiH) are currently planned separately, with one country synchronizing their plan after the other country issues its plan. **It is strongly recommended here to establish firm and continuous cooperation between network**

planners in both countries to exchange all inputs and details during the network development preparation phase. This will become increasingly important in both countries as RES projects become more dominant in the generation mix, especially if they are located in the border area.

4.4 Ten-Year Network Development Plan of Montenegro

In light of the high interconnectedness of Croatia and BiH to Montenegro, and the important HVDC line from Montenegro to Italy, we carefully explored the grid and outlook for the power system there. The most current Montenegrin TYNDP covers 2020 – 2029, and the NRA adopted it in 2021 with some restrictions regarding the connection of two solar plants and one wind plant.

For this study, the Montenegro TYNDP is important with regard to two points:

- The 400 kV HVDC cable between Italy and Montenegro (MONITA)
- 110 kV interconnection between BiH and MNE: OHL 110 kV Trebinje (BiH) – Herceg Novi

Simulation results, both from the CGES TYNDP and this Study, have shown that the 110 OHL Trebinje (BiH) – Herceg Novi can be overloaded in certain system conditions, including high flows on the HVDC cable that flow into the 400 kV CGES transmission system. If there is an outage on one 400 kV line, say the OHL 400 kV Trebinje (BiH) – Podgorica, some of the energy will spill into the 110 kV network, overloading the OHL 110 kV Trebinje (BIH) – Herceg Novi. This happens because there are two parallel networks - 400 kV and 110 kV - and since the 110 kV does not have nearly have the capacity of the 400 kV one, overloading takes place.

Presently CGES solves this problem with busbar sectioning in SS 110 kV Budva, which changes the 110 kV system topology to avoid such overloadings. At such times, the area around the cities of Herceg Novi and Tivat are supplied radially i.e., from Trebinje. The area in question is show in the yellow circle in the figure below. To avoid this, CGES plans in the long term to build a new OHL 110 kV Herceg Novi – Vilusi and create a 110 kV triangle, securing another supply route.

A further point on the HVDC cable MONITA is that flows can be expected in both directions. This depends on:

- Regional hydrology
- Phasing out of NPPs and TPPs in Romania and Bulgaria

In case of dry hydrology and phasing out of the plants in Bulgaria and Romania, we would expect larger flows from Italy, and vice versa.

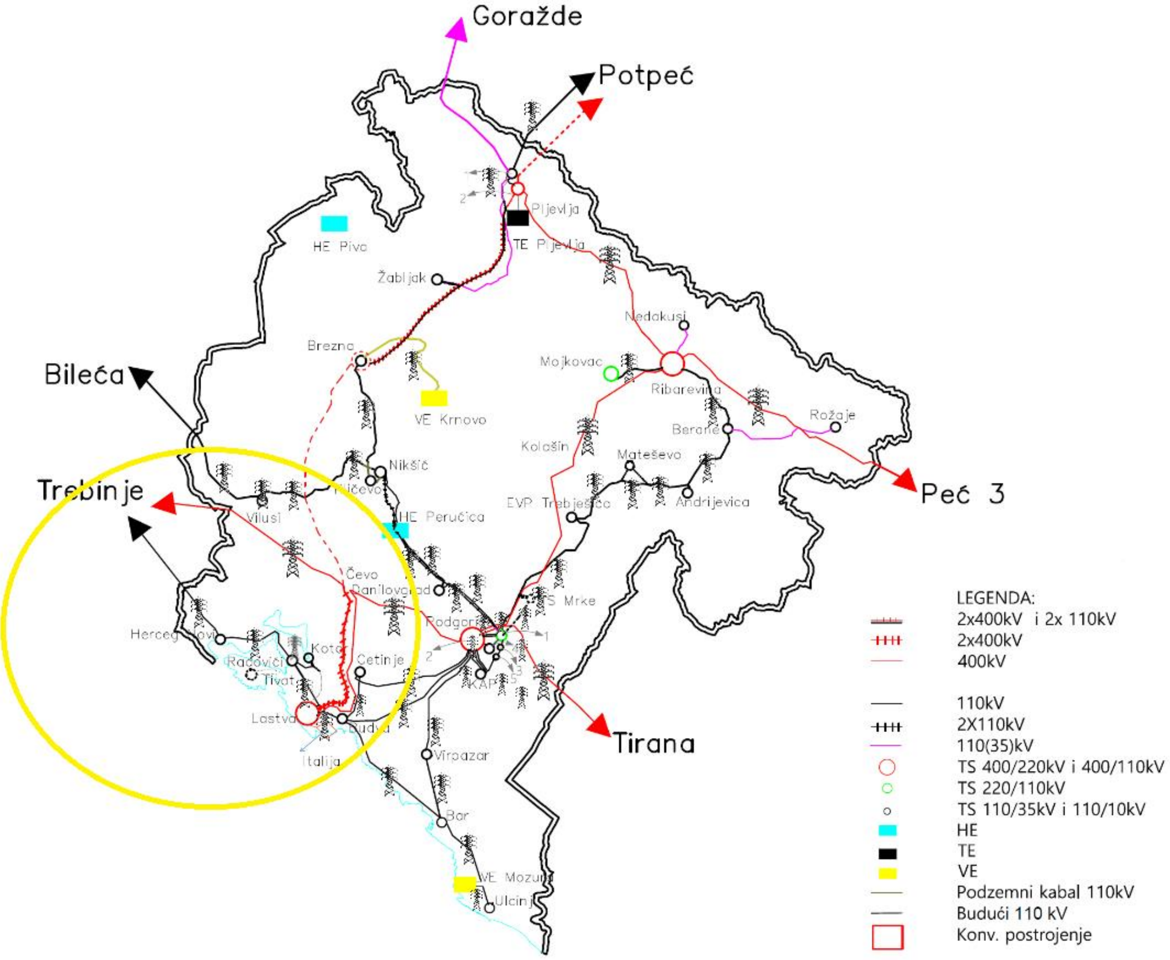


Figure 14 Present topology of CGES 400, 220 and 110 kV transmission system

5 METHODOLOGY AND SCENARIOS

This Chapter discusses scenarios we analyzed in this study, with NOS BiH's agreement. It is based on NOS BIH's operational practice and experience, and harmonized with the principles adopted in prior EMI activities and reports [4 - 5], as verified by the EMI working group. We designed the scenarios to cover the primary uncertainties and combinations of the most important variables. These scenarios vary: a) the time frame (2025 and 2030); b) the level of load; c) the level of hydro and wind; d) the level of decarbonization; and e) contingencies (n-1), and their impact on the region and the BiH transmission network. We describe each of these variables below.

5.1 RES and Decarbonization Scenarios

NOS BiH provided and we evaluated a single target RES level in BiH. We also assessed three levels of decarbonization by evaluating decommissioning alternatives. There are many TPPs in the region and in BiH, and we selected the TPPs to decommission in each country, for 2025 and 2030, based on three main criteria:

a) **Commissioning year** (older units are the first candidates for decommissioning)

b) **Heat rate levels** (less efficient units are the first candidates for decommissioning)

c) **Point of connection** (units that provide relevant voltage support and that provide heat as well of electricity are not the first candidates for decommissioning)

Since the TSOs must treat all network users and market participants equally, we used the criteria above to propose a list of TPPs to be treated as decommissioned in 2025 and 2030, beyond those already selected in the TYNDPs and other official plans. **NOS BiH reviewed and approved this list for BiH, as we present in Section 5.4.**

Our selection of additional TPP retirements is hypothetical and does not reflect or carry any legal requirement. It serves only for this study to test and understand the potential impacts of such decommissioning on the grid's operation. NOS BIH's approval of the added decommissioning list is just an agreement that this list can be used for the "what-if" exercise in this study and does not suggest that this list represents the current position of any TSOs in the region.

For each market area, including BiH, and for the SEE region as a whole, the EMI Decarbonization study of 2021 [1] modeled and analyzed three levels of thermal decommissioning:

- **Referent Decarbonization Scenario** - in line with data provided by the EMI members

  There is already considerable decommissioning of old thermal units in the referent (officially determined) plans of all EMI members. In specific, this scenario would decommission approximately half of the coal and lignite generation in SEE by 2030. However, in most countries, this level is still below the environmental requirements posed by the EU and the Energy Community Treaty.

- **Moderate Decarbonization Scenario** – This assumes additional decommissioning of thermal units based on the criteria above (commissioning year, efficiency,…). It includes, in most cases, decommissioning of TPPs commissioned more than 40 years ago, and it would retire about 2/3 of all coal and lignite generation in the region by 2030.

- **Extreme Decarbonization Scenario** - This scenario assumes decommissioning of "younger" and more efficient TPPs, ones commissioned more than 30 years ago. These retirements would reach ¾ of all coal and lignite generation in SEE by 2030.

While preparing the network reinforcement scenarios, NOS BiH updated several inputs from the initially defined scenarios:

- **HVDC MONITA submarine cable link capacity**: This value was initially set to 1000 MW in the regional models for 2025 and 2030 (as in the Montenegrin TYNDP [3]), and NOS BiH requested we test an alternative by keeping this capacity at 500 MW in 2025, and varying it in 2030. While reasonable from their operational perspective and expected developments in the region, this doubled the number of analyzed scenarios in 2030.

- **New 400 kV nodes/links**: two new 400 kV links / nodes were foreseen in the ToR: Bihać and Banja Luka. During the study preparation, NOS BiH confirmed our findings that new node Bihać 400 kV is not needed by 2030, since it would not bring any new contribution to RES integration or network reliability in this area.

Therefore, during the study we changed and extended the scenarios to analyze **62 scenarios.** These included 12 basic scenarios for 2025; 16 basic scenarios for 2030; 17 reinforcement scenarios for the max reference case with MONITA at 500 MW in 2030; and 17 reinforcement scenarios for the max reference case with MONITA at 1000 MW in 2030.

We also determined the most critical reinforcement scenarios for 2030, i.e., the one with the most contingencies, and those were the scenarios with the maximum system load, reference decarbonization and MONITA at 500 MW. NOS BiH confirmed based on their operational experience that this combination of inputs is the most stressful and pivotal for the BiH network analysis in this study. Further, it was important to assess simultaneously high levels of RES, HPP generation and local demand, since this would lead to the highest BiH network loading under extreme conditions, with the highest potential need for reinforcements.

In terms of potential network reinforcements, we used NOS BiH’s planning experience with RES connection requests and budget minimization (conductor replacements are cheaper than new lines) to carefully select and analyze these 17 potential new elements:

1) New OHL 400 kV B.Luka – Lika
2) New OHL 400 kV B.Luka – Tumbri
3) New OHL 400 kV B.Luka – Žerjavinec
4) New OHL 400 kV B.Luka – Šuica
5) New OHL 400 kV Konjsko – Mostar
6) New OHL 400 kV B.Luka – Lika and new OHL 400 kV B.Luka – Tumbri
7) New OHL 400 kV B.Luka – Lika and new OHL 400 kV B.Luka – Žerjavinec
8) New OHL 400 kV B.Luka – Lika and new OHL 400 kV B.Luka – Šuica
9) New OHL 400 kV B.Luka – Lika and new 400 kV Konjsko – Mostar
10) New OHL 400 kV B.Luka – Tumbri and new OHL 400 kV B.Luka – Žerjavinec
11) New OHL 400 kV B.Luka – Tumbri and new OHL 400 kV B.Luka – Šuica
12) New OHL 400 kV B.Luka – Tumbri and new 400 kV Konjsko – Mostar
13) New OHL 400 kV B.Luka – Žerjavinec and new OHL 400 kV B.Luka – Šuica
14) New OHL 400 kV B.Luka – Žerjavinec and new 400 kV Konjsko – Mostar
15) New OHL 400 kV B.Luka – Šuica and new 400 kV Konjsko – Mostar
16) New OHL 400 kV Konjsko – Mostar and reinforcement of
    a. OHL 110 kV B.Blato – Livno (ACCC conductors type Lisbon 230 MVA)
    b. OHL 110 kV Livno – Šuica (ACCC conductors type Lisbon 230 MVA)
    c. OHL 110 kV Komolac – Trebinje (ACCC conductors type Lisbon 230 MVA)
    d. OHL 110 kV Baljci – Šuica (ACCC conductors type Lisbon 230 MVA)
    e. OHL 110 kV Trebinje – H.Novi (ACCC conductors type Rovinj 165 MVA)
17) New 400 kV Šuica – B.Luka and reinforcement of
    a. OHL 110 kV B.Blato – Livno (ACCC conductors type Lisbon 230 MVA)
    b. OHL 110 kV Livno – Šuica (ACCC conductors type Lisbon 230 MVA)
    c. OHL 110 kV Komolac – Trebinje (ACCC conductors type Lisbon 230 MVA)
    d. OHL 110 kV Baljci – Šuica (ACCC conductors type Lisbon 230 MVA)
    e. OHL 110 kV Trebinje – H.Novi (ACCC conductors type Rovinj 165 MVA)

For each scenario we conducted:

- Load-flows and voltage profiles in the 400 kV, 220 kV and 110 kV networks, and
- A contingency (N-1) assessment

While the scenarios we analyzed are plausible and numerous, we focused on whether the impacts and differences are meaningful, particularly for BiH. To do so, we modeled and analyzed 62 network reinforcement scenarios, for 2025 and 2030, as graphically depicted below.

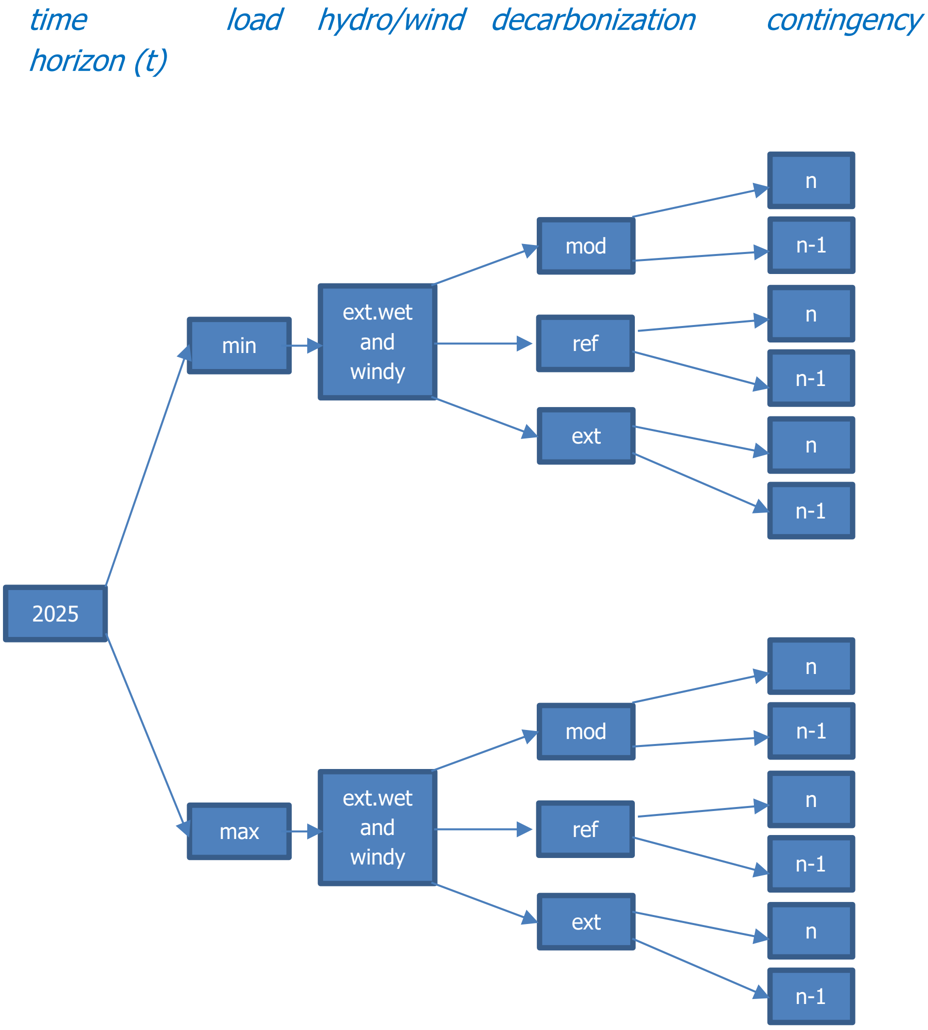
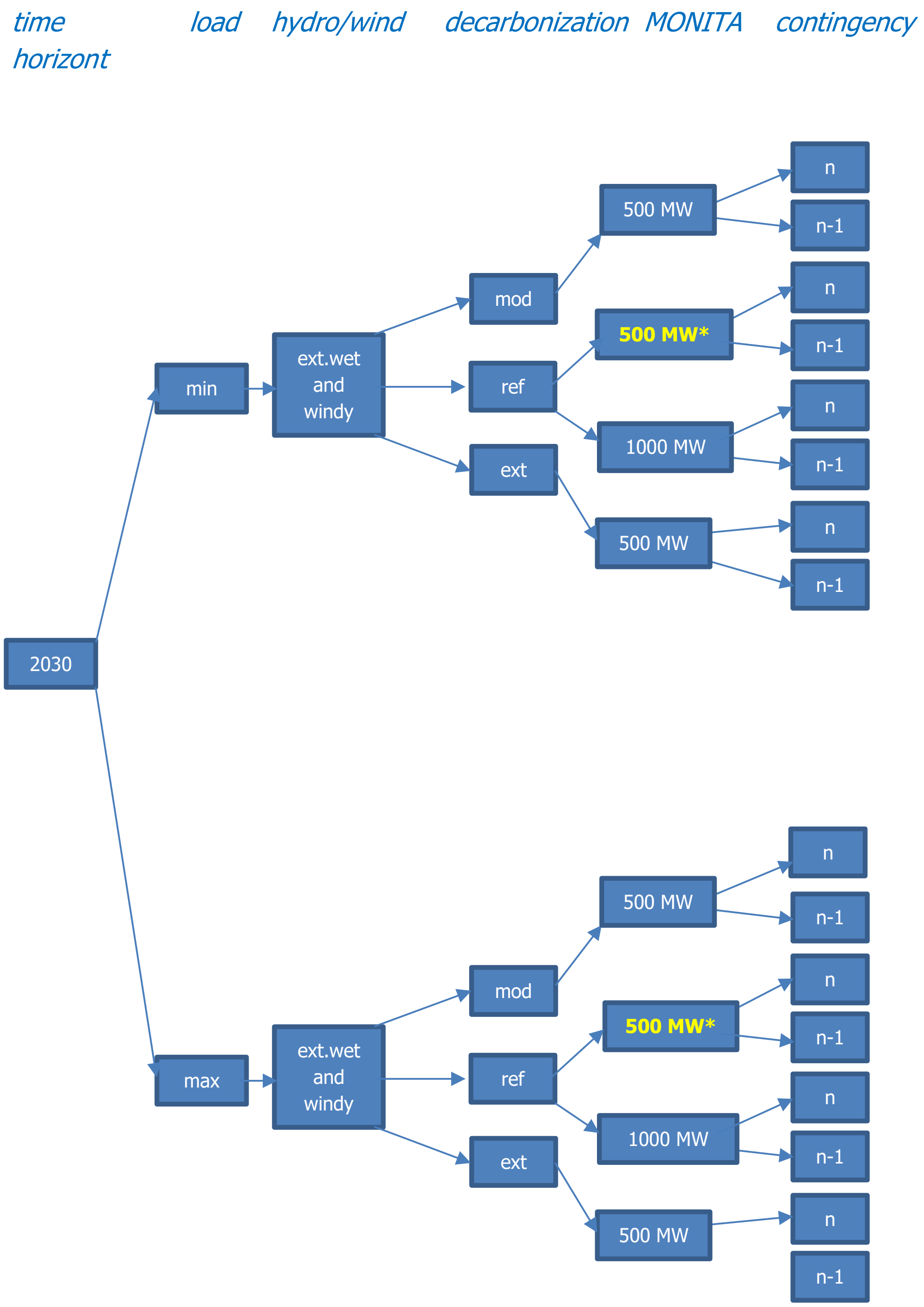


Figure 15: Analyzed network scenarios for NOS BiH in 2025



*For this scenario 17 network reinforcements are additionally analyzed

Figure 16: Analyzed scenarios for NOS BiH in 2030

5.2 TPP decommissioning scenarios

As presented in Chapter 5.1, for each market area and for SEE, we analyzed three TPP decommissioning scenarios – referent, moderate and extreme.

The EMI members provided the data for the referent scenario, and in the other two scenarios (moderate and extreme) we further reduced TPP capacity. This subchapter provides an overview of the proposed decommissioned TPP units through 2030 in the moderate and extreme scenarios, and its decrease compared to the referent scenario. All TPP capacities are given as sent-out or net capacity (without self-consumption).

Table 24 presents the total installed TPP capacity in the SEE region in 2030, including the **agreed total decommissioned TPP capacities** that we analyzed in this study for each market area, and the rate of capacity change in the moderate and extreme scenarios. We provided the values for BiH TPP installed and engaged capacities in Chapter 4.1.

*Table 22: TPP commissioning and decommissioning in the EMI region in **2030** in the moderate and extreme scenarios*

Market area	Total TPP installed capacity in 2030 (MW) -Referent scenario	TPP capacity decommissioned in the Moderate scenario (MW)	Additional TPP capacity decommissioned in the Extreme scenario (MW)	Total TPP capacity in operation in the Moderate scenario (MW)	Total TPP capacity in operation in the Extreme scenario (MW)	Rate of TPP capacity decrease - Moderate scenario	Rate of TPP capacity decrease - Extreme scenario
Albania	300	100	100	200	100	-33.3%	-66.7%
BiH	**2,837**	**190**	**466**	**2,647**	**2,371**	**-6.7%**	**-16.4%**
Bulgaria	4,728	658	600	4,070	3,470	-13.9%	-26.6%
Greece	7,768	600	674	7,167	6,493	-7.7%	-16.4%
Croatia	981	105	192	876	684	-10.7%	-30.3%
Kosovo	978	450	264	528	264	-46.0%	-73.0%
Montenegro	225	0	225	225	0	0.0%	-100.0%
N.Macedonia	586	0	0	586	586	0.0%	0.0%
Romania	10,055	1,493	1,672	8,562	6,889	-14.9%	-31.5%
Serbia	4,829	795	1,124	4,033	2,909	-16.5%	-39.8%
Slovenia	1,757	767	53	990	937	-43.7%	-46.7%
TOTAL	**33,837**	**5,387**	**5,523**	**28,451**	**23,346**	**-15.9%**	**-31.0%**

The following tables presents the total BiH TPP decommissioning capacity in two analyses: the USEA EMI Decarbonization Study [1] finalized in 2021, and this assessment. Clearly, there were some recent changes in BiH, leading to a more rapid decommissioning plan.

Table 23: Total BiH TPP capacity decommissioning comparison in the 2021 EMI study

TPP capacity decommissioned (MW)	Decarbonization scenario		
	Referent	moderate	extreme
	0	190 (TPP Tuzla 6)	276 (TPP Gacko) + 190 (TPP Tuzla 6)

The following table presents the coal-fired TPP blocks in BiH planned to be decommissioned by 2030 due to its lifetime. Three units are planned to be closed in 2024, with total capacity of 418 MW, while in 2027 decommissioning is foreseen for TPP Tuzla 5, for a total of 618 MW.

Table 24: The scheduled BiH TPP decommissioning timeline

	Capacity (MW)	Decommissioning year
TPP Kakanj 5	118	2024
TPP Tuzla 3	100	2024
TPP Tuzla 4	200	2024
TPP Tuzla 5	200	2027

However, knowing of the uncertainty of the local generation decommissioning, especially under the new energy crisis conditions, NOS BiH provided inputs for this analysis to keep the EMI's moderate (190 MW) and extreme (466 MW) levels of decarbonization in BiH by 2030.

5.3 Approach and methodology

The network element loadings are driven by:

1. Electricity demand, particularly at times of maximum and minimum system load
2. Dispatch of the generating units,
3. The development status and changes to neighboring, regional networks
4. Topology and operational status of the network elements

To minimize uncertainties, we defined all these aspects and presented the input data and scenarios to NOS BIH, which reviewed and approved them. We used the same approach for the Croatian power system, which is strongly connected to the BiH system. This consistent approach - with input data from the neighboring systems submitted and verified by all other SEE TSOs and MOs through the EMI project - is the most reliable path to this kind of analysis in the region.

Based on the verified input data, and the use of the PSS/E network models, our analysis focused on the impacts of decarbonization and RES integration on the BiH power sector in 2025 and 2030. These scenarios produced a wide range of network conditions based on the levels of decarbonization, load, network topology options and network availability. Several conditions are quite uncertain, especially the RES grid connection candidates and system dynamics.

For every analyzed scenario, we determined four main outputs (results) of network operation:

1. Load flows in BiH 400, 220 and 110 kV transmission network elements
2. Voltage profiles on all BiH transmission network nodes
3. Transmission network losses for the BiH transmission network
4. Network bottlenecks under security (N-1) conditions.

These outputs, based on the application of a verified regional electricity market and network model, will help NOS BiH and Elektroprijenos BiH in structuring and prioritizing which lines to develop. Using these scenarios' picture of power flows, cross-border exchanges, voltage violations, network losses and bottlenecks, they can compare these results with their TYNDPs, and further detect issues and alleviate the impacts of RES integration on their networks.

In addition, there are lessons learned from this analysis about the value of coordinated transmission planning with neighboring countries, particularly BiH and Croatia; how to jointly ensure that the most challenging conditions do not put system reliability at risk; and the level of electricity interdependence between the countries of SEE.

In this study we primarily focused on network topology issues and proposals for reinforcements needed to support the expected changes in the power generation mix by 2030.

5.4 Other modeling assumptions

5.4.1 Different hydro and wind conditions

Hydro conditions can be critical for BiH and Croatia, as well as for other SEE countries, due to their high share of hydro generation, and it can meaningfully affect regional flows and balance positions. Thus, we evaluated the impact of decarbonization and TPP decommissioning, along with the most critical hydro conditions in BiH. Based on the operational experience verified by NOS BiH this refers to extremely wet hydrology.

Similarly, NOS BiH provided inputs on expected wind power plant engagement in 2025 and 2030 in line with the current RES project development list and indicative generation development plans.

5.4.2 Different regional energy balance levels

One of the issues for policy consideration involves the extent to which a market should rely on others for its power supplies. BiH is committed to SEE regional integration, and reducing the TPPs in different decommissioning scenarios would change the regional balance of imports and exports. We do not expect these scenarios to jeopardize BiH's self-sustainability due to its existing and future surplus. For other SEE countries, we used decarbonization scenarios and country energy balances provided by the EMI members in the 2021 EMI Decarbonization Study [1].

6 NETWORK MODELING PRINCIPLES

We used the data collected to update the PSS/E model for BiH, Croatia and the SEE region. In this process we employed the following process:

- Definition of the relevant input data needed for the power flow analyses on the regional level in the selected software tool – PSS
- Collection of input data focused for 2025 and 2030 from the NOS BiH and HOPS through a comprehensive spreadsheet
- Clarification of conflicting input data and suggestions for solutions, including sources such as the Ten-Year Network Development Plans (TYNDPs), Generation Development Plans, and other publicly available sources, as well as the Consultants' databases
- Clarification with NOS BiH for fine tuning of BiH transmission system topology and generation of each generator in the model

The following approach was used to model the PSS/E power systems and neighboring areas:

- As a base for PSS/E we have used Croatian PSS/E model for network development study, which is based upon EMI model
- We have replaced model information for BiH system with new input data from NOS BiH
- After merging models, as model of Croatia and BiH were slightly different, each BiH cross border line is manually verified

For this study, we used Regional Transmission System Models (RTSMs) for the following initial four base cases, in line with standard ENTSO-e approach:

1. the third Wednesday in January 2025 at 18:00 (CET) (considered as the maximum load regime 2025);
2. the third Wednesday in May 2025 at 04:00 am (CET) (considered as the minimum load regime 2025).
3. the third Wednesday in January 2030 at 18:00 (CET) (considered as the maximum load regime 2030);
4. the third Wednesday in May 2030 at 04:00 am (CET) (considered as the minimum load regime 2030).

We expand each of these basic regimes to a number of scenarios defined in the previous Chapter.

To create a regional network model, it was necessary to collect individual models from all participating TSOs and merge them into a single regional one. That was done by previous two activities: EMI [1] and Croatian 400 kV network development study [2]. The development of the 400 kV network, and the transmission network in general, in Croatia strongly impacts the transmission network development in BiH, since these two systems are so well connected, with 21 interconnection lines. For the rest of the region (less influential on internal BiH network loadings) we used EMI models for the referent decarbonization scenario. Knowing of the recent developments on the electricity market and the gas supply crisis, we expect that the decarbonization process will not speed up in the next few years in the BiH neighborhood.

Based on these inputs we used the adjusted regional models for detailed AC load flow simulations. This was based on the generation dispatch we obtained from the market simulation scenarios with different levels of RES, different hydrological conditions, and different levels of consumption and CO_2 emission prices.

To prepare for these comprehensive simulations, we conducted a preliminary test analysis with our initially created regional transmission grid models. The results are given below.

6.1 Level of modeling for grid analyses

The level of grid modeling of power systems in these countries is very detailed, and includes four main principles:

1. The complete transmission network at the voltage level of 110 kV and above
    a. If there are parallel branches, we model each branch separately (i.e., we did not model parallel branches as one equivalent or aggregated branch)

2. Every conventional generation unit connected to the transmission grid is modeled at the generation voltage level, and connected to the system through a step-up transformer
    a. Where there are power plants with multiple conventional units, each unit is modeled separately (i.e., we did not model multiple generation units as one equivalent unit)

3. Every wind and solar power plant connected to the transmission grid is modeled as one unit at the point of common coupling (PCC), where generation from all units are collected, and this “unit” is connected to the transmission grid through a step-up transformer

4. There are no equivalents with regard to the network in the SEE area. Equivalents are used on the regional borders to Austria, Italy and Hungary

6.2 Modeling of the tie-lines

To better organize this report, handle the models and allocate the electricity losses in each country on the tie-lines, we modeled each tie-line with a fictitious node (the so-called *X-node* or *border node*), which is on the border between countries/TSOs (see Figure 17).

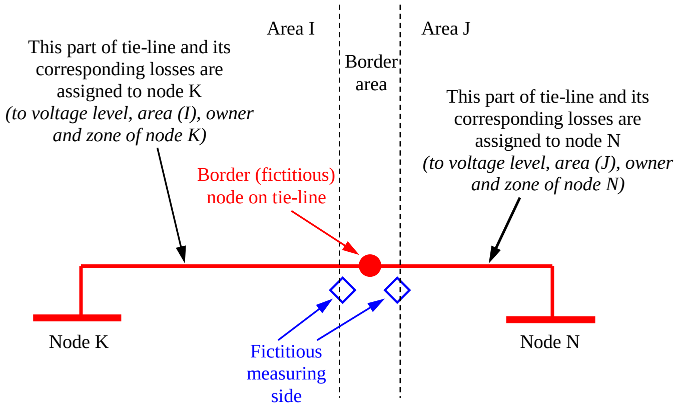


Figure 17: Modeling of tie-lines

Practically, each tie-line is divided in two parts. We assigned each border node to a fictitious border area and we placed the measuring point of each part of tie-line on their side of the border node. With this approach, we can assign losses in each part of tie-line to the corresponding area.

In the case of tie-lines connecting areas within the system of interest (e.g., tie-lines between BiH and its neighbors) these fictitious border nodes do not have any load or generation. Therefore, the areas containing such nodes are shown in the area summary report with all zero data (zero generation, zero load, zero losses and zero net interchange).

6.3 Reporting format

Some reports in this Study are taken directly from the PSS/E software tool. For easier understanding this subchapter describes basic PSS/E reporting format. For a better understanding, we have prepared each sample report and inserted the figure with a detailed explanation of all parts of the data.

For any type of branch, the assignment to the node and its area, zone, owner and voltage level depends on the branch's defined measuring point. Since the measuring point defines the place where we measure the power interchange between two nodes, we assign each branch to a node (and therefore to its area, zone, owner and voltage level) on the opposite side of the measuring point. For a clear explanation, we provide an example of a small part of the grid in Figure 18.

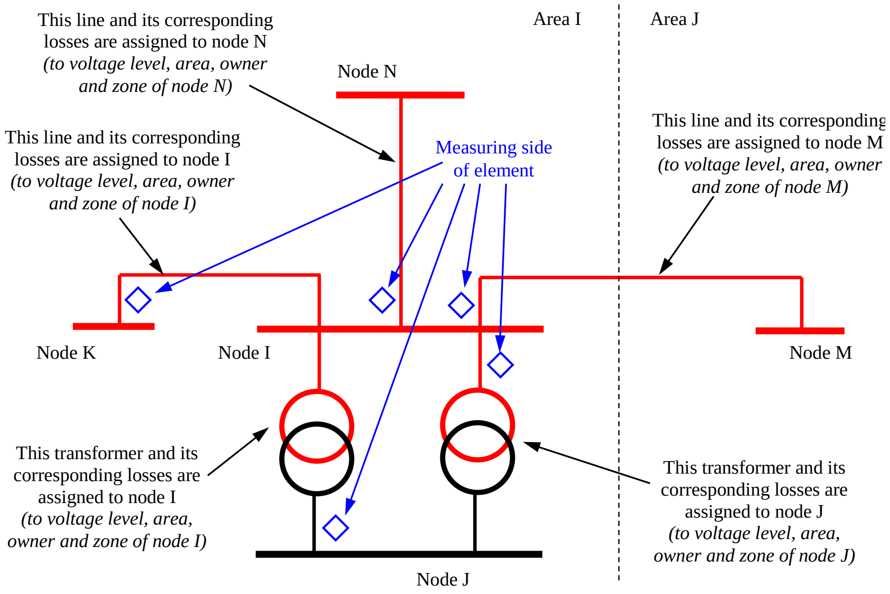


Figure 18: Explanation of rules for assignment branches to nodes and their areas, zones, owners and voltage levels

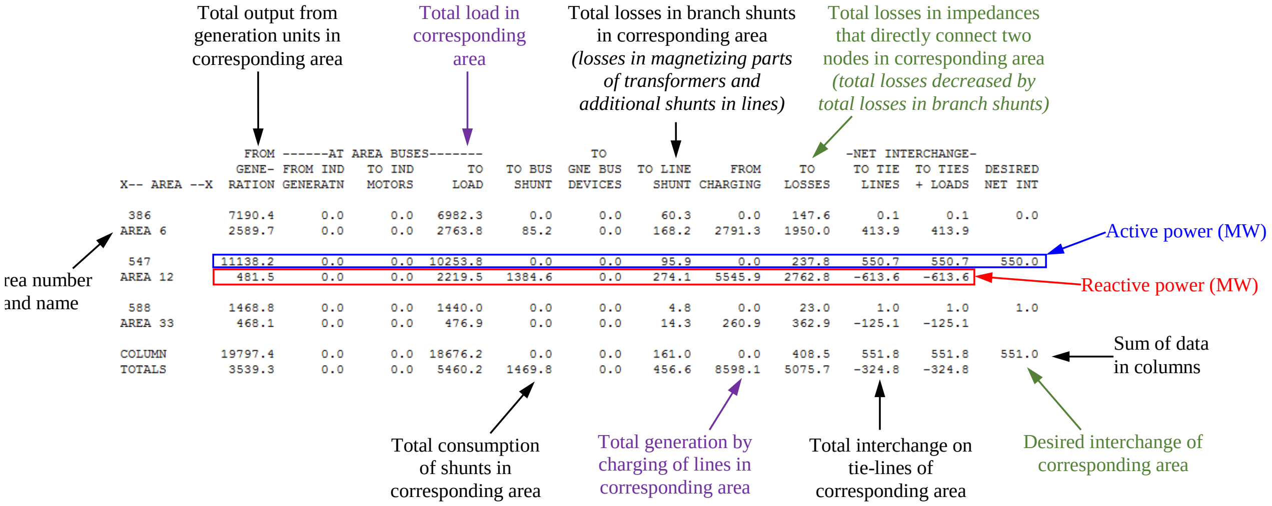
In the case of three winding transformers, we define two measuring points, so that such a transformer, and its losses, is assigned to the node on the side where there is no measuring point. When reporting power flows, PSS®E shows power flows registered on the branch measuring side.

Tie-lines are modeled with border nodes, which are placed on the border between two TSOs, which means that each tie-line is modeled as two lines, the first one from the border node to the corresponding substation in one area, and the second one from the border node to the corresponding substation in the other area. The measuring point on each of these two lines is inside the border nodes, so losses in each line are assigned to the corresponding area.

6.4 Area summary report

We also use an PSS/E area summary report to show summary data for each selected area. The following Figure 19 shows an example of an area summary report, with a detailed description of the data columns in such a report.

Total losses include two parts, i.e., for one area total losses are the sum of the data in the column "TO LOSSES" and "TO LINE SHUNTS" for the corresponding area.



```
                  FROM ------AT AREA BUSES-------            TO                                   -NET INTERCHANGE-
                  GENE-  FROM IND    TO IND       TO   TO BUS   GNE BUS  TO LINE     FROM      TO    TO TIE  TO TIES  DESIRED
X-- AREA --X     RATION GENERATN    MOTORS      LOAD    SHUNT  DEVICES    SHUNT  CHARGING  LOSSES    LINES  + LOADS  NET INT

 386             7190.4      0.0       0.0    6982.3      0.0      0.0     60.3       0.0   147.6      0.1      0.1      0.0
AREA 6           2589.7      0.0       0.0    2763.8     85.2      0.0    168.2    2791.3  1950.0    413.9    413.9

 547            11138.2      0.0       0.0   10253.8      0.0      0.0     95.9       0.0   237.8    550.7    550.7    550.0
AREA 12           481.5      0.0       0.0    2219.5   1384.6      0.0    274.1    5545.9  2762.8   -613.6   -613.6

 588             1468.8      0.0       0.0    1440.0      0.0      0.0      4.8       0.0    23.0      1.0      1.0      1.0
AREA 33           468.1      0.0       0.0     476.9      0.0      0.0     14.3     260.9   362.9   -125.1   -125.1

COLUMN          19797.4      0.0       0.0   18676.2      0.0      0.0    161.0       0.0   408.5    551.8    551.8    551.0
TOTALS           3539.3      0.0       0.0    5460.2   1469.8      0.0    456.6    8598.1  5075.7   -324.8   -324.8
```

Total output from generation units in corresponding area

Total load in corresponding area

Total losses in branch shunts in corresponding area *(losses in magnetizing parts of transformers and additional shunts in lines)*

Total losses in impedances that directly connect two nodes in corresponding area *(total losses decreased by total losses in branch shunts)*

rea number and name

Active power (MW)

Reactive power (MW)

Sum of data in columns

Total consumption of shunts in corresponding area

Total generation by charging of lines in corresponding area

Total interchange on tie-lines of corresponding area

Desired interchange of corresponding area

Figure 19: Description of data shown in area summary report from PSS®E

6.5 Overview of SEE regional transmission grid model

For the readers that are not following EMI working group activities, in this chapter we give brief overview of the EMI regional transmission model created (merged) from the TSOs' national models to support this network analysis.

We created the regional models by merging all the collected national models. The total number of power system elements in the regional model are shown in Table 25.

Table 25: Number of elements in the regional models

```
    8480 BUSES        1463 PLANTS           1245 MACHINES       0 INDUCTION GENS        0 INDUCTION MOTORS
    3392 LOADS          47 FIXED SHUNTS      151 SWITCHED SHUNTS
    9746 BRANCHES     3663 TRANSFORMERS        2 DC LINES         1 FACTS DEVICES         0 GNE DEVICES
```

In addition to a summary for each area, and an analysis of the voltage profile, for each scenario we assessed steady-state security against single outages as well. This assessment included analyses of the grid conditions in case of a single outage of branches. We included these branches in the list of outages and in the list of monitoring elements:

- all 400 kV lines
- all 220 kV lines
- all transformers 400/220 kV
- all BiH tie-lines

In the case of parallel branches, we considered the outage of each single branch.

In other words, we simulated all possible outages of single element (no multiple failures were tested) in the BiH transmission network no matter of its probability of occurrence. This is typical deterministic approach used in the transmission planning studies.

Besides that, voltage profiles are also considered here for complete BiH transmission network. Usually, high voltage grid (220 and 400kV) is considered as of national (state-level) importance, while all problems related to 110 kV voltage level is considered as local problem.

6.6 Maximum load regime

Here we show a regional area summary, as reported in PSS®E, for the maximum system load regime in 2025 and 2030. The first row for each country represents data related to active power (in MW), while the second row shows data related to reactive power (in MVar).

Table 26: Summaries of areas in regional model – maximum load 2025

```
                FROM ------AT AREA BUSES-------             TO                              -NET INTERCHANGE-
               GENE- FROM IND   TO IND       TO   TO BUS  GNE BUS  TO LINE     FROM       TO   TO TIE  TO TIES  DESIRED
X-- AREA --X  RATION GENERATN   MOTORS     LOAD    SHUNT  DEVICES    SHUNT CHARGING   LOSSES    LINES  + LOADS  NET INT

   13         3368.7      0.0      0.0   1900.0      0.0      0.0     15.7      0.0    120.1   1333.0   1333.0   1333.0
BA             767.3      0.0      0.0    806.7      0.0      0.0     56.5    973.3   1075.9   -198.6   -198.6

   16         3618.2      0.0      0.0   2828.4      0.0      0.0      0.0      0.0    155.7    634.0    634.0    634.0
HR             119.8      0.0      0.0    397.9      0.0      0.0      0.2   1346.4   1350.8   -282.6   -282.6

   38          809.2      0.0      0.0    810.3      0.6      0.0      3.8      0.0     30.5    -36.0    -36.0    -36.0
ME             272.6      0.0      0.0    216.6    -37.1      0.0     27.5    387.1    278.2    174.4    174.4

   46         4821.0      0.0      0.0   4651.7      0.0      0.0     13.4      0.0     84.9     71.0     71.0     71.0
RS            1449.2      0.0      0.0   1504.8      0.0      0.0     47.6   1661.6    989.4    569.1    569.1

COLUMN       12617.1      0.0      0.0  10190.3      0.6      0.0     32.9      0.0    391.2   2002.0   2002.0   2002.0
TOTALS        2608.9      0.0      0.0   2926.0    -37.1      0.0    131.8   4368.4   3694.2    262.3    262.3
```

Table 27: Summaries of areas in regional model – maximum load 2030

```
                FROM ------AT AREA BUSES-------             TO                              -NET INTERCHANGE-
               GENE- FROM IND   TO IND       TO   TO BUS  GNE BUS  TO LINE     FROM       TO   TO TIE  TO TIES  DESIRED
X-- AREA --X  RATION GENERATN   MOTORS     LOAD    SHUNT  DEVICES    SHUNT CHARGING   LOSSES    LINES  + LOADS  NET INT

   13         3632.3      0.0      0.0   2000.0      0.0      0.0     16.2      0.0    109.1   1507.0   1507.0   1507.0
BA             722.1      0.0      0.0    849.3      0.0      0.0     64.6    997.8   1072.7   -266.7   -266.7

   16         4433.0      0.0      0.0   3308.0      0.0      0.0      0.0      0.0    157.0    967.9   1025.9    968.0
HR             219.9      0.0      0.0    459.7      0.0      0.0      0.2   1529.8   1500.0   -210.2   -208.7
   38          808.8      0.0      0.0    810.3      0.6      0.0      3.8      0.0     30.1    -36.0    -36.0    -36.0
ME             275.6      0.0      0.0    216.6    -37.1      0.0     27.5    386.9    275.2    180.2    180.2

   46         4821.1      0.0      0.0   4651.7      0.0      0.0     13.4      0.0     85.1     71.0     71.0     71.0
RS            1466.3      0.0      0.0   1504.8      0.0      0.0     47.6   1660.6    992.0    582.5    582.5

COLUMN       13695.2      0.0      0.0  10770.0      0.6      0.0     33.4      0.0    381.3   2510.0   2568.0   2510.0
TOTALS        2683.8      0.0      0.0   3030.4    -37.1      0.0    139.9   4575.1   3839.9    285.8    287.3
```

The level of active power losses in BiH is 110-120 MW or around 3.5% of generation.

6.7 Minimum load regime

We summarize here the SEE area totals reported from PSS®E for the minimum load regimes in 2025 and 2030. The lThe level of active power losses in BiH is 81-91 MW or around 4,7% of generation.

7 STUDY RESULTS AND NETWORK REINFORCEMENT NEEDS

In this Chapter we present the study results in all analyzed scenarios, along with the proposed network reinforcements for BiH. Our numerous scenarios produced a large set of outputs. We present the most important findings in this Chapter, with other results in the Annex.

7.1 Location of new 400 kV node

Both the ToR and the input data set anticipate in the base scenario for 2025 a new 400 kV switchyard in Šuica. While previous studies show that this new switchyard is necessary to connect new RES projects in this area, its micro location was not previously defined, so we do so here. Therefore, here it is taken as given input data, without a need for additional justification.

However, since it is not feasible to construct a new 400 kV line in just few years, we use only the 110 kV switchyard in 2025. In 2030 scenarios we assume that the new substation 400/110 kV Šuica will be completed, with two new 400/110 kV transformers (each one with 300 MVA of installed capacity).

The basic scenario for 2030 includes construction of the SS 400/110 kV Šuica and its connection to the existing OHL 400 kV Konjsko – Mostar 4 as the shortest possible solution for its interpolation into the existing 400 kV network. According to the draft of the relevant Spatial Plan of Zapadnohercegovačka County [10], the location for grid connection to the existing OHL 400 kV Konjsko – Mostar is foreseen near Posušje on the BiH side of the Croatia – BiH border (see next figure). This location seems very convenient for further analysis.

This location was initially defined for the grid connection of the new coal-fired TPP Kongora (2x275 MW or 1x300 MW) near Livno that was planned 10-15 years ago. The construction of TPP Kongora is postponed and very uncertain now, and it is surely not realistic by 2030. In addition, it is not included in the transmission development plan nor in the Indicative generation expansion plan, so we have not included this TPP into our models.

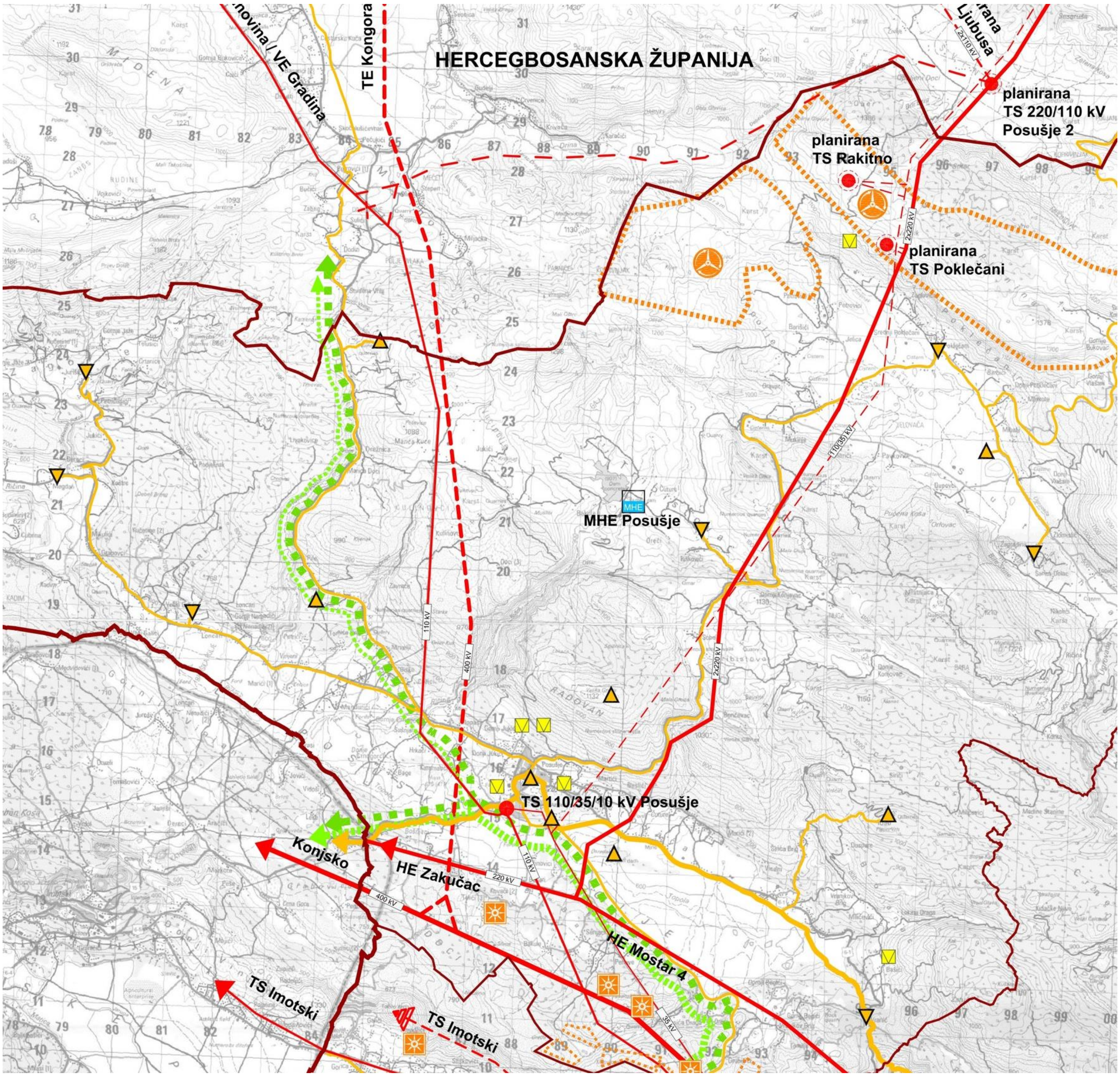


Figure 20: Spatial plan of Zapadnohercegovačka County (5. Energy System – draft)

To define the optimal location for substation 400/110 kV we used the following criteria:

- Spatial plans limitations [4]
- Altitude below 1.000 m above sea level,
- Wide flat area
- Minimum distance to the existing houses
- Possibility for OHL approach to the SS
- Existing road infrastructure nearby

---

[4] The area of Šuica can be threatened by flooding of the Šuica sinkhole river during snowmelt. The proposed location is far from the river Šuica and is located east of the old road and Roman bridge built in the 1st century, which has been used for pedestrian traffic. Therefore, the authors assume that it is not a flood area. More detailed analysis will certainly be conducted during the project design phase.

Using these criteria we preliminary propose the SS 400/110 kV Šuica location on the flat field about 1 km south of Šuica village. This is wide flat area with unrestricted approach from the South and East sides for OHL connection at 920 m above sea level (see next two figures).

Figure 21: Satellite image of proposed location for SS 400/110 kV Šuica

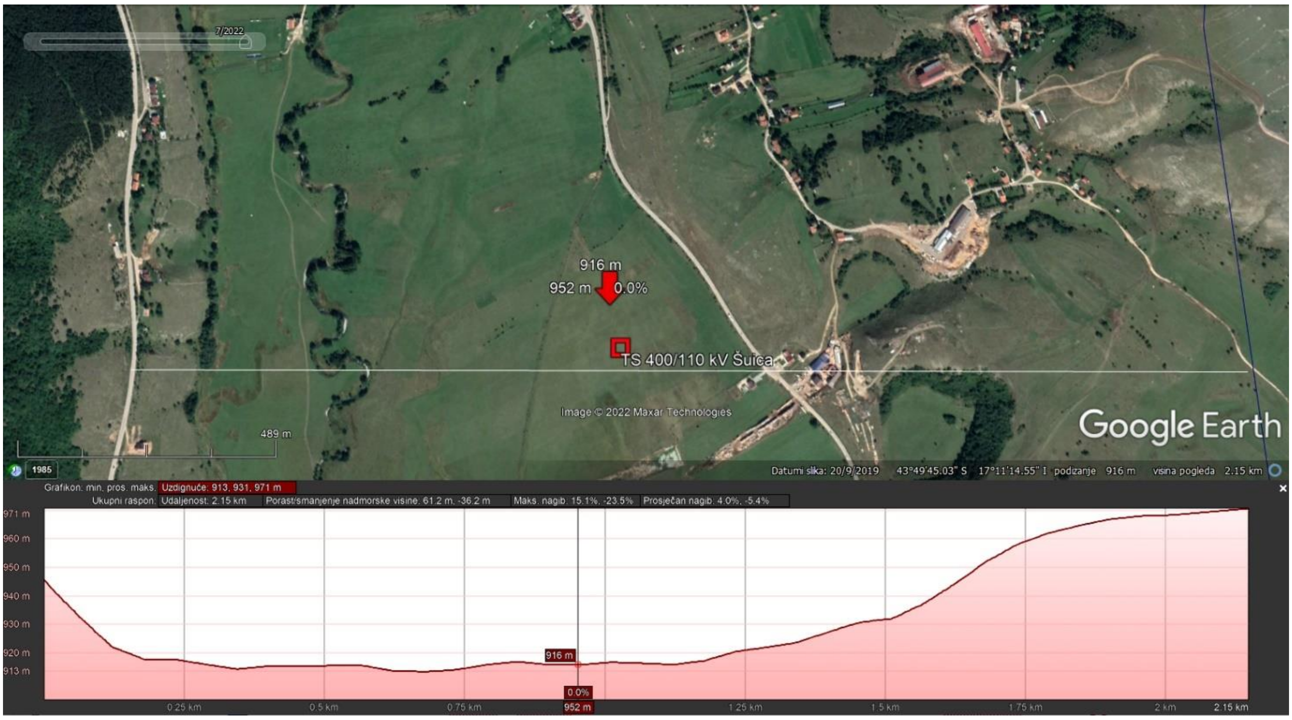


Figure 22: Ground profile of SS 400/110 kV Šuica location

Given this location for the future 400 kV network node Šuica, we now need to analyze possible new 400 kV lines to resolve critical power system operation regimes till 2030. We will further discuss this after the load flow analysis in the following subchapter.

7.2 Load flow results

In this subchapter we show the results of network analysis for 12 basic scenarios for 2025 and 2030 with the three levels of decarbonization (normal, moderate (MOD) and extreme (EXT)). The most important results with line current ratings are shown in the following table with Monita HVDC cable loaded with 500 MW (direction to Italy) and all elements available (n analysis). Table 28 below shows all 400 kV grid element loadings and shows that the only overloaded elements are on the 220 kV and 110 kV network in any of the scenarios.

Table 28: Transmission element loadings (%) in normal operation (all elements available) in analyzed scenarios in 2025 and 2030 with HVDC MONITA 500 MW

Scenario	**2025 MAX**	**2025 MAX**	**2025 MAX**	**2025 MIN**	**2025 MIN**	**2025 MIN**	**2030 MAX**	**2030MAX**	**2030 MAX**	**2030 MIN**	**2030 MIN**	**2030 MIN**
Decarbonisation level	**-**	**MOD**	**EXT**	**-**	**MOD**	**EXT**	**-**	**MOD**	**EXT**	**-**	**MOD**	**EXT**
OHL 400 kV Banja Luka - Stanari	13%	13%	13%	3%	3%	3%	14%	14%	13%	5%	5%	5%
OHL 400 kV Ernestinovo - Žerjavinec	23%	21%	19%	21%	20%	18%	22%	20%	19%	16%	15%	15%
OHL 400 kV HE Višegrad - Višegrad	15%	15%	15%	5%	5%	5%	15%	15%	15%	4%	4%	4%
OHL 400 kV Konjsko - Mostar 4	17%	17%	20%	28%	29%	33%						
OHL 400 kV Lastva - Trebinje	44%	44%	40%	44%	44%	39%	43%	43%	39%	40%	40%	40%
OHL 400 kV Melina - Tumbri	14%	13%	12%	17%	17%	15%	20%	19%	18%	21%	20%	20%
OHL 400 kV Mostar 4 - Gacko	10%	10%	18%	11%	11%	22%	9%	9%	18%	23%	22%	22%
OHL 400 kV Mostar 4 - Sarajevo 10	27%	28%	24%	25%	25%	21%	26%	27%	23%	20%	20%	20%
OHL 400 kV RHE Velebit - Konjsko	28%	26%	24%	26%	24%	21%	16%	15%	13%	11%	11%	11%
OHL 400 kV RHE Velebit - Melina	62%	60%	57%	65%	63%	60%	54%	53%	51%	56%	55%	55%
OHL 400 kV Sarajevo 10 - Tuzla 4	23%	23%	20%	24%	25%	21%	21%	21%	18%	19%	20%	20%
OHL 400 kV Sarajevo 20 - Sarajevo 10	6%	5%	5%	4%	4%	4%	6%	6%	6%	4%	4%	4%
OHL 400 kV TE Tuzla - Tuzla 4	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
OHL 400 kV Trebinje - Gacko	24%	24%	19%	29%	29%	22%	24%	23%	18%	23%	23%	23%
OHL 400 kV Tumbri - Žerjavinec	11%	10%	9%	9%	8%	7%	11%	11%	10%	10%	10%	10%
OHL 400 kV Tuzla 4 - Stanari	5%	6%	5%	7%	7%	7%	5%	5%	5%	10%	10%	10%
OHL 400 kV Tuzla 4 - Ugljevik	29%	15%	23%	26%	24%	20%	27%	24%	21%	21%	19%	19%
OHL 400 kV Tuzla 4 - Višegrad	10%	12%	12%	6%	7%	7%	11%	12%	12%	5%	5%	5%
OHL 400 kV Ugljevik - Ernestinovo	32%	29%	27%	32%	30%	27%	31%	29%	27%	28%	26%	26%
OHL 400 kV Ugljevik - S. Mitrovica	6%	5%	4%	8%	6%	5%	6%	5%	4%	8%	6%	6%
OHL 400 kV Višegrad - B. Bašta	7%	6%	6%	3%	3%	3%	7%	6%	6%	2%	2%	2%
TR1 400/220 kV B.Luka 6	35%	35%	35%	36%	36%	36%	34%	33%	33%	29%	29%	29%
TR2 400/220 kV B.Luka 6	58%	57%	57%	41%	41%	41%	60%	59%	59%	49%	49%	49%
TR1 400/220 kV Sarajevo 20	8%	8%	8%	7%	7%	7%	8%	9%	9%	7%	7%	7%
TR2 400/110 kV Sarajevo 20	26%	26%	26%	10%	11%	10%	29%	29%	29%	11%	12%	12%
TR1 400/220 kV Trebinje	67%	67%	72%	49%	49%	56%	67%	67%	73%	59%	59%	59%
TR1 400/110 kV Stanari	32%	33%	33%	12%	13%	12%	33%	34%	34%	15%	15%	15%
TR2 400/110 kV Stanari	32%	33%	33%	12%	13%	12%	33%	34%	34%	15%	15%	15%
TR1 400/110 kV Ugljevik	39%	43%	44%	13%	16%	17%	41%	46%	46%	14%	18%	18%
TR1 400/110 kV Višegrad	15%	16%	16%	9%	9%	8%	16%	17%	17%	8%	8%	8%
TR1 400/110 kV Sarajevo 10	30%	30%	30%	12%	13%	12%	32%	33%	32%	14%	14%	14%
TR1 400/220 kV Tuzla 4	25%	26%	26%	26%	17%	17%	25%	28%	27%	30%	21%	21%
TR1 400/220 kV Mostar 4	37%	36%	39%	15%	14%	18%	37%	36%	39%	21%	20%	20%
TR2 400/220 kV Mostar 4	37%	36%	39%	15%	14%	18%	37%	35%	39%	21%	20%	20%
OHL 400 kV Konjsko - Lika							42%	41%	39%	41%	40%	40%
OHL 400 kV Konjsko - Šuica							6%	4%	2%	11%	12%	12%
OHL 400 kV Lika - Melina							41%	40%	38%	40%	39%	39%
OHL 400 kV Šuica - Mostar 4							14%	16%	19%	31%	32%	32%
TR1 400/110 kV Šuica							42%	42%	43%	46%	45%	45%
TR2 400/110 kV Šuica							42%	42%	43%	46%	45%	45%
OHL 110 kV Kupres - Bugojno	108%	110%	109%	108%	109%	108%	68%	70%	69%	68%	70%	70%
OHL 110 kV Trebinje - H. Novi	111%	110%	110%	109%	109%	109%	108%	108%	108%	111%	111%	111%
OHL 110 kV Debelo Brdo - Kupres	110%	112%	111%	109%	110%	109%	70%	73%	71%	69%	70%	70%
OHL 110 kV Šuica - Debelo Brdo	110%	112%	111%	108%	109%	108%	36%	39%	38%	40%	42%	42%
OHL 110 kV B.Blato - Livno	27%	28%	28%	46%	47%	47%	64%	66%	68%	105%	107%	107%

There are four 110 kV OHLs with ratings above 100% in normal operation in 2025 (given in red). They are mostly located near SS 400/110 kV Šuica.

In general, the network loading in 2030 is better than in 2025. Despite commissioning of new power plants, with the new 400/110 kV substation Šuica, the network loading situation improves.

The only disadvantage of this topology is the overloading of OHL 110 kV B.Blato – Livno during the minimum system load regime, with large RES generation in Croatia. Namely, after the construction of the new SS 400/110 kV Šuica, and with large scale RES integration, the load flow from Croatia toward BiH (over SS B. Blato – Livno – Šuica) is significantly increased, which results in the overloading of OHL 110 kV B. Blato – Livno.

The following figures show the power flow results in the basic 2025 and 2030 scenarios.

While these figures can be challenging to interpret, these guidelines apply: Elements of the 400 kV grid are presented in red, 220 kV grid in green and 110 kV grid in black colors. We present the overloaded elements with a red rectangle and a figure (the current flow percentage relative to the element’s nominal current).

The following two figures present the complete 400 kV and 220 kV grid of BiH and Croatia. Due to paper size limitations, it is divided into two parts on two sheets.

The main purpose for the construction of SS 400/110 kV Šuica is to accept and evacuate electricity generated in RES that are connected to the 110 kV voltage level. Figures 23 – 26 show the 2025 timeframe, with overloadings of the 110 kV grid near Šuica.

After construction of the 400/110 kV transformation in 2030, more than 250 MW goes from the 110 kV upstream to the 400 kV level, which unloads the 110 kV grid (except the OHL 110 kV B. Blato – Livno due to load flows caused by RES in Croatia).

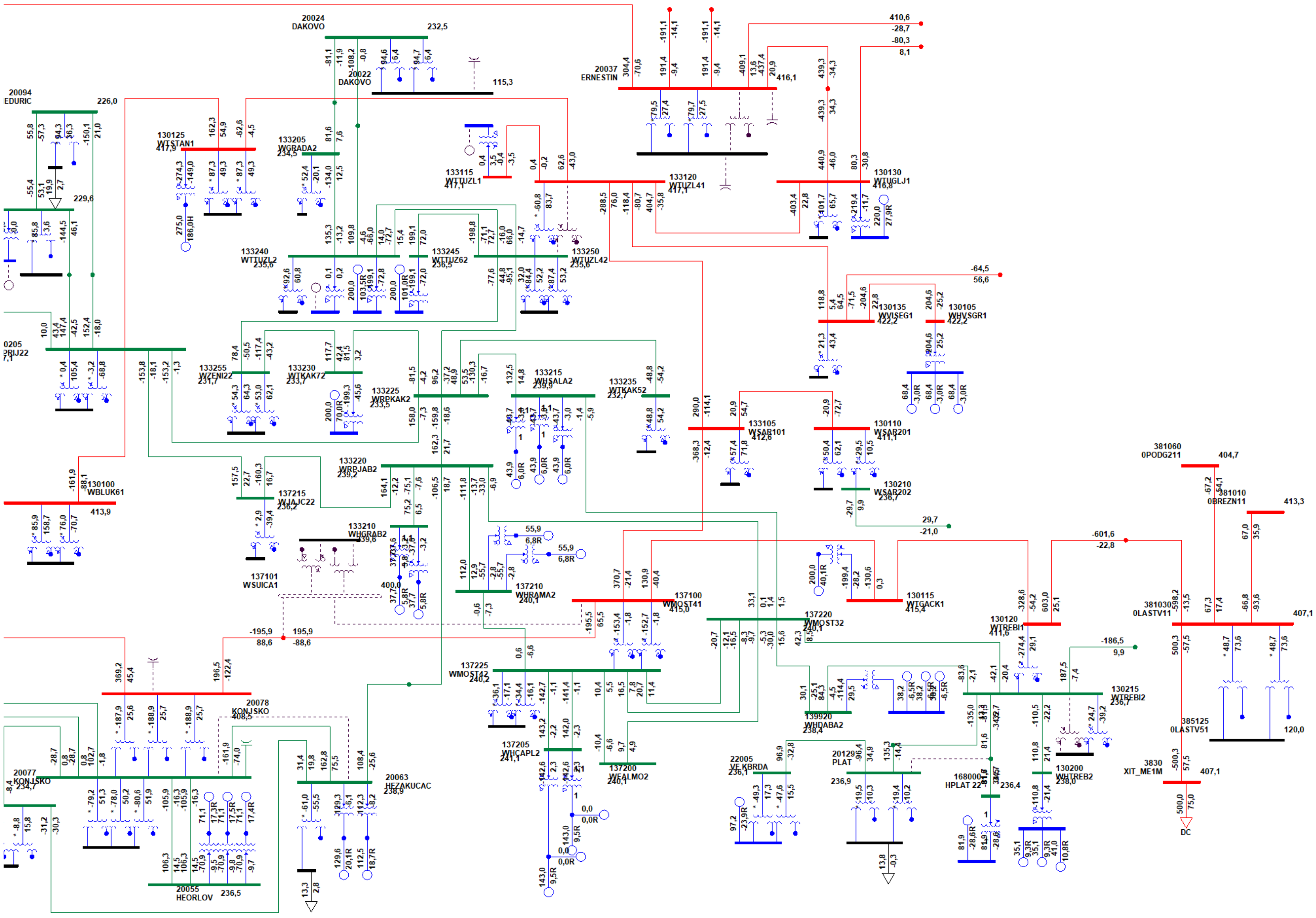


Figure 23: BiH 400 kV and 220 kV network topology and loadings (MAX 2025) – eastern area

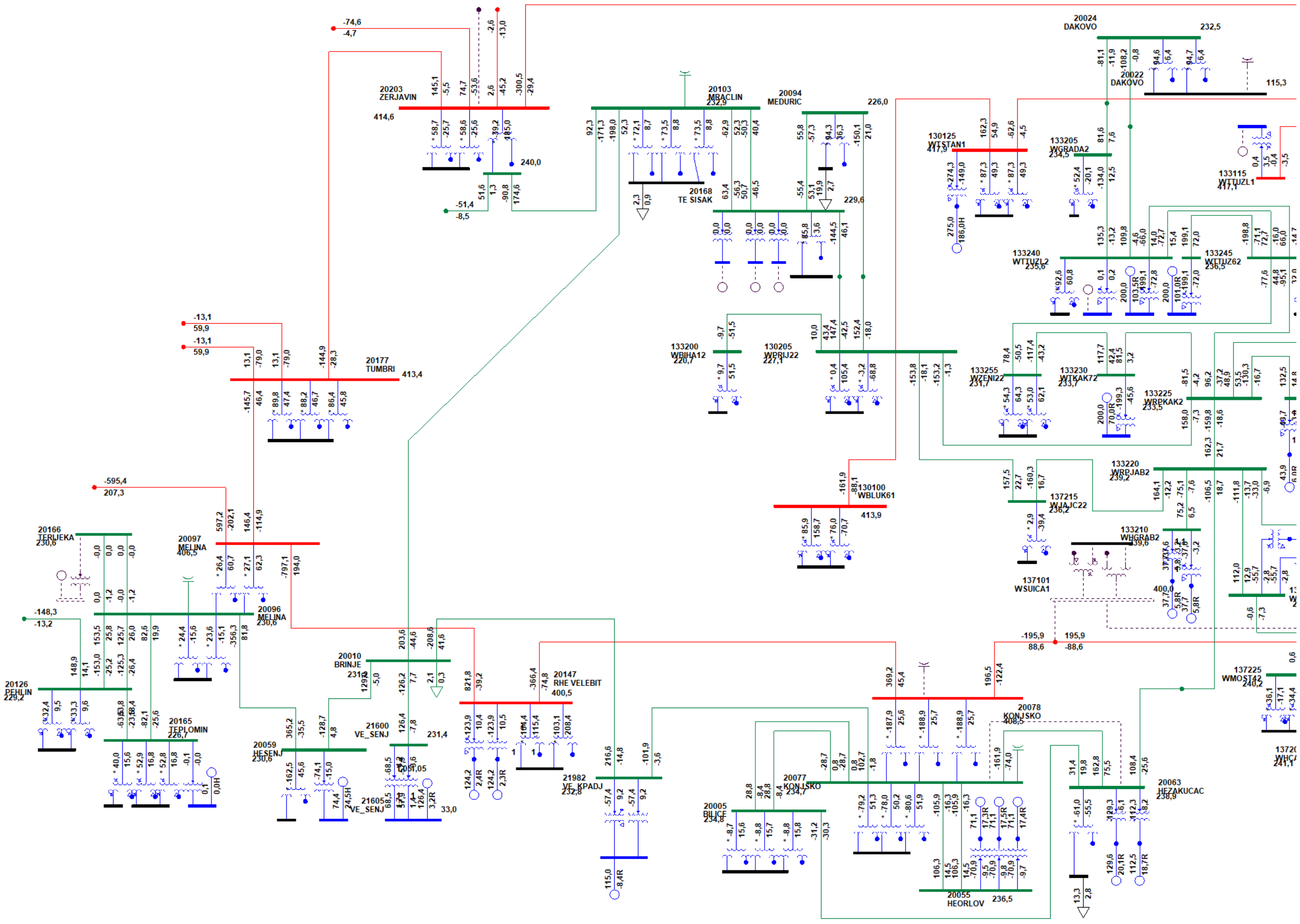


Figure 24: BiH 400 kV and 220 kV network topology and loadings (MAX 2025) – western area

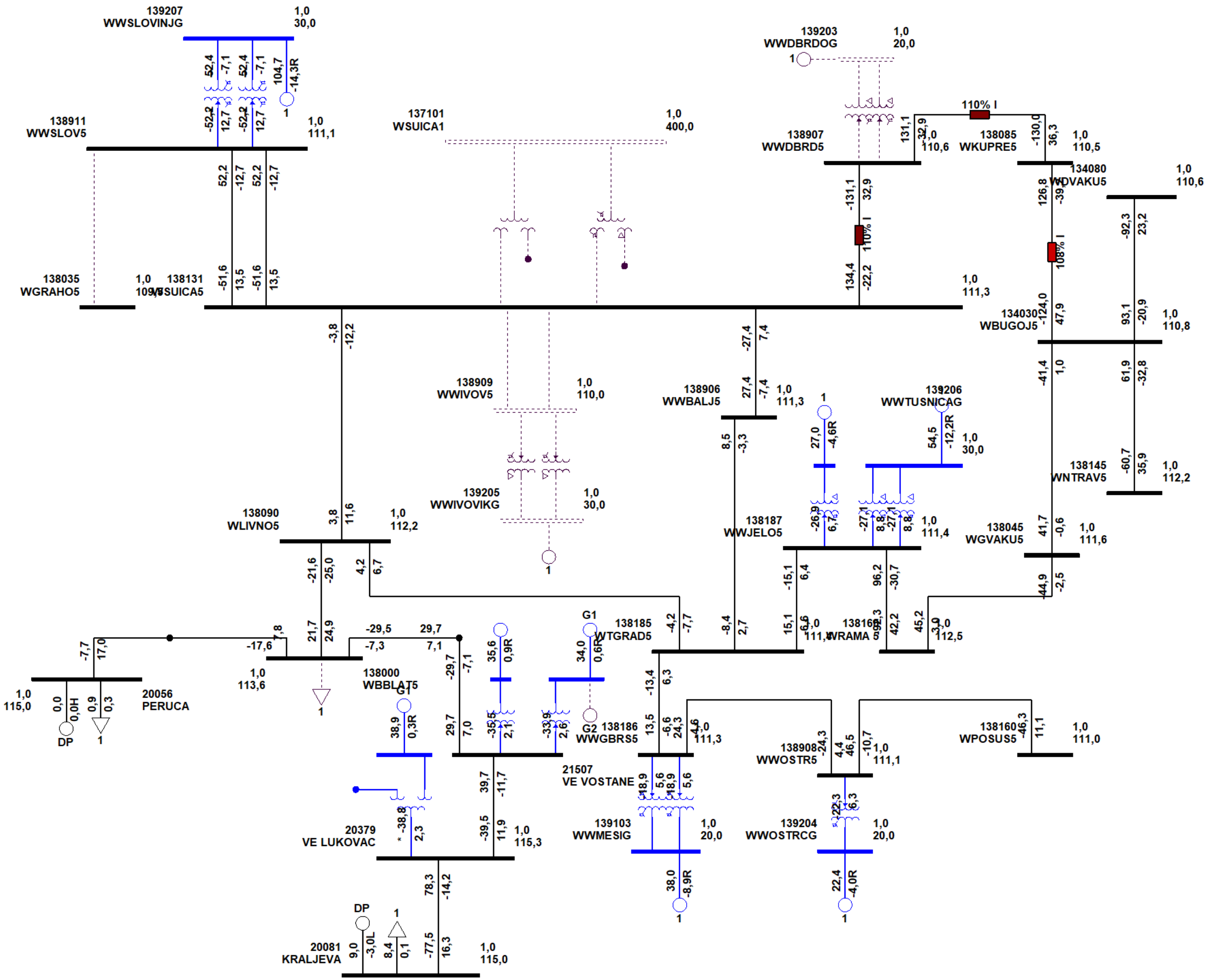


Figure 25: BiH 400 kV and 220 kV network topology and loadings near SS Šuica (MAX 2025)

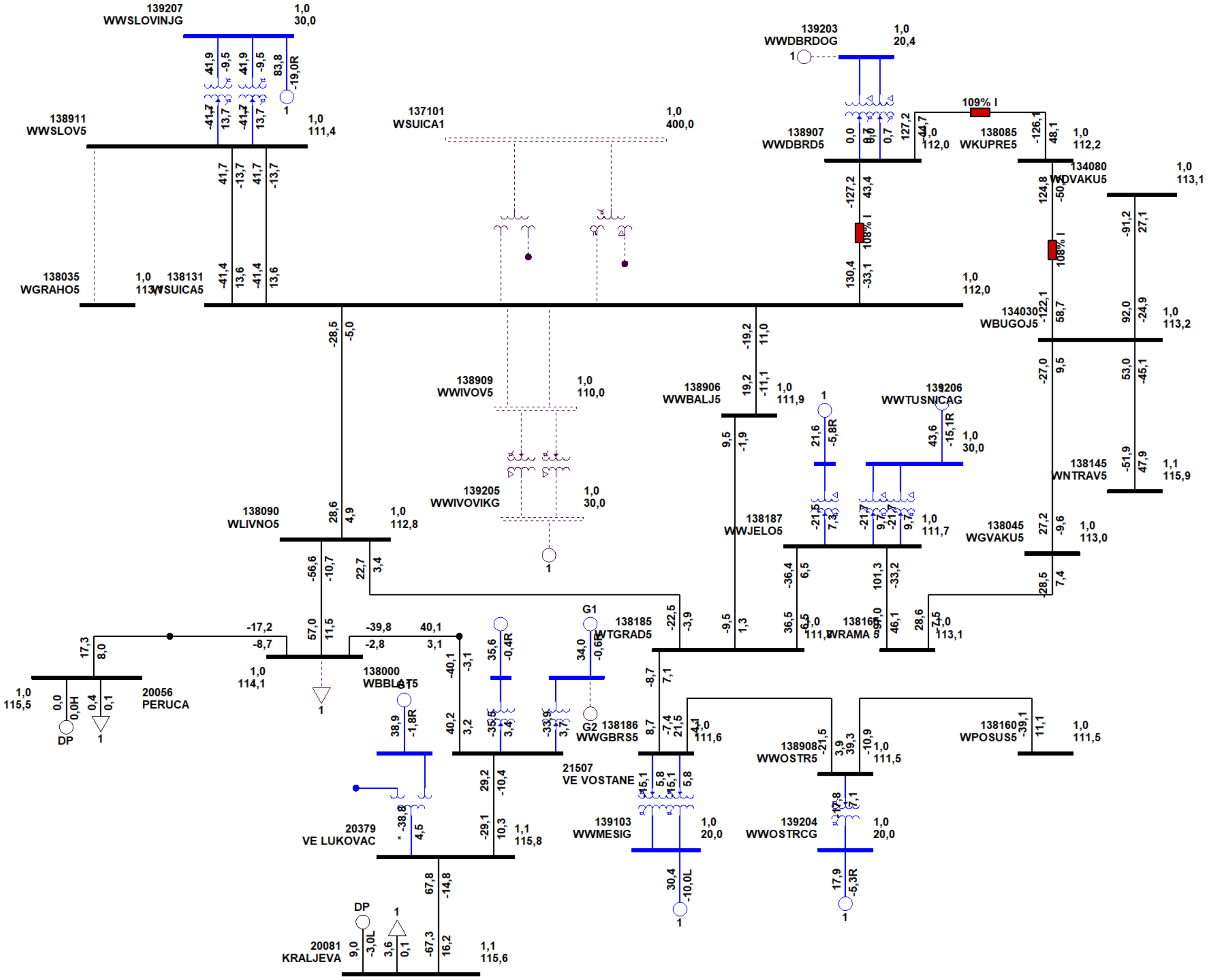


Figure 26: BiH 400 kV and 220 kV network topology and loadings near SS Šuica (MIN 2025)

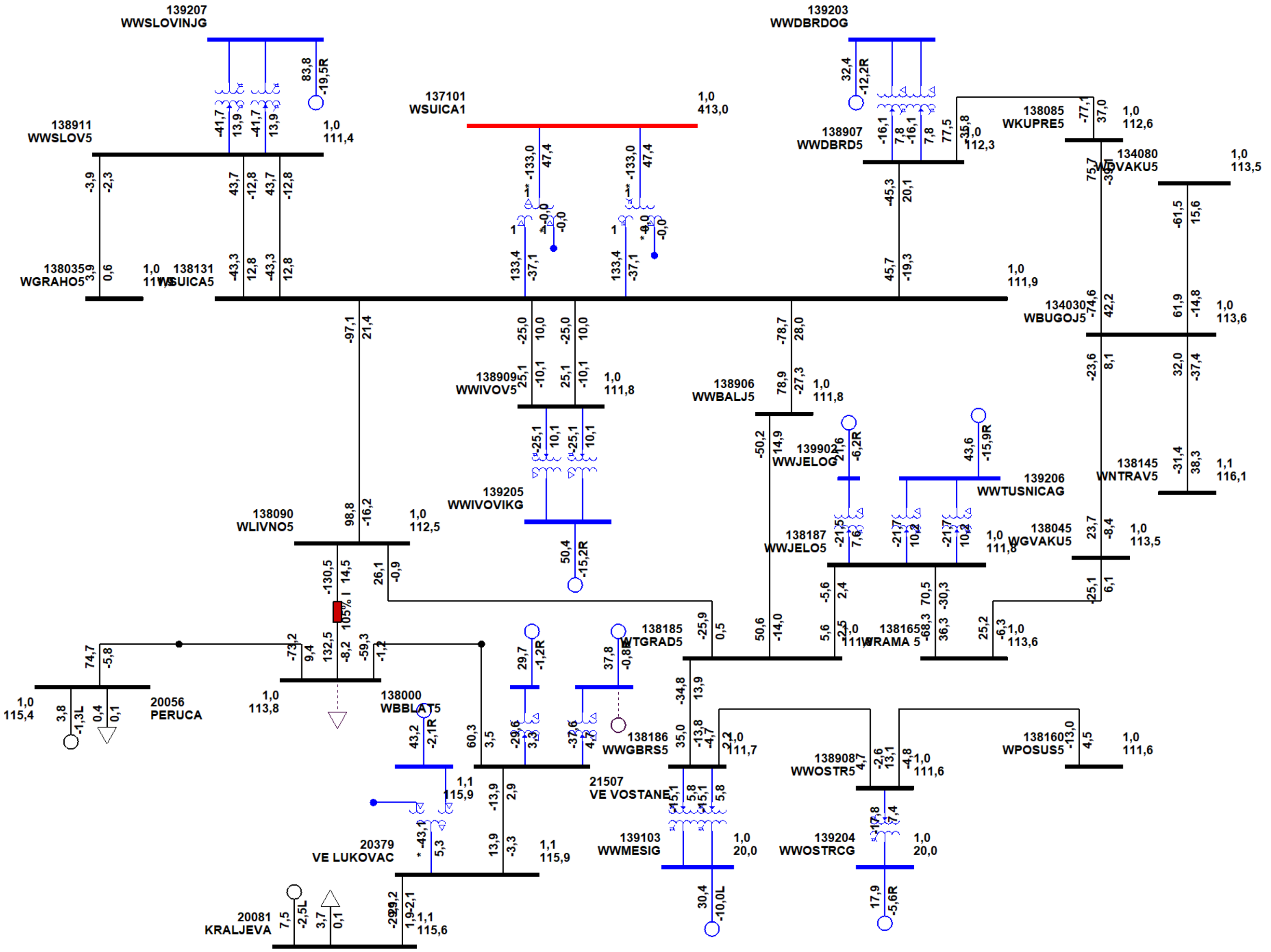


Figure 27: BiH 400 kV and 220 kV network topology and loadings near SS Šuica (MIN 2030)

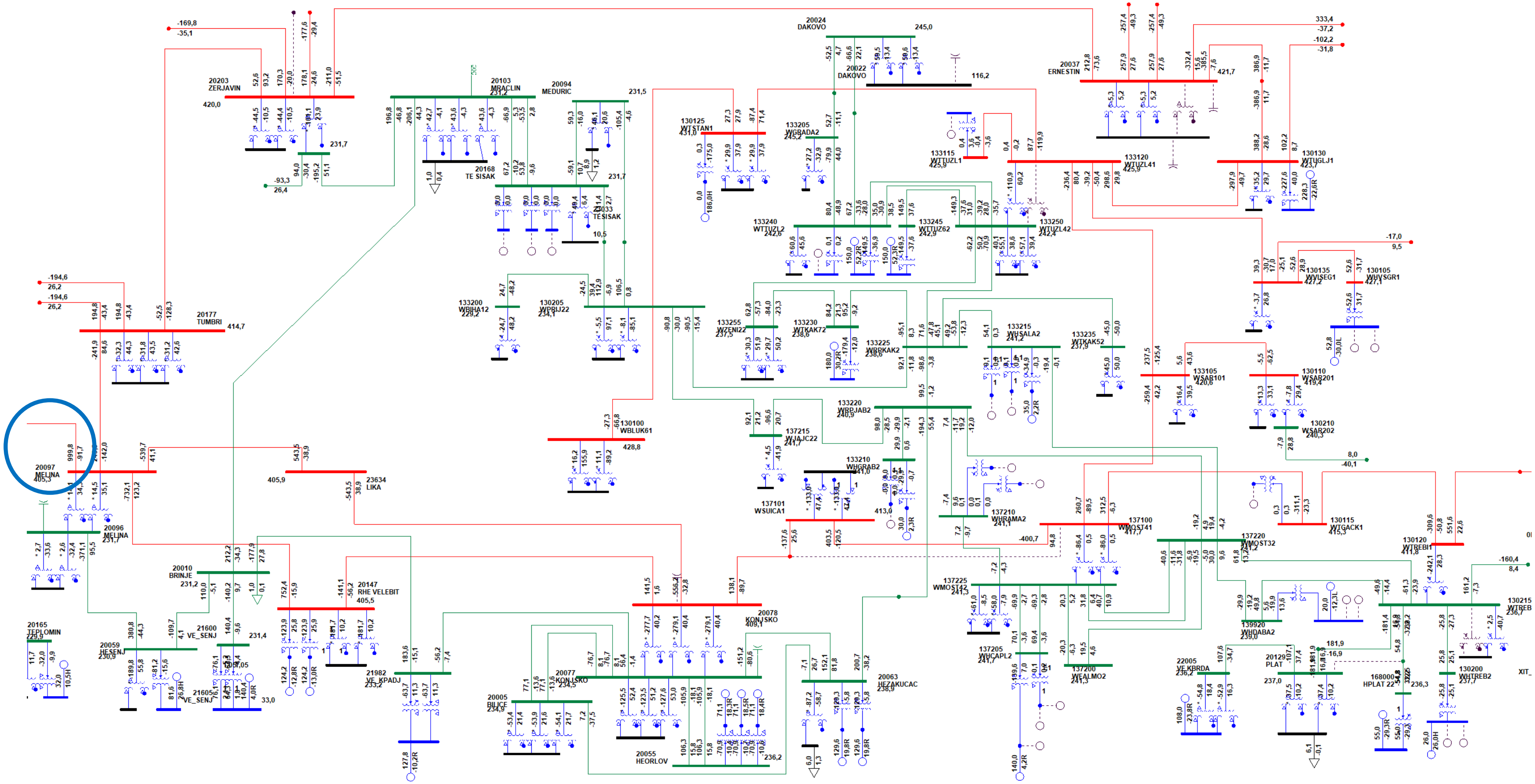


Figure 28: Topology and loadings 400 kV and 220 kV grid (MIN 2030)

As shown encircled on the previous figure, the highest loaded 400 kV element is the OHL Melina (HR) – Divača (SI) with a loading of about 1000 MW. In the case of the MONITA HVDC 1000 MW (direction to Italy), the OHL 400 kV Melina – Divača loading drops to 865 MW. Italy is mostly an electricity importer. Construction of the HVDC Monita phase II could result in a 400 kV grid loadflow reduction in the direction Croatia - Slovenia – Italy, with higher loading of the 400 kV lines in the direction BiH – Montenegro – Italy.

A similar situation occurs in the 220 kV grid with interconnector OHL 220 kV Pehlin (HR) – Divača (SI), as its loading drops from 299 MW to 240 MW when MONITA’s capacity rises. This is the expected consequence of regional export to central Europe through two streams: MONITA and the Slovenian network. If the MONITA capacity is reduced, then a higher loading on the Slovenian network is an inevitable consequence.

On the other hand, when we increase MONITA’s capacity, power flow increases from BiH and Serbia to Montenegro and MONITA, as expected. In this case, the OHL 110 kV OHL Trebinje – Herceg Novi becomes quite overloaded in normal operation in scenario MIN 2030, as it grows from 108% (MONITA 500 MW) to 130% (MONITA 1000 MW) of the rated capacity. Before upgrade of the MONITA cable it is necessary to solve problems in the surrounding grid and upgrade the overloaded lines.

7.3 List of contingencies

We conducted N-1 criteria analyses for all the scenarios, and the following table shows that in 2025, there are four grid elements overloaded in the base case (n availability), and an additional five grid elements overloaded under n-1 conditions. The highest overloading occurs on OHL 110 kV Trebinje – Herceg Novi (185%) which occurs in the case of outage of interconnector OHL 400 kV Lastva (MNE) – Trebinje (BiH).

Table 29: Transmission element overloading (%) during N-1 analysis in basic scenarios 2025

Element / Conductor cross section	**Scenario 2025**	**Loading**		**Worst outage**
		A	**%**	
OHL 110 kV Kupres - Bugojno	MAX	910	142%	OHL 110 kV Jelovača - Rama
Al/Fe 240/40 mm^2	MIN	922	144%	OHL 110 kV Jelovača - Rama
OHL 110 kV Trebinje - Herceg Novi	MAX	871	185%	OHL 400 kV Lastva - Trebinje
Al/Fe 150/25 mm^2	MIN	858	182%	OHL 400 kV Lastva - Trebinje
OHL 110 kV Debelo Brdo - Kupres	MAX	922	144%	OHL 110 kV Jelovača - Rama
Al/Fe 240/40 mm^2	MIN	924	144%	OHL 110 kV Jelovača - Rama
OHL 110 kV Šuica - Debelo Brdo	MAX	923	144%	OHL 110 kV Jelovača - Rama
Al/Fe 240/40 mm^2	MIN	924	144%	OHL 110 kV Jelovača - Rama
OHL 220 kV Trebinja - HE Perućica	MAX	873	110%	OHL 400 kV Lastva - Trebinje
Al/Fe 360/57 mm^2	MIN	809	102%	OHL 400 kV Lastva - Trebinje
OHL 110 kV Komolac - Trebinje 2	MAX	818	128%	OHL 220 kV Trebinje - Plat
Al/Fe 240/40 mm^2 & 150/25 mm^2	MIN	1061	165%	OHL 220 kV Trebinje - Plat
OHL 110 kV Jelovača - Rama	MAX	818	128%	OHL 110 kV Šuica - Debelo Brdo
Al/Fe 240/40 mm^2	MIN	835	130%	OHL 110 kV Debelo Brdo - Kupres

OHL 110 kV Bugojno - Donji Vakuf	MAX	654	102%	OHL 110 kV Bugojno - N. Travnik
Al/Fe 240/40 mm2	MIN			
OHL 110 kV Donji Vakuf - Jajce 2	MAX	640	100%	OHL 110 kV Bugojno - N. Travnik
Al/Fe 240/40 mm2	MIN			

In 2030, along with the construction of SS 400/110 kV Šuica, many of these overloadings in the 110 kV grid disappear, as shown in the following table, for different scenarios. Higher overloading of new grid elements in 2030 is caused by the topology changes, outage of the OHL 400 kV Konjsko – Šuica and new RES in the 2030 scenario.

Table 30: Transmission element overloading (%) in N-1 conditions in 2025 and 2030 in the referent, moderate and extreme decarbonization scenarios

Scenario	**2025 MAX**	**2025 MAX**	**2025 MAX**	**2025 MIN**	**2025 MIN**	**2025 MIN**	**2030 MAX**	**2030 MAX**	**2030 MAX**	**2030 MIN**	**2030 MIN**	**2030 MIN**
Decarbonisation level	**-**	**MOD**	**EXT**	**-**	**MOD**	**EXT**	**-**	**MOD**	**EXT**	**-**	**MOD**	**EXT**
OHL 110 kV Buško Blato - Livno Al/Fe 240/40 mm2										125%	128%	128%
OHL 110 kV Trebinje - Herceg Novi (ME) Al/Fe 150/25 mm2	185%	184%	178%	183%	182%	174%	181%	180%	174%	179%	178%	178%
OHL 110 kV Livno - Šuica Al/Fe 240/40 mm2										109%	109%	109%
OHL 220 kV Trebinje - HE Perućica (ME) Al/Fe 360/57 mm2	111%	109%	102%	102%	102%		108%	107%	100%			
OHL 110 kV Komolac (HR) - Trebinje 2 Al/Fe 240/40 mm2 (BiH) & 150/25 (HR)	128%	104%	129%	166%	166%	168%	110%	110%	112%	164%	164%	164%
TR1 400/220 kV Trebinje 400 MVA	105%	104%	102%				103%	103%	100%			
OHL 110 kV Jelovača - Rama Al/Fe 240/40 mm2	127%	128%	128%	130%	131%	131%						
OHL 110 kV Bugojno - D. Vakuf Al/Fe 240/40 mm2	102%	103%	101%									
OHL 110 kV D. Vakuf - Jajce 2 Al/Fe 240/40 mm2	100%	101%										
OHL 110 kV Kupres - Bugojno Al/Fe 240/40 mm2	142%	144%	143%	144%	145%	144%				110%	113%	113%
OHL 110 kV Debelo Brdo - Kupres Al/Fe 240/40 mm2	144%	146%	145%	144%	145%	145%				111%	114%	114%
OHL 110 kV Šuica - Debelo Brdo Al/Fe 240/40 mm2	144%	146%	145%	144%	145%	145%						
OHL 110 kV Baljci - Šuica Al/Fe 240/40 mm2							100%	100%	100%	102%	102%	101%

This table shows that different decarbonization levels in BiH will have a minor influence on the grid overloading, meaning that the transmission network is robust enough for the decarbonization scenarios we analyzed here. Therefore, we conducted further grid reinforcements analyses just for the basic scenarios for 2030 (min and max system load).

7.4 Grid reinforcement proposals

In the previous Chapter we identified all critical elements in the BiH transmission grid for the 2025 and 2030 scenarios. However, by 2025 it is impossible to construct new 400 kV grid elements, especially if there has been no prior preparation or completed project designs (which is the case in BiH), so we propose no reinforcements in the 400 kV grid by then. All bottlenecks in this timeframe need to be resolved with reinforcements in 110 kV network.

We thus focused our 400 kV grid reinforcement analysis on 2030. We tested the 2025 improvements in the 110 kV suitable in 2030 as well, so our network reinforcement solutions will fit both the 2025 and 2030 timeframe.

Our analyses have shown that in normal operation (n available elements) that the influence of different decarbonization scenarios on the 400 kV element loadings is marginal. Therefore, new 400 kV (and other voltage level) substations and line construction will be justified with the n-1 criterion and the need to connect all new network user candidates and transfer electricity from this area to the other areas without constructing several new lines on the lower voltage levels.

Clearly, due to the large size of expected RES, the 110 kV voltage reinforcements cannot fully alleviate the overloading issues. In other words, 400 kV network reinforcement is needed.

Therefore, we prepared this analysis in three main steps, as follows.

The first step is to propose all feasible 400 kV network reinforcements with respect to technical (n-1), spatial and economic criteria. As our analysis in Chapter 7.2 didn't show any problems in the Bihać region, we proposed the following potential 400 kV network reinforcements in BiH that is concentrated around two strong 400 kV network nodes (Banja Luka and Mostar/Šuica):

A.	OHL 400 kV Banja Luka – Lika	(~123 km)
B.	OHL 400 kV Banja Luka – Tumbri	(~145 km)
C.	OHL 400 kV Banja Luka – Žerjavinec	(~150 km)
D.	OHL 400 kV Banja Luka – Šuica	(~125 km)
E.	OHL 400 kV Konjsko – Mostar	(~113 km)

We use the letters shown above (A through E) to refer to these options below.

All these potential network reinforcements are of comparable lengths (113 – 150 km), but just one option is entirely internal to BiH (Banja Luka – Šuica), while the other four options are new interconnections with Croatia. The next step was to test, one by one, these proposed reinforcements, and check its impact on network loadings and the reduction of contingencies. We also compared each alternative with the base case. In this way we developed a clear ranking of five proposed network reinforcement scenarios in 2030, as given in the following table and figure for the MONITA 500 MW option, in the direction of Italy.

Table 31: Number of contingencies in 2030 Base case MAX & MIN with grid reinforcements (MONITA 500 MW)

	Base Case	Grid reinforcement scenario				
		A	B	C	D	E
Number of contingencies	11	12	12	12	10	10

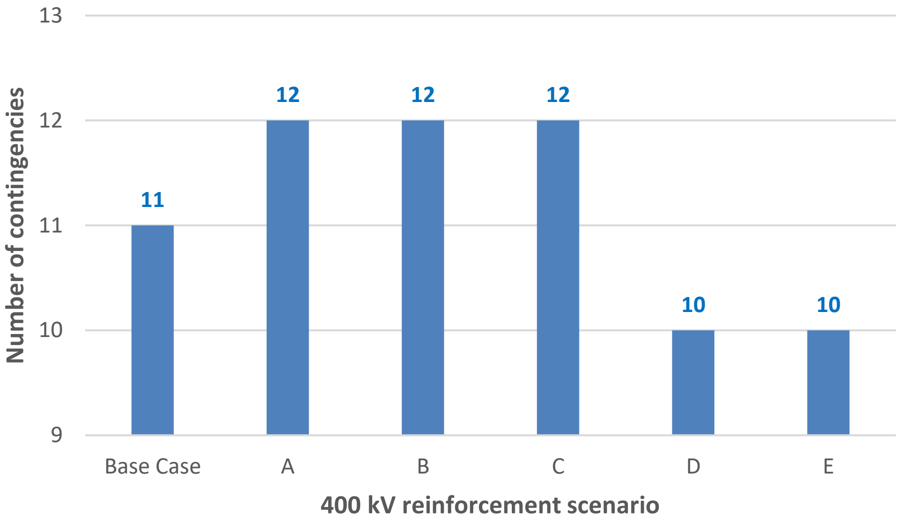


Figure 29: Number of contingencies in 2030 Base case MAX & MIN with grid reinforcements

Based on this comparison, we conclude that reinforcement scenarios D (OHL 400 kV Banja Luka – Šuica) and E (OHL 400 kV Konjsko – Mostar) have the best rankings for further analysis.

The second step is to further test all combinations of the two above-mentioned 400 kV grid reinforcements with each of the other 400 kV reinforcements (an additional 10 scenarios: five 400 kV reinforcements candidates (A, B, C, D, E) combined in the groups of two (AB, AC, AD…)) to determine if one of them provides the best option for BiH. To do so, we evaluated a combination of the initial 400 kV reinforcements (i.e., "AB scenario" assumes construction of reinforcement A (OHL 400 kV Banja – Luka – Lika) AND reinforcement B (OHL 400 kV Banja Luka – Tumbri)).

Table 32: Number of contingencies in 2030 Base case MAX & MIN with two 400 kV grid reinforcements

	Base Case	Grid reinforcement scenario														
		A	B	C	D	E	AB	AC	AD	AE	BC	BD	BE	CD	CE	DE
Number of contingencies	11	12	12	12	10	10	12	12	10	10	13	9	10	9	10	10

As shown in the Table above, even with two new 400 kV lines we are not able to solve all contingencies in the grid, as they mostly occur in the 110 kV grid.

Double 400 kV reinforcements resulted with some minor improvement of the grid loadings and reduction of contingencies. But, the network should be released of all congestions, not just some of them. Therefore, construction of two new 400 kV lines is not justified.

For the remaining problems in the 110 kV grid, we find that it would be less expensive to resolve them by strengthening the 110 kV grid rather than further strengthening at 400 kV voltage level or constructing an additional 400/110 kV substation.

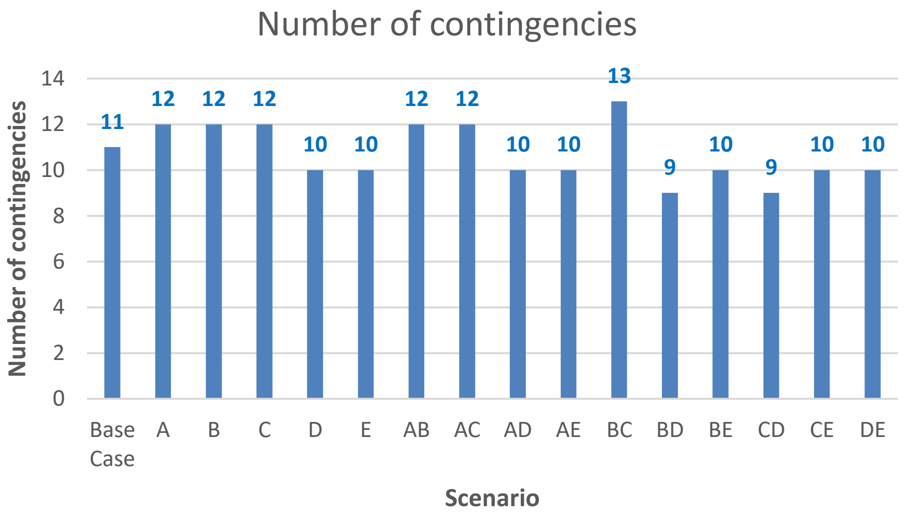


Figure 30: Number of contingencies in 2030 Base case MAX & MIN with two 400 kV grid reinforcements

For illustration, the following two tables show the results of n-1 analyses for 2030 with both MONITA capacities of 1000 MW and 500 MW. We marked the table columns with network reinforcement designation A – E as given above. Clearly, reviewing the bottom lines in each table, the higher HVDC MONITA capacity will lead to higher loadings in the network, especially close to the Montenegrin system, as well as more contingencies.

The main conclusion drawn here is that two proposed 400 kV grid reinforcements in combination cannot resolve all problems in the 220 kV and 110 kV BiH grid. So, additional (multiple) strengthenings of the 400 kV network is not justified, and we need to check a combination of reinforcements in both the 400 kV and 110 kV network.

Table 33: N-1 security analyses results (network element current loadings) in the basic 400 kV reinforcement scenarios in 2030 (MONITA 1000 MW)

Element	Scenario	Base	Grid reinforcement														
		Case	A	B	C	D	E	AB	AC	AD	AE	BC	BD	BE	CD	CE	DE
OHL 110 kV Buško Blato - Livno	MAX												105%		103%		
Al/Fe 240/40 mm2	MIN	143%	138%	147%	147%	154%	111%	140%	140%	152%	112%	148%	164%	113%	164%	113%	116%
OHL 110 kV Trebinje - Herceg Novi	MAX	228%	228%	228%	227%	222%	228%	227%	227%	222%	229%	227%	219%	228%	218%	228%	222%
Al/Fe 150/25 mm2	MIN	225%	225%	225%	224%	219%	227%	224%	224%	219%	227%	225%	217%	227%	216%	227%	221%
OHL 110 kV Livno - Šuica	MAX												103%		102%		
Al/Fe 240/40 mm2	MIN	111%	111%	112%	112%	122%	106%	112%	111%	124%	106%	113%	128%	106%	128%	106%	116%
OHL 220 kV Trebinje - HE Perućica	MAX	131%	132%	131%	131%	127%	132%	131%	130%	126%	132%	131%	124%	132%	123%	132%	127%
Al/Fe 360/57 mm2	MIN	121%	121%	121%	120%	116%	124%	120%	120%	116%	124%	120%	114%	124%	113%	123%	119%
OHL 110 kV Komolac - Trebinje 2	MAX	119%	119%	119%	119%	118%	117%	119%	119%	118%	118%	120%	118%	118%	118%	118%	116%
Al/Fe 240/40 mm2 (BiH) & 150/25 (HR)	MIN	173%	173%	174%	173%	172%	169%	173%	172%	172%	169%	174%	172%	170%	172%	170%	168%
TR1 400/220 kV Trebinje	MAX	135%	136%	136%	135%	133%	136%	135%	135%	133%	136%	135%	131%	136%	130%	136%	133%
400 MVA	MIN	127%	127%	127%	127%	124%	128%	126%	126%	124%	128%	127%	123%	128%	119%	128%	125%
OHL 110 kV Grude - Široki Brijeg 2	MAX																
Al/Fe 240/40 mm2	MIN	108%	104%	109%	109%				104%			110%					
OHL 110 kV Kupres - Bugojno	MAX			105%	105%			101%				107%					
Al/Fe 240/40 mm2	MIN	121%	115%	125%	125%				116%			125%					
OHL 110 kV Debelo Brdo - Kupres	MAX	101%	100%	107%	106%			103%	102%			109%					
Al/Fe 240/40 mm2	MIN	122%	115%	125%	125%			117%	117%			127%					
OHL 110 kV Široki Brijeg - Mostar 4 (2)	MAX																
Al/Fe 240/40 mm2	MIN	103%	102%	105%	104%							105%					
OHL 110 kV Široki Brijeg 2 - Š. Brijeg	MAX																
Al/Fe 240/40 mm2	MIN	106%	102%	107%	107%			102%	102%			105%					
OHL 220 kV HE Zakučac - RP Jablanica	MAX																
Al/Fe 360/57 mm2	MIN	100%		102%	102%							103%					
OHL 110 kV Baljci - Šuica	MAX	100%	101%	101%	101%	106%	100%	101%	101%	109%	100%	101%	112%		112%	101%	106%
Al/Fe 240/40 mm2	MIN	102%	102%	101%	101%	115%	100%	102%	102%	116%	100%	101%	119%	101%	119%		112%
OHL 110 kV Knin - B. Grahovo	MAX																
Al/Fe 240/40; 150/25 mm2	MIN												104%		104%		
No. of overloadings		19	18	20	20	12	12	16	17	12	12	20	15	11	15	11	12
No. of significant overloadings (>120%)		10	8	10	10	8	7	8	8	7	7	11	9	7	7	7	6

Table 34: N-1 security analyses results (network element current loadings (%)) in the basic 400 kV reinforcement scenarios in 2030 (MONITA 500 MW)

Element	Scenario	Base	Grid reinforcement														
		Case	A	B	C	D	E	AB	AC	AD	AE	BC	BD	BE	CD	CE	DE
OHL 110 kV Buško Blato - Livno	MAX																
Al/Fe 240/40 mm2	MIN	125%	125%	132%	131%	137%	108%	127%	126%	142%	108%	133%	153%	110%	152%	110%	113%
OHL 110 kV Trebinja - Herceg Novi	MAX	182%	182%	181%	180%	176%	181%	180%	180%	175%	182%	180%	172%	181%	171%	180%	176%
Al/Fe 150/25 mm2	MIN	179%	179%	178%	178%	173%	180%	178%	177%	172%	180%	178%	170%	180%	169%	179%	174%
OHL 110 kV Livno - Šuica	MAX												102%		101%		
Al/Fe 240/40 mm2	MIN		110%	110%	110%	120%	105%	110%	109%	124%	105%	110%	127%	105%	127%	105%	116%
OHL 220 kV Trebinje - HE Perućica	MAX	108%	108%	107%	107%	103%	108%	107%	107%	102%	108%	107%	109%	107%	108%	107%	103%
Al/Fe 360/57 mm2	MIN																
OHL 110 kV Komolac - Trebinje 2	MAX	110%	110%	111%	110%	108%	109%	110%	110%	109%	109%	110%		110%		110%	108%
Al/Fe 240/40 mm2 (BiH) & 150/25 (HR)	MIN	164%	164%	165%	164%	162%	161%	164%	164%	163%	161%	165%	162%	161%	162%	161%	160%
TR1 400/220 kV Trebinje	MAX	104%	104%	101%	103%	101%	104%	103%	103%	100%	104%	103%		103%		103%	101%
400 MVA	MIN																
OHL 110 kV Kupres - Bugojno	MAX																
Al/Fe 240/40 mm2	MIN	110%	108%	116%	116%			110%	110%			118%					
OHL 110 kV Debelo Brdo - Kupres	MAX											101%					
Al/Fe 240/40 mm2	MIN	111%	108%	117%	116%			111%	110%			119%					
OHL 110 kV Baljci - Šuica	MAX	101%	101%	101%	101%	106%	100%	101%	101%	110%	101%	101%	113%	101%	101%	101%	106%
Al/Fe 240/40 mm2	MIN	109%	102%	102%	102%	115%	101%	102%	102%	117%	101%	101%	121%	100%	121%	100%	113%
No. of overloadings		11	12	12	12	10	10	12	12	10	10	13	9	10	9	10	10
No. of significant overloadings (>120%)		4	4	4	4	5	3	4	4	5	3	4	6	3	6	3	4

The third step was to identify critical elements within the 220 kV and 110 kV grids, with only one reinforcement of the 400 kV grid. In order to select the best single 400 kV network reinforcements we checked the contingency analysis results and we found that the OHL 400 kV Banja Luka – Šuica and OHL 400 kV Konjsko – Mostar have the smallest number of grid overloadings in both the MONITA scenarios (500 MW and 1000 MW).

Therefore, these two 400 kV reinforcements are the best options compared to other three proposed 400 kV reinforcements. In both of these 400 kV reinforcement options we need additional 110 kV reinforcements to alleviate overloading on the 110 kV system.

The simplest solution is to upgrade the line capacity of the overloaded lines using high temperature low sag (HTLS) conductors with high current ratings. In this case, line towers can remain the same (to be checked), which is a much easier and cheaper solution than constructing new lines. Our analysis showed that these five proposed 110 kV network reinforcements would eliminate all of the 110 kV network overloadings:

a)	OHL 110 kV Komolac - Trebinje	(~18 km)	ACCC Lisbon 230 MVA
b)	OHL 110 kV Buško Blato - Livno	(~13 km)	ACCC Lisbon 230 MVA
c)	OHL 110 kV Livno - Šuica	(~18 km)	ACCC Lisbon 230 MVA
d)	OHL 110 kV Trebinje – Herceg Novi	(~31 km)	ACCC Rovinj 165 MVA
e)	OHL 110 kV Šuica – Baljci	(~4 km)	ACCC Lisbon 230 MVA

All these reinforcements would replace the conductors on the existing lines. New conductors have significantly higher capacities (156 MVA or 230 MVA) than existing ones (90 – 120 MVA).

With these reinforcements, we can significantly reduce the number and level of contingencies in all our scenarios, as shown in the following table. Coming from initial 11 contingencies in the base case and 9 – 13 in the analyzed initial reinforcement scenarios, here with combined 400 kV and 110 kV network reinforcements in the scenarios D+110 and E+110 we have just 2 minor overloadings in the network with just 102-107% of nominal current.

Table 35: N-1 calculations with 400 kV and 110 kV reinforcements 2030 (MONITA 500 MW) and network element current loadings (%)

Element	Scenario	Grid reinforcement		Worst outage
		D+110	E+110	
OHL 220 kV Trebinja - HE Perućica	MAX	103%	107%	OHL 400 kV Lastva - Trebinje
Al/Fe 360/57 mm2	MIN			
TR1 400/220 kV Trebinje	MAX	101%	103%	OHL 400 kV Trebinje - Gacko
400 MVA	MIN			
No. of overloadings		2	2	
No. of significant overloadings (>120%)		0	0	

As expected, if we have these 400 kV and 110 kV network reinforcements and we lose direct connection to the BiH network to HVDC MONITA link (outage of OHL 400 kV Trebinje (BiH) - Lastva (MNE) circled in the figure below), BiH network loadings fall, and are far below limits, as shown on the figure below. The only one overloaded line is 220 kV Trebinje (BiH) – Perućica (MNE) (105% loading of the nominal current from BiH side, and 107% from the MNE side).

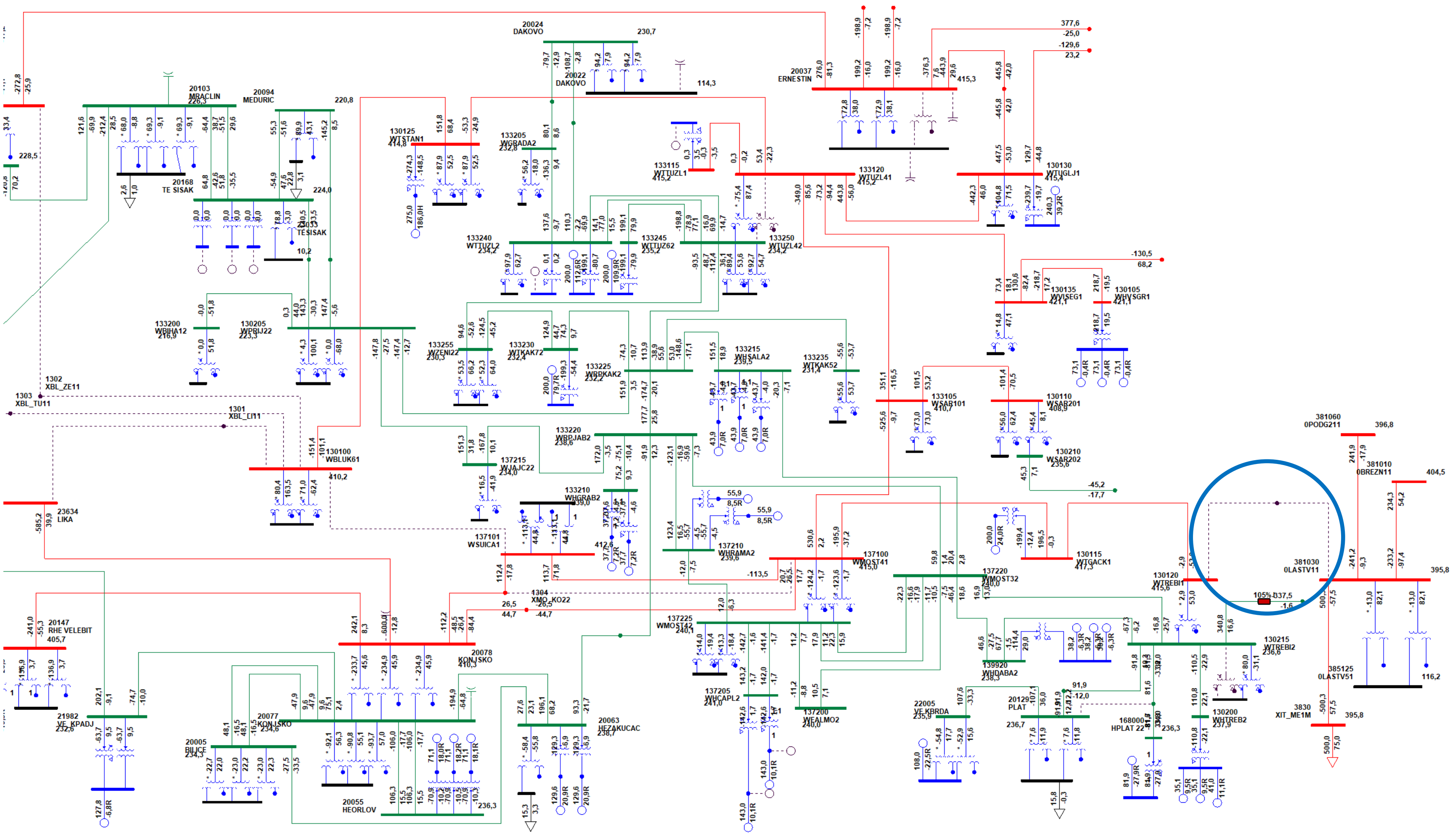


Figure 31: Topology and loadings 400 kV and 220 kV grid with reinforcements E+110 kV (MAX 2030) during outage of OHL 400 kV Lastva – Trebinje

7.5 Grid reinforcement estimated costs and recommendations

Reconstruction of the above mentioned existing 110 kV lines with HTLS conductors or construction of new lines with HTLS is significantly cheaper than construction of any single 400 kV line as shown in the following table. The cost to reconstruct existing 110 kV OHL with ACCC conductor upgrade is estimated at 35 – 40% of the cost of a new 110 kV OHL line with ACSR conductors. Unit price are based upon Elektroprenos' Price list[5] issued in April 2022. Given values are rough estimation and does not deal with project specific upgrades like replacement of CTs with higher rating CTs in existing substations.

Table 36: Grid reinforcements cost estimation

Reinforcement	**OHL 1x400 kV (km)**	**400 kV BAY (piece)**	**OHL 1x110 kV ACCC Lisbon upgrade (km)**	**OHL 1x110 kV ACCC Rovinj upgrade (km)**	**Total costs (mil.BAM)**
Unit price (BAM)	**840.000 BAM/km**	**1.900.000 BAM/pc.**	**~40% of 270.000 BAM/km**	**~35% of 270.000 BAM/km**	
new OHL 400 kV B. Luka - Lika	123	2			**107,12**
new OHL 400 kV B. Luka - Tumbri	145	2			**125,60**
new OHL 400 kV B. Luka - Žerjavinec	150	2			**129,80**
new OHL 400 kV B. Luka - Šuica	125	2			**108,80**
new OHL 400 kV Konjsko - Mostar	113	2			**98,72**
upgrade OHL 110 kV Komolac - Trebinje			18		**1,94**
upgrade OHL 110 kV B. Blato - Livno			13		**1,40**
upgrade OHL 110 kV Livno - Šuica			18		**1,94**
upgrade OHL 110 kV Trebinje - Herceg Novi				31	**2,93**
upgrade OHL 110 kV Šuica - Baljci			4		**0,43**

Table 37: Selected grid reinforcement scenarios cost estimation

Reinforcement	**Total costs (mil.BAM)**
D (OHL 400 kV B. Luka - Šuica)	108,80
E (OHL 400 kV Konjsko - Mostar)	98,72
5 OHL 110 kV upgrades	8,65
D+110	**117,45**
E+110	**107,37**

Thus, as a first pass, it appears that the construction of the Konjsko-Mostar 400 kV line, in conjunction with the 110 kV upgrades shown here, would be the best option. However, we note that these costs are generic, and that the on-the-ground situation may lead to actual costs that vary due to the terrain and permitting. The shorter line is not always the least expensive.

Thus, as a general conclusion, to accommodate the planned generation capacities in all analyzed scenarios, in conjunction with the planned transmission development activities in Croatia, we propose deeper consideration of the following combination of grid reinforcements in BiH by 2030 (E+110):

1. **Construction of new single 400 kV OHL Konjsko – Mostar 4 (which is fully in line with HOPS 400 kV development study results [2])**
2. **Conductor replacements on:**

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[5] JEDINIČNE CIJENE_VARIJABILNI DIO NAKNADE ZA PRIKLJUČAK_Izdanje broj 2_200422.pdf (elprenos.ba)

a. **OHL 110 kV Komolac - Trebinje (~18 km) ACCC Lisbon 230 MVA**
b. **OHL 110 kV Buško Blato - Livno (~13 km) ACCC Lisbon 230 MVA**
c. **OHL 110 kV Livno - Šuica (~18 km) ACCC Lisbon 230 MVA**
d. **OHL 110 kV Trebinje – Herceg Novi (~31 km) ACCC Rovinj 165 MVA**
e. **OHL 110 kV Šuica – Baljci (~4 km) ACCC Lisbon 230 MVA**

However, if the construction of this 400 kV line is not feasible in the given timeframe for any reason (different time dynamics with neighboring TSO, cross-border issues, permitting and spatial details, financial issues etc.), we propose second option, and that is the construction of the new 400 kV OHL Banja Luka – Šuica, with the same reinforcements of the 110 kV grid (D+110).

The total costs for the first recommended 400 kV and 110 kV grid reinforcement are estimated to be 107 - 117 mil. BAM (approx. 54 - 59 mil.€). This cost does not include the price to construct the new 400/110 kV substation Šuica and the 400 kV and 110 kV OHL connections to the substation.

In the table below there is indicative cost estimation construction of SS 400/110 kV Šuica with 400 kV and 110 kV OHL connections.

Table 38: Basic model 2030 reinforcement cost estimation

Upgrades already in 2030 model	OHL 2x400 kV (km)	400 kV BAY (piece)	110 kV BAY (piece)	Transformer 400/110 kV 300 MVA	OHL 1x110 kV Al/Fe 240/40mm2	OHL 2x110 kV Al/Fe 240/40mm2	OHL 2x110 kV ACCC Lisbon	Total costs (mil.BAM)
Unit price (BAM)	**1.540.000 BAM/km**	**1.900.000 BAM/pc.**	**700.000 BAM/pc.**	**8.000.000 BAM/pc**	**270.000 BAM/km**	**450.000 BAM/km**	**600.000 BAM/km**	
OHL 2x400 kV Konjsko - Šuica - Mostar	46							**70,84**
OHL 110 kV Livno - Šuica 123 MVA			1		18			**5,56**
OHL 110 kV Slovinj - Grahovo 123 MVA			2		50			**14,90**
OHL 2x110 kV Slovinj - Šuica 231 MVA			2				41	**26,00**
OHL 2x110 kV Ivovik - Šuica 123 MVA			2			9		**5,45**
OHL 110 kV D. Brdo - Kupres 123 MVA			2		6			**3,02**
OHL 110 kV Baljci - Šuica 123 MVA			2		4			**2,48**
OHL 110 kV G. Vakuf - Rama 123 MVA			2		16			**5,72**
400 kV switchyard Šuica		5						**9,50**
110 kV switchyard Šuica			10					**7,00**
Transformer 400/110 kV 300 MVA				2				**16,00**
Project, Civil works and other								**30,00**

It is important to say that costs estimation does not include all costs of grid reinforcement in the 2030 model, but only cost for elements near Šuica.

Table 39: Basic model 2030 reinforcement cost summary

Upgrades	Total costs (mil.BAM)
400 kV grid reinforcement	**70,84**
110 kV grid reinforcement	**63,13**
SS 400/110 kV Šuica	**62,50**
Total	**196,47**

Above mention costs in basic model are significantly higher than proposed model reinforcement costs. Part of calculated costs should pay RES investors during project grid connection procedure. Due to the rapid growth of prices and uncertainties related to the selection of the location, the costs of building SS 400/110 kV Šuica may be significantly higher than the stated estimation.

The following figure shows the BiH and Croatian 400 and 220 kV grid topology with interconnecting lines in 2030 with SS 400/110 kV Šuica. We also present the recommended grid reinforcements D – OHL 400 kV B.Luka – Šuica and E – OHL 400 kV Konjsko – Mostar.

Figure 32: 400 kV and 220 kV transmission network topology in Croatia and BiH with proposed D and E 400 kV grid reinforcements

7.6 Network voltage profiles

The connection of RES, primarily wind power plants or photovoltaics to the 110 kV network (if they operate with a power factor close to one) generally causes a voltage increase in the connection hubs due to the active power injection. It can also be said that the connection of any power plant, including RES, makes the voltage more stable, that is, better controlled or "more robust". On the other hand, during powerplant outages, unloaded OHLs generate reactive power and increase the grid voltage, and that is the most obvious on 400 kV level.

Wind and solar power plants can actively influence voltages and participate in the reactive power control, i.e., they produce/consume reactive inductive power based on the wind turbines, internal compensation devices, or power transformer controls.

The BiH Grid Code requirements define acceptable voltage ranges in the following table.

Table 40: BiH Grid Code voltage requirements

Voltage level (kV)	Voltage range (kV)	Voltage range (pu)	Duration of operation
400 kV	340 - 380	0.85 - 0.95	60 min
	380 - 420	0.95 - 1,05	unlimited
	420 - 440	1.05 - 1.10	60 min
220 kV	187 - 198	0.85 - 0.9	60 min
	198 - 245	0.9 - 1.114	unlimited
	245 - 253	1.114 - 1.15	60 min
110 kV	93,5 - 99	0.85 - 0.9	60 min
	99 - 123	0.9 - 1.118	unlimited
	123 - 126,5	1.118 - 1.15	60 min

It is worth noting that the Croatian Grid Code has slightly different voltage ranges for normal operation: 360 – 420 kV and 198 – 246 kV.

The following table shows the voltage violations we detected in the BiH transmission network and interconnection nodes in the neighboring systems for the basic 2025 and 2030 scenarios, as well as the scenarios with the proposed grid reinforcements.

The total number of voltage violations depends on the scenario. In 2025 it is between 3 (max load) and 10 (min load) per scenario. In 2030 it is between 3 (max load) and 18 (min load) per scenario. With the proposed 400 kV network reinforcements, the total number of voltage violations slightly grows, and ranges from 19 (E scenario) to 21 (D+110 scenario). However, in all cases most of the voltage violations are in the 400 kV network, with quite low overvoltage levels, very close to the upper limit. New compensation devices in Croatia and Slovenia, the HVDC converter station in Montenegro, and new RES with increasing loadings of the 400 kV OHL can reduce these over-voltages in the future.

Table 41: Voltage violations in normal operation in the BiH grid (n available elements)

Voltage violations (kV)	Scenario											
Bus	**2025 MAX**	**2025 MIN**	**2030 MAX**	**2030 MIN**	**2030 MAX D**	**2030 MIN D**	**2030 MAX E**	**2030 MIN E**	**2030 MAX D+110**	**2030 MIN D+110**	**2030 MAX E+110**	**2030 MIN E+110**
400 kV B.Bašta	423,25	425,77	422,87	427,45	423,28	427,49	422,88	427,37	423,28	427,5	422,89	427,38
400 kV Ernestinovo		420,85		423,1		422,88		422,9		422,89		422,91
400 kV S. Mitrovica		420,8		422,81		422,67		422,66		422,69		422,67
400 kV B. Luka 6		421,16		428,75		425,86		428,68		425,93		428,7
400 kV HE Višegrad	422,19	425,08	421,74	427,09	422,24	427,15	421,76	427	422,24	427,17	421,77	427,01
400 kV Sarajevo 20						420,75				420,79		
400 kV Stanari		421,39		430,98		429,47		430,89		429,52		430,9
400 kV Ugljevik		421,24		423,74		423,6		423,58		423,62		423,59
400 kV Višegrad	422,2	425,15	421,74	427,18	422,25	427,23	421,76	427,08	422,25	427,25	421,77	427,09
400 kV Sarajevo 10				420,64		422,08		420,55		422,13		420,58
400 kV TE Tuzla		422,15		425,91		425,88		425,78		425,9		425,8
400 kV Tuzla 4		422,15		425,92		425,88		425,79		425,91		425,81
220 kV Gradačac				245,15		245,25		245,09		245,26		245,11
110 kV HAK				123,45		123,5		123,45		123,5		123,45
110 kV Tuzla								123,5		123,5		123,45
110 kV Tušanj				123,13		123,17		123,12		123,17		123,12
110 kV Tuzla 3				123,04		123,07		123,03		123,08		123,03
110 kV Tuzla 4				123,45		123,79		123,73		123,79		123,74
110 kV Tuzla 5				123,13		123,07		123,02		123,08		123,03
110 kV Tuzla Centar				123,21		123,25		123,2		123,25		123,21
400 kV Mostar 4						420,61				420,68		
No. of violations	**3**	**10**	**3**	**18**	**3**	**20**	**3**	**19**	**3**	**21**	**3**	**19**

During the n-1 contingency regimes, the number and level of voltage violations are not as critical or significantly different than under normal operating regime (n elements available).

7.7 Network losses

One of the tasks in this assignment was to evaluate the impact of different scenarios on power network losses. Generally, losses in the transmission grid mostly occur on the heavily loaded 110 kV grid. Grid strengthening with new 400 kV lines and substations (from 2025 → 2030) significantly reduce losses despite the increasing number of new RES projects, as clearly indicated in the following table.

Calculated losses refer to power lost in a specific scenario in one moment, in MW.

Yearly losses are the sum of energy losses in the system (input – output) during the whole Year, and they are calculated in GWh.

Table 42: Transmission network losses in BiH and Croatia

System losses (MW)	Scenario											
Country	2025 MAX	2025 MIN	2030 MAX	2030 MIN	2030 MAX D	2030 MIN D	2030 MAX E	2030 MIN E	2030 MAX D+110	2030 MIN D+110	2030 MAX E+110	2030 MIN E+110
Bosnia and Herzegovina	120,1	90,6	109,1	81	102,2	73,5	108,7	78,1	101,2	71,8	107,8	76,7
Croatia	155,7	166,5	157	166,6	152,7	161,9	156	161,4	152,6	161,9	156	161,4
Sum of BiH losses in max and min scenarios	210,7		190,1		175,7		186,8		173		184,5	

Additional construction of the 400 kV lines with OHL 400 kV B. Luka – Šuica (D) or OHL 400 kV Konjsko – Mostar 4 (E) reduce losses in the BiH transmission grid, as shown in the following figure. Conductor replacement on the five existing 110 kV lines additionally reduce network losses in BiH. In the reinforcement scenario D+110, losses drop by ~18% compared to initial 2025 total scenario value, and 9% compared to the initial 2030 total scenario. In reinforcement scenario E+110, the network losses drop by ~12% compared to initial 2025 total scenario value, and 3% compared to the initial 2030 total scenario.

In the next phase of the analysis of these options, NOS BiH and Elektroprenos could take the level of losses into account in determining which is the best option for BiH.

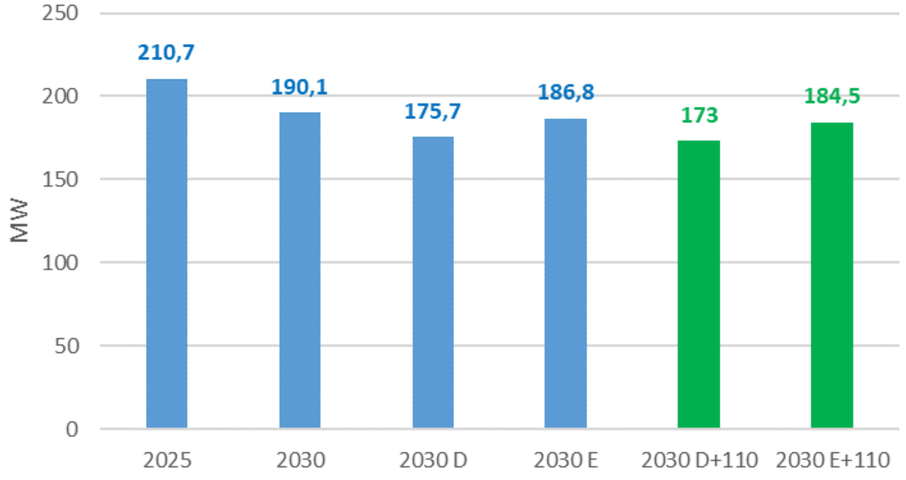

Figure 33: Sum of BiH transmission network losses in all analyzed scenarios

It is important to note that these are indicative power network losses for selected snapshots in given scenarios. Even though this assessment compares several scenarios, to determine the total electricity loss in the network during the year (and the allocated costs), it would be necessary to run an hourly power system simulation, which was beyond the scope of this study.

8 CONCLUSIONS

The main scope of work in this assignment was: 1) to develop, coordinate and analyze the 400 kV network development needs on both sides of the Croatia - BiH border; and 2) to ensure that network development would support the significant expected changes in the generation portfolio of this sub-region, including substantial decarbonization and large-scale RES integration. These factors are quite important in BiH due to the high share of coal-fired thermal power plants in the generation mix, as well as BiH's high RES potential. In addition, given BiH's proximity to and interconnectedness with Croatia, especially in the region where there could be massive RES development, it was critical to take grid developments in Croatia into account.

The electricity market and network conditions in Southeast Europe (SEE) are quite specific. These 11 countries are mostly small power systems that are well connected, with strong mutual impact, and BiH and Croatia are the most extreme case, with 21 interconnections. Accordingly, the analyses of any new grid project, especially fundamental network projects such as the 400 kV backbones, requires a cross-border and regional perspective.

This analysis evaluated the need for BiH transmission network reinforcement, taking into account the expected Croatian transmission development plan, especially on the 400 kV network.

For this assessment we used the PSS/E software package and regional power system model for 2025 and 2030 verified by the 11 neighboring TSOs. This model captures 8480 buses, 1463 power plants, 3392 loads, 9746 branches and 3663 transformers. For this study, we updated the model with HOPS input data for Croatia and NOS BIH input data for BiH.

For this analysis we defined 32 scenarios in the ToR (16 for 2025 and 16 for 2030). However, during the Study and definition of the network reinforcement scenarios, NOS BiH updated several inputs that changed the initial scenarios:

- **HVDC MONITA submarine cable link capacity to Italy**: this value was initially set to 500 / 1000 MW in the regional models for 2025 / 2030 (consistent with the Montenegrin TYNDP [3]). NOS BiH requested to reduce this to 500 MW for 2030, to be more realistic. This request was reasonable from an operational perspective and expected regional developments, though it nearly doubled number of analyzed scenarios in 2030.

- **New 400 kV nodes/links**: two new 400 kV links / nodes were foreseen in the ToR: Bihać and Banja Luka. During the study preparation, NOS BiH confirmed our initial findings that the new node Bihać 400 kV is not needed by 2030 for 400 kV development, since it does not enhance RES integration or network reliability in this area. Therefore, we abandoned the scenarios with the node Bihać 400 kV node.

Accordingly, in the study we agreed upon and analyzed 62 scenarios (12 basic scenarios for 2025 and 16 basic scenarios for 2030, plus 34 reinforcement scenarios for the max reference case with both the MONITA 500 MW and 1000 MW in 2030), as described in Chapter 4.

We included a total installed generation capacity in BiH for 2030 of 5936 MW, which is a significant increase of about 1330 MW compared to existing installed capacity. We projected the largest share of generation capacity in 2030 to go to thermal power units (2837 MW or 47,8%); hydro plant capacity remains the same as today (1998 MW or 33,7% of total installed generation capacity); while RES (wind and solar power units) will grow significantly to 1100 MW or 18,5%.

Along with decommissioning of the old units in TPP Gacko (276 MW) in the moderate decarbonization scenario, and TPP Tuzla 6 BiH (190 MW) in the extreme decarbonization scenario, there are also plans to commission two new TPP units by 2030: TPP Tuzla 7 (450 MW) and TPP Kakanj 8 (300 MW). Actually, TPP Kakanj 8 is a potential replacement for Units 1, 2, 3 and 4, which are already closed, but its status is still questionable. We will closely follow development of these plans in the light of current European energy crisis. If either or both of these TPPs does not come on line, or is delayed past 2030, or if more TPPs are decommissioned in BiH than currently planned, those would be material changes requiring further analysis of the impacts of a different generation mix on the grid.

Total system peak load in BiH is expected to increase, though quite slowly. In 2030 it is expected to be 2000 MW, which is just 100 MW higher than in 2025, and about the same as in 2021 (1909 MW). In other words, the total planned generation capacity in 2030 (5936 MW) will be almost three times higher than the peak load (2000 MW).

The main expected outcome of this study was to identify the optimal network topology for the BiH power system that will accommodate the expected significant changes in generation capacities in 2025 and 2030, taking substation Šuica 400/110 kV as a given input.

Based on the analyses in this study, and **to accommodate planned generation capacities in all analyzed scenarios combined with planned transmission development activities in the neighboring well-connected Croatian power system, we propose the following grid reinforcements in BiH by 2030:**

1. **Construct a new single 400 kV OHL Konjsko – Mostar 4 (fully in line with the HOPS 400 kV development study [2])**
2. **Place conductor replacements on five 110 kV lines:**
    a. **OHL 110 kV Komolac - Trebinje (~18 km) ACCC Lisbon 230 MVA**
    b. **OHL 110 kV Buško Blato - Livno (~13 km) ACCC Lisbon 230 MVA**
    c. **OHL 110 kV Livno - Šuica (~18 km) ACCC Lisbon 230 MVA**
    d. **OHL 110 kV Trebinje – Herceg Novi(~31 km) ACCC Rovinj 165 MVA**
    e. **OHL 110 kV Šuica – Baljci (~4 km) ACCC Lisbon 230 MVA**

If the construction of this 400 kV line is not feasible in the given timeframe for any reason (e.g., different time dynamics with the neighboring TSO, cross-border issues, permitting and spatial details, financial issues, etc.), the second option would be to construct a new 400 kV OHL Banja Luka – Šuica, and add the same reinforcements on the 110 kV grid.

We estimate the total costs for the first recommended 400 kV OHL and the 110 kV grid reinforcements at 107 - 117 million BAM (about 54 - 59 million €), based on the unit prices recently updated by Elektroprenos. These costs do not include the cost of the new 400/110 kV substation Šuica and the relevant 400 kV and 110 kV OHL connections to it.. These costs estimated to **200 million BAM** could vary depending on the range of factors just mentioned, and the next phase of the analysis of these options should develop more granular, more site-specific costs.

In the study we also analyzed voltage profiles. The number of voltage violations (voltages on the transmission nodes outside allowed limits) depends on the scenario. In 2025 it is between 3 (max load) and 10 (min load). In 2030 it is between 3 (max load) and 18 (min load). With the proposed 400 kV network reinforcements, the number of voltage violations slightly grows to 19 to 21. However, most of these cases are in the 400 kV network, with quite low overvoltage levels, close to the upper limit, so these violations are not critical. Further voltage profile analysis and reactive power compensation could be the subject of another study.

We also analyzed the impact of grid reinforcement on BiH transmission network losses. We determined that reinforcement of the 400 kV grid in both proposed options (the OHL 400 kV B. Luka – Šuica (D) or the OHL 400 kV Konjsko – Mostar 4 (E)) will reduce losses in the transmission grid. Conductor replacement on five existing 110 kV additionally reduces BiH losses.

In the reinforcement scenario (D+110) it drops about 18% compared to the initial 2025 total scenario value, and 9% compared to the initial 2030 total scenario.

In the reinforcement scenario E+110, the network losses drop about 12% compared to the initial 2025 total scenario, or 3% compared to initial 2030 scenario.

These significant reductions in losses result in real customer savings, and are another basis for serious consideration of comparison between the two recommended new potential 400 kV grid reinforcement lines.

9 ANNEX – DETAILED N-1 RESULTS

Table 43: N-1 contingency results – maximum load 2025 – referent decarbonization

Element	Number of contingencies	Parametar	Value	The most critical outage
DV 110 kV KUPRES - BUGOJNO	398	P [MW]	164,5	DV 110 kV VE JELOVAČA - RAMA
		Q [MVAr]	-54,9	
		S [MVA]	173,4	
		I [A]	910,8	
		%In	142,2	
DV 110 kV TREBINJE - HERCEG NOVI	406	P [MW]	159,0	DV 400 kV LASTVA - TREBINJE
		Q [MVAr]	-51,1	
		S [MVA]	167,0	
		I [A]	871,2	
		%In	185,5	
DV 110 kV VE DEBELO BRDO - KUPRES	400	P [MW]	169,5	DV 110 kV VE JELOVAČA - RAMA
		Q [MVAr]	-46,0	
		S [MVA]	175,6	
		I [A]	922,3	
		%In	144,0	
DV 110 kV ŠUICA - VE DEBELO BRDO	400	P [MW]	175,2	DV 110 kV VE JELOVAČA - RAMA
		Q [MVAr]	-27,3	
		S [MVA]	177,3	
		I [A]	923,0	
		%In	144,1	
DV 220 kV TREBINJE - HE PERUČICA	1	P [MW]	-354,3	DV 400 kV LASTVA - TREBINJE
		Q [MVAr]	-3,6	
		S [MVA]	354,3	
		I [A]	873,0	
		%In	110,5	
DV 110 kV KOMOLAC - TREBINJE 2	2	P [MW]	156,3	DV 220 kV PLAT - PLAT
		Q [MVAr]	-21,2	
		S [MVA]	157,7	
		I [A]	817,9	
		%In	127,7	
TR1 400/220 kV TREBINJE	1	P [MW]	-424,7	DV 400 kV TREBINJE - GACKO
		Q [MVAr]	20,4	
		S [MVA]	425,2	
		I [A]	606,7	
		%In	105,1	
DV 110 kV VE JELOVAČA - RAMA	3	P [MW]	152,0	DV 110 kV ŠUICA - VE DEBELO BRDO
		Q [MVAr]	-35,9	
		S [MVA]	156,2	
		I [A]	812,2	
		%In	126,8	
DV 110 kV BUGOJNO - DONJI VKAUF 2	1	P [MW]	121,0	DV 110 kV BUGOJNO - NOVI TRAVNIK
		Q [MVAr]	-28,9	
		S [MVA]	124,4	
		I [A]	654,4	
		%In	102,2	
DV 110 kV DONJI VKAUF - JAJCE 2 2	1	P [MW]	116,6	DV 110 kV BUGOJNO - NOVI TRAVNIK
		Q [MVAr]	-34,5	
		S [MVA]	121,6	
		I [A]	640,7	
		%In	100,1	

Table 44: N-1 contingency results – maximum load 2025 - moderate decarbonization

Element	Number of contingencies	Parametar	Value	The most critical outage
DV 110 kV KUPRES - BUGOJNO	398	P [MW]	166,54	DV 110 kV VE JELOVAČA - RAMA
		Q [MVAr]	-54,46	
		S [MVA]	175,22	
		I [A]	921,85	
		%In	143,96	
DV 110 kV TREBINJE - HERCEG NOVI	406	P [MW]	157,92	DV 400 kV LASTVA - TREBINJE
		Q [MVAr]	-51,16	
		S [MVA]	166,00	
		I [A]	865,82	
		%In	184,31	
DV 110 kV VE DEBELO BRDO - KUPRES	401	P [MW]	171,60	DV 110 kV VE JELOVAČA - RAMA
		Q [MVAr]	-45,38	
		S [MVA]	177,50	
		I [A]	933,56	
		%In	145,79	
DV 110 kV ŠUICA - VE DEBELO BRDO	401	P [MW]	177,42	DV 110 kV VE JELOVAČA - RAMA
		Q [MVAr]	-26,20	
		S [MVA]	179,34	
		I [A]	934,22	
		%In	145,90	
DV 220 kV TREBINJE - HE PERUČICA	1	P [MW]	-351,02	DV 400 kV LASTVA - TREBINJE
		Q [MVAr]	-3,21	
		S [MVA]	351,04	
		I [A]	864,80	
		%In	109,48	
DV 110 kV KOMOLAC - TREBINJE 2	2	P [MW]	156,35	DV 220 kV PLAT - PLAT
		Q [MVAr]	-21,14	
		S [MVA]	157,77	
		I [A]	818,07	
		%In	127,76	
TR1 400/220 kV TREBINJE	1	P [MW]	-421,50	DV 400 kV TREBINJE - GACKO
		Q [MVAr]	20,24	
		S [MVA]	421,98	
		I [A]	601,99	
		%In	104,27	
DV 110 kV VE JELOVAČA - RAMA	3	P [MW]	153,82	DV 110 kV ŠUICA - VE DEBELO BRDO
		Q [MVAr]	-35,20	
		S [MVA]	157,79	
		I [A]	821,05	
		%In	128,22	
DV 110 kV BUGOJNO - DONJI VKAUF 2	2	P [MW]	121,88	DV 110 kV BUGOJNO - NOVI TRAVNIK
		Q [MVAr]	-28,61	
		S [MVA]	125,19	
		I [A]	659,36	
		%In	102,97	
DV 110 kV DONJI VKAUF - JAJCE 2 2	1	P [MW]	117,51	DV 110 kV BUGOJNO - NOVI TRAVNIK
		Q [MVAr]	-34,31	
		S [MVA]	122,41	
		I [A]	645,64	
		%In	100,83	

Table 45: N-1 contingency results – maximum load 2025 - extreme decarbonization

Element	Number of contingencies	Parametar	Value	The most critical outage
DV 110 kV KUPRES - BUGOJNO	398	P [MW]	165,6	DV 110 kV VE JELOVAČA - RAMA
		Q [MVAr]	-54,7	
		S [MVA]	174,5	
		I [A]	917,1	
		%In	143,2	
DV 110 kV TREBINJE - HERCEG NOVI	406	P [MW]	151,4	DV 400 kV LASTVA - TREBINJE
		Q [MVAr]	-51,4	
		S [MVA]	159,9	
		I [A]	834,0	
		%In	177,5	
DV 110 kV VE DEBELO BRDO - KUPRES	400	P [MW]	170,7	DV 110 kV VE JELOVAČA - RAMA
		Q [MVAr]	-45,7	
		S [MVA]	176,7	
		I [A]	928,7	
		%In	145,0	
DV 110 kV ŠUICA - VE DEBELO BRDO	400	P [MW]	176,4	DV 110 kV VE JELOVAČA - RAMA
		Q [MVAr]	-26,7	
		S [MVA]	178,5	
		I [A]	929,4	
		%In	145,1	
DV 220 kV TREBINJE - HE PERUČICA	1	P [MW]	-328,8	DV 400 kV LASTVA - TREBINJE
		Q [MVAr]	-1,4	
		S [MVA]	328,8	
		I [A]	809,5	
		%In	102,5	
DV 110 kV KOMOLAC - TREBINJE 2	2	P [MW]	158,1	DV 220 kV PLAT - PLAT
		Q [MVAr]	-20,5	
		S [MVA]	159,4	
		I [A]	827,2	
		%In	129,2	
TR1 400/220 kV TREBINJE	2	P [MW]	-412,5	DV 400 kV MOSTAR 4 - GACKO
		Q [MVAr]	37,3	
		S [MVA]	414,2	
		I [A]	586,1	
		%In	101,5	
DV 110 kV VE JELOVAČA - RAMA	3	P [MW]	153,4	DV 110 kV ŠUICA - VE DEBELO BRDO
		Q [MVAr]	-35,5	
		S [MVA]	157,4	
		I [A]	819,1	
		%In	127,9	
DV 110 kV BUGOJNO - DONJI VKAUF 2	1	P [MW]	119,8	DV 110 kV BUGOJNO - NOVI TRAVNIK
		Q [MVAr]	-29,0	
		S [MVA]	123,2	
		I [A]	648,4	
		%In	101,3	

Table 46: N-1 contingency results – minimum load 2025 - referent decarbonization

Element	Number of contingencies	Parametar	Value	The most critical outage
DV 110 kV KUPRES - BUGOJNO	397	P [MW]	165,34	DV 110 kV VE JELOVAČA - RAMA
		Q [MVAr]	-67,03	
		S [MVA]	178,41	
		I [A]	922,39	
		%In	144,05	
DV 110 kV TREBINJE - HERCEG NOVI	406	P [MW]	157,42	DV 400 kV LASTVA - TREBINJE
		Q [MVAr]	-50,59	
		S [MVA]	165,35	
		I [A]	858,79	
		%In	182,82	
DV 110 kV VE DEBELO BRDO - KUPRES	397	P [MW]	168,49	DV 110 kV VE JELOVAČA - RAMA
		Q [MVAr]	-58,86	
		S [MVA]	178,47	
		I [A]	925,02	
		%In	144,46	
DV 110 kV ŠUICA - VE DEBELO BRDO	397	P [MW]	174,26	DV 110 kV VE JELOVAČA - RAMA
		Q [MVAr]	-38,82	
		S [MVA]	178,53	
		I [A]	924,14	
		%In	144,32	
DV 220 kV TREBINJE - HE PERUČICA	1	P [MW]	-330,12	DV 400 kV LASTVA - TREBINJE
		Q [MVAr]	-6,94	
		S [MVA]	330,19	
		I [A]	809,50	
		%In	102,48	
DV 110 kV KOMOLAC - TREBINJE 2	2	P [MW]	203,04	DV 220 kV PLAT - PLAT
		Q [MVAr]	-27,24	
		S [MVA]	204,86	
		I [A]	1061,30	
		%In	165,74	
DV 110 kV VE JELOVAČA - RAMA	3	P [MW]	155,81	DV 110 kV VE DEBELO BRDO - KUPRES
		Q [MVAr]	-40,36	
		S [MVA]	160,95	
		I [A]	835,29	
		%In	130,45	

Table 47: N-1 contingency results – minimum load 2025 - moderate decarbonization

Element	Number of contingencies	Parametar	Value	The most critical outage
DV 110 kV KUPRES - BUGOJNO	397	P [MW]	166,85	DV 110 kV VE JELOVAČA - RAMA
		Q [MVAr]	-66,74	
		S [MVA]	179,70	
		I [A]	930,18	
		%In	145,27	
DV 110 kV TREBINJE - HERCEG NOVI	406	P [MW]	156,57	DV 400 kV LASTVA - TREBINJE
		Q [MVAr]	-50,64	
		S [MVA]	164,56	
		I [A]	854,73	
		%In	181,95	
DV 110 kV VE DEBELO BRDO - KUPRES	397	P [MW]	170,03	DV 110 kV VE JELOVAČA - RAMA
		Q [MVAr]	-58,46	
		S [MVA]	179,80	
		I [A]	932,88	
		%In	145,69	
DV 110 kV ŠUICA - VE DEBELO BRDO	397	P [MW]	175,89	DV 110 kV VE JELOVAČA - RAMA
		Q [MVAr]	-38,10	
		S [MVA]	179,97	
		I [A]	932,01	
		%In	145,55	
DV 220 kV TREBINJE - HE PERUČICA	1	P [MW]	-327,58	DV 400 kV LASTVA - TREBINJE
		Q [MVAr]	-6,61	
		S [MVA]	327,65	
		I [A]	803,29	
		%In	101,69	
DV 110 kV KOMOLAC - TREBINJE 2	2	P [MW]	203,05	DV 220 kV PLAT - PLAT
		Q [MVAr]	-27,20	
		S [MVA]	204,87	
		I [A]	1061,44	
		%In	165,76	
DV 110 kV VE JELOVAČA - RAMA	5	P [MW]	157,12	DV 110 kV VE DEBELO BRDO - KUPRES
		Q [MVAr]	-39,80	
		S [MVA]	162,08	
		I [A]	841,48	
		%In	131,41	

Table 48: N-1 contingency results – minimum load 2025 - extreme decarbonization

Element	Number of contingencies	Parametar	Value	The most critical outage
DV 110 kV KUPRES - BUGOJNO	397	P [MW]	165,65	DV 110 kV VE JELOVAČA - RAMA
		Q [MVAr]	-66,74	
		S [MVA]	178,59	
		I [A]	923,81	
		%In	144,27	
DV 110 kV TREBINJE - HERCEG NOVI	406	P [MW]	148,54	DV 400 kV LASTVA - TREBINJE
		Q [MVAr]	-50,75	
		S [MVA]	156,97	
		I [A]	814,87	
		%In	173,47	
DV 110 kV VE DEBELO BRDO - KUPRES	397	P [MW]	168,80	DV 110 kV VE JELOVAČA - RAMA
		Q [MVAr]	-58,55	
		S [MVA]	178,66	
		I [A]	926,47	
		%In	144,69	
DV 110 kV ŠUICA - VE DEBELO BRDO	397	P [MW]	174,59	DV 110 kV VE JELOVAČA - RAMA
		Q [MVAr]	-38,46	
		S [MVA]	178,77	
		I [A]	925,60	
		%In	144,55	
DV 110 kV KOMOLAC - TREBINJE 2	2	P [MW]	205,17	DV 220 kV PLAT - PLAT
		Q [MVAr]	-26,61	
		S [MVA]	206,88	
		I [A]	1073,04	
		%In	167,57	
DV 110 kV VE JELOVAČA - RAMA	5	P [MW]	156,52	DV 110 kV VE DEBELO BRDO - KUPRES
		Q [MVAr]	-40,03	
		S [MVA]	161,56	
		I [A]	838,71	
		%In	130,98	

Table 49: N-1 contingency results – maximum load 2030 - referent decarbonization – HVDC MONITA 500 MW

Element	Number of contingencies	Parametar	Value	The most critical outage
DV 110 kV KUPRES - BUGOJNO	398	P [MW]	164,5	DV 110 kV VE JELOVAČA - RAMA
		Q [MVAr]	-54,9	
		S [MVA]	173,4	
		I [A]	910,8	
		%In	142,2	
DV 110 kV TREBINJE - HERCEG NOVI	406	P [MW]	159,0	DV 400 kV LASTVA - TREBINJE
		Q [MVAr]	-51,1	
		S [MVA]	167,0	
		I [A]	871,2	
		%In	185,5	
DV 110 kV VE DEBELO BRDO - KUPRES	400	P [MW]	169,5	DV 110 kV VE JELOVAČA - RAMA
		Q [MVAr]	-46,0	
		S [MVA]	175,6	
		I [A]	922,3	
		%In	144,0	
DV 110 kV ŠUICA - VE DEBELO BRDO	400	P [MW]	175,2	DV 110 kV VE JELOVAČA - RAMA
		Q [MVAr]	-27,3	
		S [MVA]	177,3	
		I [A]	923,0	
		%In	144,1	
DV 220 kV TREBINJE - HE PERUČICA	1	P [MW]	-354,3	DV 400 kV LASTVA - TREBINJE
		Q [MVAr]	-3,6	
		S [MVA]	354,3	
		I [A]	873,0	
		%In	110,5	
DV 110 kV KOMOLAC - TREBINJE 2	2	P [MW]	156,3	DV 220 kV PLAT - PLAT
		Q [MVAr]	-21,2	
		S [MVA]	157,7	
		I [A]	817,9	
		%In	127,7	
TR1 400/220 kV TREBINJE	1	P [MW]	-424,7	DV 400 kV TREBINJE - GACKO
		Q [MVAr]	20,4	
		S [MVA]	425,2	
		I [A]	606,7	
		%In	105,1	
DV 110 kV VE JELOVAČA - RAMA	3	P [MW]	152,0	DV 110 kV ŠUICA - VE DEBELO BRDO
		Q [MVAr]	-35,9	
		S [MVA]	156,2	
		I [A]	812,2	
		%In	126,8	
DV 110 kV BUGOJNO - DONJI VKAUF 2	1	P [MW]	121,0	DV 110 kV BUGOJNO - NOVI TRAVNIK
		Q [MVAr]	-28,9	
		S [MVA]	124,4	
		I [A]	654,4	
		%In	102,2	
DV 110 kV DONJI VKAUF - JAJCE 2 2	1	P [MW]	116,6	DV 110 kV BUGOJNO - NOVI TRAVNIK
		Q [MVAr]	-34,5	
		S [MVA]	121,6	
		I [A]	640,7	
		%In	100,1	

Table 50: N-1 contingency results – maximum load 2030 - moderate decarbonization – HVDC MONITA 500 MW

Element	Number of contingencies	Parametar	Value	The most critical outage
DV 110 kV TREBINJE - HERCEG NOVI	416	P [MW]	154,04	DV 400 kV LASTVA - TREBINJE
		Q [MVAr]	-51,26	
		S [MVA]	162,34	
		I [A]	847,21	
		%In	180,35	
DV 220 kV TREBINJE - HE PERUČICA	1	P [MW]	-342,79	DV 400 kV LASTVA - TREBINJE
		Q [MVAr]	-0,56	
		S [MVA]	342,79	
		I [A]	845,68	
		%In	107,06	
DV 110 kV KOMOLAC - TREBINJE 2	2	P [MW]	135,14	DV 220 kV PLAT - PLAT
		Q [MVAr]	-15,38	
		S [MVA]	136,01	
		I [A]	704,52	
		%In	110,02	
TR1 400/220 kV TREBINJE	1	P [MW]	-415,67	DV 400 kV TREBINJE - GACKO
		Q [MVAr]	23,23	
		S [MVA]	416,32	
		I [A]	594,61	
		%In	102,99	
DV 110 kV VE BALJCI - ŠUICA	1	P [MW]	117,68	DV 110 kV VE JELOVAČA - RAMA
		Q [MVAr]	-38,13	
		S [MVA]	123,70	
		I [A]	641,76	
		%In	100,22	

Table 51: N-1 contingency results – maximum load 2030 - extreme decarbonization – HVDC MONITA 500 MW

Element	Number of contingencies	Parametar	Value	The most critical outage
DV 110 kV TREBINJE - HERCEG NOVI	416	P [MW]	147,70	DV 400 kV LASTVA - TREBINJE
		Q [MVAr]	-51,48	
		S [MVA]	156,41	
		I [A]	816,35	
		%In	173,78	
DV 220 kV TREBINJE - HE PERUČICA	1	P [MW]	-320,96	DV 400 kV LASTVA - TREBINJE
		Q [MVAr]	1,23	
		S [MVA]	320,96	
		I [A]	791,47	
		%In	100,20	
DV 110 kV KOMOLAC - TREBINJE 2	2	P [MW]	137,23	DV 220 kV PLAT - PLAT
		Q [MVAr]	-14,76	
		S [MVA]	138,02	
		I [A]	715,64	
		%In	111,76	
TR1 400/220 kV TREBINJE	2	P [MW]	-407,02	DV 400 kV MOSTAR 4 - GACKO
		Q [MVAr]	40,33	
		S [MVA]	409,01	
		I [A]	579,52	
		%In	100,38	
DV 110 kV VE BALJCI - ŠUICA	1	P [MW]	118,27	DV 110 kV VE JELOVAČA - RAMA
		Q [MVAr]	-37,69	
		S [MVA]	124,13	
		I [A]	644,27	
		%In	100,61	

Table 52: N-1 contingency results – minimum load 2030 - referent decarbonization – HVDC MONITA 500 MW

Element	Number of contingencies	Parametar	Value	The most critical outage
DV 110 kV BUŠKO BLATO - LIVNO	409	P [MW]	156,11	DV 400 kV KONJSKO - KONJSKO
		Q [MVAr]	-16,05	
		S [MVA]	156,94	
		I [A]	797,99	
		%In	124,62	
DV 110 kV TREBINJE - HERCEG NOVI	417	P [MW]	153,33	DV 400 kV LASTVA - TREBINJE
		Q [MVAr]	-50,69	
		S [MVA]	161,49	
		I [A]	839,07	
		%In	178,62	
DV 110 kV KOMOLAC - TREBINJE 2	2	P [MW]	201,39	DV 220 kV PLAT - PLAT
		Q [MVAr]	-21,21	
		S [MVA]	202,50	
		I [A]	1048,57	
		%In	163,75	
DV 110 kV KUPRES - BUGOJNO	1	P [MW]	127,07	DV 400 kV ŠUICA - MOSTAR 4
		Q [MVAr]	-50,13	
		S [MVA]	136,60	
		I [A]	706,51	
		%In	110,34	
DV 110 kV VE DEBELO BRDO - KUPRES	1	P [MW]	129,54	DV 400 kV ŠUICA - MOSTAR 4
		Q [MVAr]	-44,52	
		S [MVA]	136,98	
		I [A]	709,62	
		%In	110,82	
DV 110 kV VE BALJCI - ŠUICA	1	P [MW]	119,58	DV 110 kV LIVNO - ŠUICA
		Q [MVAr]	-40,74	
		S [MVA]	126,33	
		I [A]	652,13	
		%In	101,84	
DV 110 kV LIVNO - ŠUICA	1	P [MW]	133,18	DV 110 kV VE BALJCI - ŠUICA
		Q [MVAr]	-27,03	
		S [MVA]	135,90	
		I [A]	697,56	
		%In	108,94	

Table 53: N-1 contingency results – minimum load 2030 - moderate decarbonization – HVDC MONITA 500 MW

Element	Number of contingencies	Parametar	Value	The most critical outage
DV 110 kV BUŠKO BLATO - LIVNO	410	P [MW]	160,20	DV 400 kV KONJSKO - KONJSKO
		Q [MVAr]	-16,42	
		S [MVA]	161,04	
		I [A]	819,28	
		%In	127,95	
DV 110 kV TREBINJE - HERCEG NOVI	417	P [MW]	152,56	DV 400 kV LASTVA - TREBINJE
		Q [MVAr]	-50,76	
		S [MVA]	160,78	
		I [A]	835,56	
		%In	177,87	
DV 110 kV KOMOLAC - TREBINJE 2	2	P [MW]	201,64	DV 220 kV PLAT - PLAT
		Q [MVAr]	-21,13	
		S [MVA]	202,74	
		I [A]	1050,02	
		%In	163,98	
DV 110 kV KUPRES - BUGOJNO	1	P [MW]	131,23	DV 400 kV ŠUICA - MOSTAR 4
		Q [MVAr]	-49,79	
		S [MVA]	140,36	
		I [A]	726,68	
		%In	113,48	
DV 110 kV VE DEBELO BRDO - KUPRES	1	P [MW]	133,77	DV 400 kV ŠUICA - MOSTAR 4
		Q [MVAr]	-43,97	
		S [MVA]	140,81	
		I [A]	729,95	
		%In	114,00	
DV 110 kV VE BALJCI - ŠUICA	1	P [MW]	119,10	DV 110 kV LIVNO - ŠUICA
		Q [MVAr]	-40,57	
		S [MVA]	125,82	
		I [A]	649,70	
		%In	101,46	
DV 110 kV LIVNO - ŠUICA	1	P [MW]	133,50	DV 110 kV VE BALJCI - ŠUICA
		Q [MVAr]	-27,02	
		S [MVA]	136,21	
		I [A]	699,33	
		%In	109,21	

Table 54: N-1 contingency results – minimum load 2030 - extreme decarbonization – HVDC MONITA 500 MW

Element	Number of contingencies	Parametar	Value	The most critical outage
DV 110 kV BUŠKO BLATO - LIVNO	410	P [MW]	160,21	DV 400 kV KONJSKO - KONJSKO
		Q [MVAr]	-16,42	
		S [MVA]	161,05	
		I [A]	819,29	
		%In	127,95	
DV 110 kV TREBINJE - HERCEG NOVI	417	P [MW]	152,56	DV 400 kV LASTVA - TREBINJE
		Q [MVAr]	-50,76	
		S [MVA]	160,79	
		I [A]	835,56	
		%In	177,87	
DV 110 kV KOMOLAC - TREBINJE 2	2	P [MW]	201,64	DV 220 kV PLAT - PLAT
		Q [MVAr]	-21,13	
		S [MVA]	202,74	
		I [A]	1050,03	
		%In	163,98	
DV 110 kV KUPRES - BUGOJNO	1	P [MW]	131,24	DV 400 kV ŠUICA - MOSTAR 4
		Q [MVAr]	-49,79	
		S [MVA]	140,37	
		I [A]	726,69	
		%In	113,49	
DV 110 kV VE DEBELO BRDO - KUPRES	1	P [MW]	133,77	DV 400 kV ŠUICA - MOSTAR 4
		Q [MVAr]	-43,97	
		S [MVA]	140,81	
		I [A]	729,95	
		%In	114,00	
DV 110 kV VE BALJCI - ŠUICA	1	P [MW]	119,10	DV 110 kV LIVNO - ŠUICA
		Q [MVAr]	-40,57	
		S [MVA]	125,82	
		I [A]	649,70	
		%In	101,46	
DV 110 kV LIVNO - ŠUICA	1	P [MW]	133,50	DV 110 kV VE BALJCI - ŠUICA
		Q [MVAr]	-27,02	
		S [MVA]	136,21	
		I [A]	699,33	
		%In	109,21	

Table 55: N-1 contingency results – maximum load 2030 - referent decarbonization – HVDC MONITA 1000 MW

Element	Number of contingencies	Parametar	Value	The most critical outage
DV 110 kV TREBINJE - HERCEG NOVI	418	P [MW]	198,88	DV 400 kV LASTVA - TREBINJE
		Q [MVAr]	-38,13	
		S [MVA]	202,50	
		I [A]	1071,59	
		%In	228,12	
DV 220 kV TREBINJE - HE PERUČICA	1	P [MW]	-416,86	DV 400 kV LASTVA - TREBINJE
		Q [MVAr]	-17,09	
		S [MVA]	417,21	
		I [A]	1041,78	
		%In	131,88	
DV 110 kV KOMOLAC - TREBINJE 2	2	P [MW]	146,05	DV 220 kV PLAT - PLAT
		Q [MVAr]	-13,30	
		S [MVA]	146,65	
		I [A]	762,81	
		%In	119,13	
TR1 400/220 kV TREBINJE	3	P [MW]	-538,09	DV 400 kV TREBINJE - GACKO
		Q [MVAr]	20,38	
		S [MVA]	538,47	
		I [A]	784,68	
		%In	135,91	
DV 110 kV VE DEBELO BRDO - KUPRES	1	P [MW]	120,70	DV 400 kV ŠUICA - MOSTAR 4
		Q [MVAr]	-26,74	
		S [MVA]	123,62	
		I [A]	643,76	
		%In	100,54	
DV 110 kV VE BALJCI - ŠUICA	1	P [MW]	117,73	DV 110 kV VE JELOVAČA - RAMA
		Q [MVAr]	-39,29	
		S [MVA]	124,11	
		I [A]	643,36	
		%In	100,47	

Table 56: N-1 contingency results – minimum load 2030 - referent decarbonization – HVDC MONITA 1000 MW

Element	Number of contingencies	Parametar	Value	The most critical outage
DV 110 kV BUŠKO BLATO - LIVNO	412	P [MW]	178,96	DV 400 kV KONJSKO - KONJSKO
		Q [MVAr]	-17,21	
		S [MVA]	179,78	
		I [A]	916,87	
		%In	143,19	
DV 110 kV TREBINJE - HERCEG NOVI	418	P [MW]	197,02	DV 400 kV LASTVA - TREBINJE
		Q [MVAr]	-38,31	
		S [MVA]	200,71	
		I [A]	1058,80	
		%In	225,40	
DV 110 kV LIVNO - ŠUICA	4	P [MW]	136,27	DV 110 kV VE BALJCI - ŠUICA
		Q [MVAr]	-26,57	
		S [MVA]	138,84	
		I [A]	713,36	
		%In	111,40	
DV 220 kV TREBINJE - HE PERUČICA	1	P [MW]	-384,84	DV 400 kV LASTVA - TREBINJE
		Q [MVAr]	-16,62	
		S [MVA]	385,20	
		I [A]	958,10	
		%In	121,29	
DV 110 kV KOMOLAC - TREBINJE 2	2	P [MW]	212,25	DV 220 kV PLAT - PLAT
		Q [MVAr]	-17,04	
		S [MVA]	212,93	
		I [A]	1109,58	
		%In	173,28	
TR1 400/220 kV TREBINJE	2	P [MW]	-502,69	DV 400 kV TREBINJE - GACKO
		Q [MVAr]	20,78	
		S [MVA]	503,12	
		I [A]	733,51	
		%In	127,05	
DV 110 kV GRUDE - ŠIROKI BRIJEG 2	1	P [MW]	130,42	DV 400 kV ŠUICA - MOSTAR 4
		Q [MVAr]	-18,87	
		S [MVA]	131,78	
		I [A]	689,56	
		%In	107,69	
DV 110 kV KUPRES - BUGOJNO	1	P [MW]	141,36	DV 400 kV ŠUICA - MOSTAR 4
		Q [MVAr]	-49,91	
		S [MVA]	149,91	
		I [A]	776,53	
		%In	121,27	
DV 110 kV VE DEBELO BRDO - KUPRES	1	P [MW]	144,05	DV 400 kV ŠUICA - MOSTAR 4
		Q [MVAr]	-43,52	
		S [MVA]	150,48	
		I [A]	780,07	
		%In	121,82	
DV 110 kV ŠIROKI BRIJEG - MOSTAR 4 2	1	P [MW]	121,03	DV 400 kV ŠUICA - MOSTAR 4
		Q [MVAr]	-31,09	
		S [MVA]	124,96	
		I [A]	658,69	
		%In	102,87	
DV 110 kV ŠIROKI BRIJEG 2 - ŠIROKI BRIJEG	1	P [MW]	126,68	DV 400 kV ŠUICA - MOSTAR 4
		Q [MVAr]	-23,82	
		S [MVA]	128,90	
		I [A]	676,96	
		%In	105,72	
DV 220 kV HE ZAKUCAC - ZAKUČAC	1	P [MW]	323,87	DV 400 kV ŠUICA - MOSTAR 4
		Q [MVAr]	-25,12	
		S [MVA]	324,84	
		I [A]	787,76	
		%In	100,06	
DV 110 kV VE BALJCI - ŠUICA	1	P [MW]	119,57	DV 110 kV LIVNO - ŠUICA
		Q [MVAr]	-39,52	
		S [MVA]	125,93	
		I [A]	650,96	
		%In	101,66	

Table 57: N-1 contingency results – maximum load 2030 - referent decarbonization – MONITA 500 MW - D + 110 kV reinforcement

Element	Number of contingencies	Parametar	Value	The most critical outage
DV 220 kV TREBINJE - HE PERUČICA	1	P [MW]	-329,10	DV 400 kV LASTVA - TREBINJE
		Q [MVAr]	-0,71	
		S [MVA]	329,10	
		I [A]	810,39	
		%In	102,59	
TR1 400/220 kV TREBINJE	1	P [MW]	-406,42	DV 400 kV TREBINJE - GACKO
		Q [MVAr]	22,38	
		S [MVA]	407,03	
		I [A]	580,51	
		%In	100,55	

Table 58: N-1 contingency results – maximum load 2030 - referent decarbonization – MONITA 500 MW - E + 110 kV reinforcement

Element	Number of contingencies	Parametar	Value	The most critical outage
DV 110 kV TREBINJE - HERCEG NOVI	417	P [MW]	154,7238007	DV 400 kV LASTVA - TREBINJE
		Q [MVAr]	-51,21224976	
		S [MVA]	162,9789886	
		I [A]	850,4263916	
		%In	181,036972	
DV 220 kV TREBINJE - HE PERUČICA	1	P [MW]	-344,8166809	DV 400 kV LASTVA - TREBINJE
		Q [MVAr]	-0,910682976	
		S [MVA]	344,8178711	
		I [A]	850,6134644	
		%In	107,6835403	
DV 110 kV KOMOLAC - TREBINJE 2	2	P [MW]	134,1650696	DV 220 kV PLAT - PLAT
		Q [MVAr]	-15,23361492	
		S [MVA]	135,0271454	
		I [A]	699,1949463	
		%In	109,1922989	
TR1 400/220 kV TREBINJE	1	P [MW]	-418,1159363	DV 400 kV TREBINJE - GACKO
		Q [MVAr]	23,27676773	
		S [MVA]	418,7633667	
		I [A]	598,1097412	
		%In	103,5956955	
DV 110 kV VE BALJCI - ŠUICA	1	P [MW]	117,1810303	DV 110 kV VE JELOVAČA - RAMA
		Q [MVAr]	-40,11204147	
		S [MVA]	123,8562469	
		I [A]	641,5193481	
		%In	100,1851654	

Table 59: N-1 contingency results – maximum load 2030 - referent decarbonization – MONITA 500 MW - D + 110 kV reinforcement

Element	Number of contingencies	Parametar	Value	The most critical outage
DV 220 kV TREBINJE - HE PERUČICA	1	P [MW]	-329,10	DV 400 kV LASTVA - TREBINJE
		Q [MVAr]	-0,71	
		S [MVA]	329,10	
		I [A]	810,39	
		%In	102,59	
TR1 400/220 kV TREBINJE	1	P [MW]	-406,42	DV 400 kV TREBINJE - GACKO
		Q [MVAr]	22,38	
		S [MVA]	407,03	
		I [A]	580,51	
		%In	100,55	

Table 60: N-1 contingency results – maximum load 2030 - referent decarbonization – MONITA 500 MW - E + 110 kV reinforcement

Element	Number of contingencies	Parametar	Value	The most critical outage
DV 220 kV TREBINJE - HE PERUČICA	1	P [MW]	-343,68	DV 400 kV LASTVA - TREBINJE
		Q [MVAr]	-0,10	
		S [MVA]	343,68	
		I [A]	847,84	
		%In	107,33	
TR1 400/220 kV TREBINJE	1	P [MW]	-416,94	DV 400 kV TREBINJE - GACKO
		Q [MVAr]	24,35	
		S [MVA]	417,65	
		I [A]	596,35	
		%In	103,29	

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12 LITERATURE

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