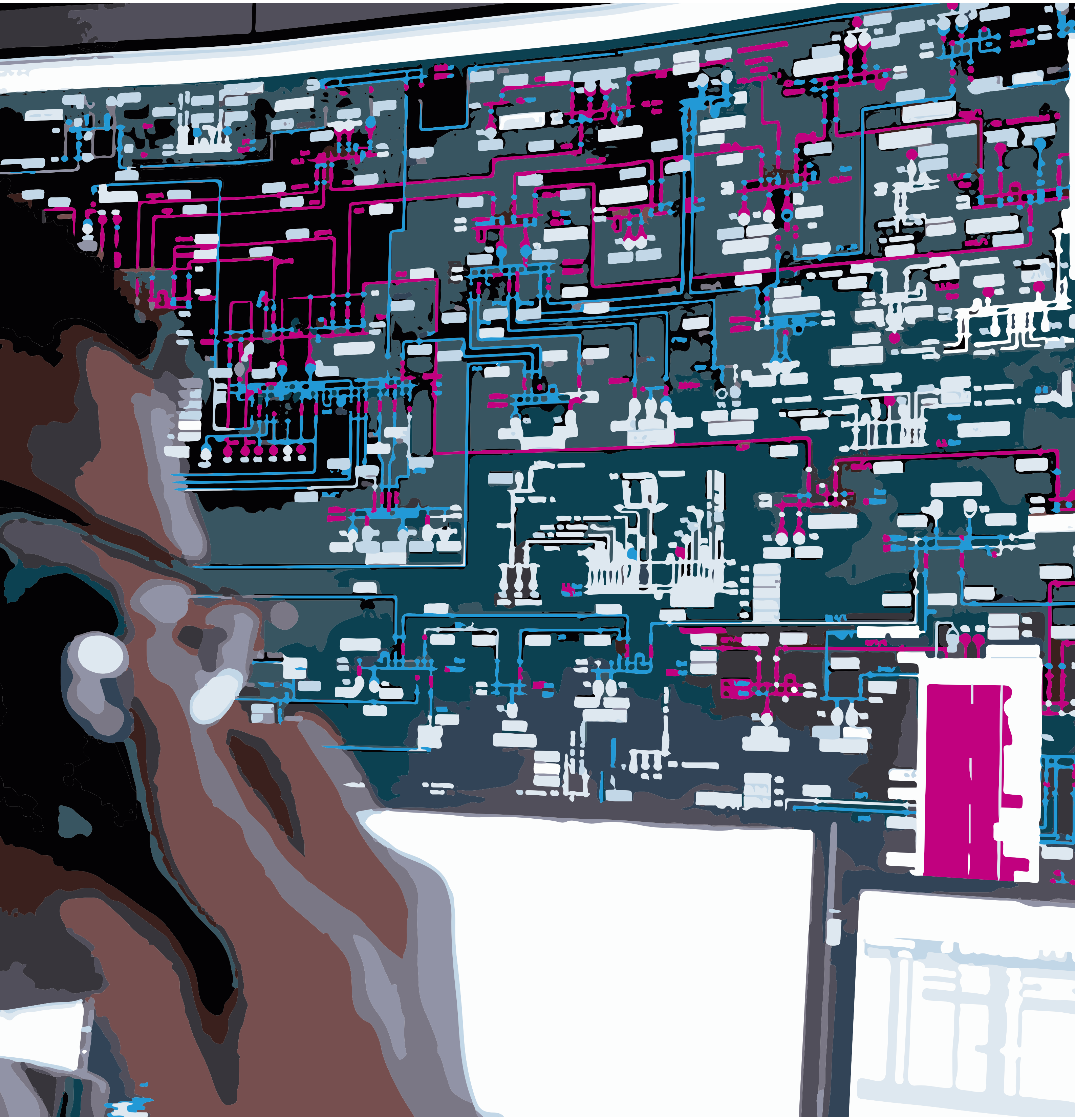
» Grid Incident in South-East Europe on 21 June 2024

ICS Investigation Expert Panel » Final Report » 25 February 2025



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» Grid Incident in South-East Europe on 21 June 2024

ICS Investigation Expert Panel

Final Report

25 February 2025

CONTENTS

1 MANAGEMENT SUMMARY

1.1 Introduction

On Friday, 21 June 2024, a significant incident occurred in South-East Europe (SEE), leading to a major disruption in the Continental Europe (CE) power system. The incident resulted in a substantial loss of load and generation, affecting multiple countries including Albania (OST), Bosnia and Herzegovina (NOSBiH), Montenegro (CGES), and Croatia (HOPS). The event was characterised by a series of contingencies in the transmission network, which ultimately led to a (partial) blackout in these four countries.

Immediately after the incident, the Transmission System Operators (TSOs) in the affected South-East Europe initiated a coordinated response to manage the situation and restore normal operations. This management summary provides a detailed overview of the system conditions before the incident, the sequence of events during the incident, the restoration process, and the communication between coordination centres and TSOs. The summary also includes an analysis of the incident based on **the Incident Classification Scale (ICS) methodology** and outlines the next steps for the further investigation and improvement of the system performance.

This final report presents the gathered facts and the analysis of the causes, offering a comprehensive understanding of the incident and its impact on the power system in the Balkan region, conclusions about the root causes of the incident and recommendations to help avoid this type of event in the future. All times in this report are Central European Summer Time (CEST), which is equivalent to UTC+02:00.

1.2 System and Market Conditions Before the Incident

The outage planning is coordinated through TSOs and Regional Coordination Centres (RCCs), with annual and weekly meetings to harmonise maintenance plans. Several lines were disconnected according to the plan on 21 June 2024, including some of the 220 kV and 400 kV lines. No unplanned outages were reported by the affected TSOs[1] close to the initial outage of the incident in SEE.

June 2024 experienced record high temperatures globally and in Europe, with significant heatwaves in SEE. Temperatures over 40°C were recorded in many places, contributing to increased power demand and other operational challenges.

Organised day-ahead market information is available in three out of four affected price zones, with significant cross-border market transactions based on explicitly allocated Cross-Zonal Capacity (CZC), which refers to the maximum amount of electricity that can be transmitted between two different price zones or regions without compromising the security of the electricity supply. The highest electricity price was in Albania at 176.32 €/MWh.

Load patterns reflected seasonal changes and increased due to tourism and similar weather conditions across the region. The daily load curve on 21 June was around 10 % higher than the working week average, with total consumption significantly increasing.

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[1] The term "affected TSOs" refers to four TSOs (CGES, HOPS, NOSBiH and OST) that were affected by the incident of scale 2 or 3. More details can be found in chapter 7.1 of this report.

Significant differences between scheduled commercial exchanges and physical flows were recorded due to the highly meshed grid and bilateral Net Transfer Capacity (NTC) methodologies applied on all the borders between the affected TSOs.

Day-ahead and intra-day security analyses performed by the concerned TSOs did not indicate any critical contingency leading to a possible violation of the operational security. The analyses showed no major critical outages during the critical period, and remedial actions were in place for identified overloads.

1.3 Evolution of System Conditions During the Event

The disturbance on 21 June 2024 involved multiple outages across various substations and voltage levels, primarily affecting 400 kV and 220 kV networks. The first trip occurred on the 400 kV line Ribarevine – Podgorica 2 at 12:09:16. The second trip occurred on the 400 kV line Zemblak – Kardia at 12:21:30. Both incidents were confirmed to be caused by insufficient clearance with vegetation. This resulted in the tripping of several other transmission lines and a voltage collapse in Bosnia and Herzegovina, Montenegro, Albania and Croatia. The event caused a substantial loss of load and generation, with a total generation loss of 2,214 MW and significant load losses across various TSOs within minutes. Transformer tap changers responded to voltage drops, with automatic voltage regulation observed mainly in the CGES (ME), HOPS (HR), and NOSBiH (BH) control areas, while OST (AL) had no automatic regulation.

1.4 Communication of Coordination Centres SAM and Between TSOs

The communication began with TERNA informing CGES about the High Voltage Direct Current (HVDC) cable Monita tripping, followed by exchanges between CGES, NOSBiH, HOPS and OST regarding the incident details and support offers. Swissgrid played a significant role in post-blackout communications, coordinating with Amprion, ELES and OST to offer assistance and gather updates on the situa¬tion. RCCs communicated effectively during the incident. The European Awareness System (EAS) was used, detailing the changes in system states for each affected TSO during the incident, including normal, alert, emergency, blackout and restoration states.

1.5 RCC Post-Event Analysis

The results of the various tasks performed by the RCCs before the incident on 21 June 2024 indicate that the grid was considered secure, and no major issues were detected in the affected area. The Outage Planning Coordination (OPC) task, conducted by SEleNe CC, SCC and TSCNET, showed no security alerts for the relevant grid elements. The Short-Term Adequacy (STA) analysis, led by SCC, confirmed that the available production capacity could meet the expected consumption. The security BIHanalysis performed by TSCNET, SCC and SEleNe CC, revealed no significant operational security risks, and the grid was deemed N-1 secure. Similarly, other RCC tasks like creation of the Common Grid Model (CGM), Coordinated Capacity Calculation (CCC) and consistency assessment of defence and restoration plans did not indicate any unsafe operation where and to the extend they have been performed (Capacity Calculation (CC), and Regional Grid Model.

The Regional Incident Analysis and Reporting (RIAR) task, as mandated by Article 37 of EU Regulation 2019/943, outlines a methodology that requires RCCs to conduct thorough post-operation and post-disturbance analyses. This methodology was applied rigorously to aid the technical analysis of the incident. The conclusions derived from this subgroup's investigation were incorporated into this chapter, providing valuable insights

1.6 Technical Analysis

The technical analysis, divided into seven subchapters, provides a comprehensive understanding of the technical factors that contributed to the grid incident and offers insights into potential improvements for future grid stability and reliability.

System Conditions

This subchapter outlines the system conditions leading up to the incident, highlighting the significant impact of air conditioning systems on load behaviour. It reveals that 30 % – 35 % of the total consumption was due to air conditioning systems, contributing to increased demand. The analysis also discusses import conditions, generation patterns, and the availability of reactive power support, concluding that high imports and increased air conditioning system use led to a voltage drop due to significant reactive power demand by loaded lines.

Trip 400 kV OHL Podgorica 2 – Ribarevine

This section details the short circuit on the 400 kV Podgorica 2 – Ribarevine line, caused by vegetation proximity. The fault occurred at 12:09:16, the leading to the line tripping. The analysis covers weather conditions, loading of the line, vegetation control practices, and the design parameters of the overhead line. It also discusses the impact of the fault on voltage levels and interconnections.

Trip 400 kV OHL Zemblak – Kardia

This subchapter examines the short circuit on the 400 kV Zemblak – Kardia line, which tripped at 12:21:33 due to a ground fault caused by vegetation. The analysis includes weather conditions, the loading of the line, vegetation control measures, and the design parameters of the line. It also discusses the impact of the fault on the interconnection between Albania and Greece.

Subsequent Trip of Multiple Lines

This section analyses the disconnection of 220 kV OHL Fierze – Prizren 2, 220 kV OHL Podgorica 1 – Mojkovac, the HVDC cable Monita, and 220 kV OHL Sarajevo 20–Piva, which happened right after the Zemblak – Kardia trip. The analysis details the sequence of events and the corresponding protection actions, discussing operational limits, overcurrent protection settings, and the impact of the trips on the grid.

Voltage Stability During the Incident

This subchapter discusses the voltage stability issues that occurred during the incident. The main factors contributing to the voltage instability and collapse were high levels of import, a lack of sufficient voltage support, and the disconnection of key 400 kV lines. The analysis explains the theoretical background of voltage stability and highlights the effects of high penetration of air conditioning load and other factors during the voltage collapse.

Situational Awareness

This section addresses the situational awareness of the affected TSOs during the incident. It covers dynamic stability assessment, N-1 security assessment, and observability areas. The conclusion emphasises the need for enhanced observability areas to ensure more accurate monitoring and faster identification of potential N-1 violations.

Outage of 400 kV OHL Tuzla – Višegrad

This subchapter explains why the 400 kV OHL Tuzla 4 – Višegrad line was out of service during the voltage collapse. It discusses the background, protection settings, and remedial actions taken to prevent overvoltage. The conclusion states that keeping the line out of service was crucial for maintaining the stability of HPP Višegrad.

1.7 Restoration Process

TSOs affected by the incident receved information by EAS and communications between affected TSOsabout voltage collapse and blackout in Albania, Montenegro, Bosnia and Herzegovina, and Croatia shortly after the disturbance, leading to immediate restoration planning.

Interconnections were used for a top-down restoration process, ensuring active power management on tie-lines according to agreements between TSOs.

- HOPS began restoring the Split area from the 220 kV voltage level due to a blackout and maintenance on a 400 kV line, followed by a series of reconnections and transformer activations to energise key substations.
- NOSBiH coordinated with neighbouring TSOs and initiated restoration from the Ugljevik substation, progressively reconnecting lines and substations, and addressing high voltage issues in the southern part of their system.
- CGES focused on restoration from the northern part of the country, starting with the reconnection of key lines and transformers, and resynchronising with OST.
- OST restored power by energising substations and synchronising with neighbouring grids, starting with IPTO and following with KOSTT and CGES.

The restoration process began with the first action at 12:33, and restoration process of the load for all TSOs was completed around 16 h.

1.8 Classification of the Incident Based on the ICS Methodology

The ICS Methodology is based on the requirements of Regulation (EC) No 714/2009 and Commission Regulation (EU) 2017/1485 and aims to provide a realistic view of system states during incidents. The criteria for incident classification are ranked by priority, with the highest priority criterion determining the incident scale. An Expert Panel investigates incidents classified as scale 2 or 3. On 21 June 2024, the OB3 criterion was met in Albania, Bosnia-Herzegovina and Montenegro, while Croatia met the L2 criterion.

The incident was classified as scale 3 due to the high demand loss. The RCC Investigation Threshold was met because multiple TSOs moved to emergency states, and the incident was confirmed as at least a scale 2 incident. Meeting the threshold prompts initiating an RCC investigation by the RCC Investigation Subgroup pursuant to Article 7 of the RCC Post-Operation and Post-Disturbances Analysis and Reporting Methodology

1.9 Conclusions, Recommendations and Internal Actions

The final chapter provides a comprehensive set of conclusions and recommendations derived from the analysis of the grid incident. The recommendations are divided into sections linked to the main causes of the incident and other critical factors not directly related to the blackout.

The conclusions summarise the following root causes of the incident:

- Short circuits on lines #1 and #2 due to vegetation proximity issues
- The lack of N-1 detection of overloads after the first line outage
- Failure to detect the potential voltage instability of the area
- Disconnections of three lines due to overcurrent protection
- The automatic action of voltage transformers
- Insufficient means to support the voltage
- The need for additional measures designed to prevent a voltage collapse

The following recommendations aim at addressing these issues:

- Check the national policy and operational process of vegetation growth control near the OHL and review them if needed.
- Evaluate the N-1 calculations of incidents in the neighbouring grid in the real-time EMS-SCADA systems and adjust the observability areas within the SCADA systems of affected TSOs if needed.
- Regularly assess voltage stability aspects in operational planning.
- Analyse the possibility of identifying an easy-to-use KPI or tool to proactively detect reduced voltage stability and the risk of voltage collapse.
- Review the existing ENTSO-E guidelines on overcurrent protections in OHL to assess the potential for updating them based on the findings of this incident. Each member of ENTSO-E to check their policy of installing overload (or overcurrent) protections in OHL and review these settings, taking into account the reviewed ENTSO-E guidelines.
- Block the ULTC (under-load tap changers) of transformers (V)HV-MV and VHV-HV where appropriate (depending on renewable infeed and load characteristics).
- Perform a voltage and reactive power assessment for potential low-voltage situations to be considered during the system design. Review the installation of support measures in areas where there is a risk of voltage collapse.
- Investigate the possibility of implementing an automatic emergency control concept for reactive power compensation devices on MVAr sources (for instance, capacitors IN, inductors OUT) at preset extreme voltage levels.
- Perform an assessment and consider the feasibility of installing under-voltage load shedding (UVLS) at loads that positively contribute to voltage, in cases where there are insufficient alternative means of voltage support.
- Verify the data provided for tie-lines in the IGMs (Imax, TRM, FRM, etc.).
- Perform timely update of topological changes in IGMs (RCC recommendation).
- Check the quality of voltage and reactive power calculations and identify whether improvements are possible (RCC recommendation).

These recommendations are intended to enhance grid stability and prevent future incidents by addressing the identified root causes and critical factors.

2 SYSTEM AND MARKET CONDITIONS BEFORE THE INCIDENT

This chapter describes the system conditions in the four affected TSOs before the incident on 21 June 2024 at 12:09. It includes an overview of scheduled and real-time topology, weather conditions during the day, respective market environment, load and production patterns and trends in the period before the incident, as well as the results of security analysis, conducted before the initial outage.

2.1 Information on Topology

2.1.1 Planned Outages

Outage planning coordination in SEE is performed through the TSOs' and RCCs' collaboration within the South-East Europe Maintenance Group[2]. The group meets at least once a year (Annual SEE MG Meeting) to harmonise individual transmission grid elements maintenance plans.

Weekly outage coordination is performed during regular weekly operational teleconferences (WOPT), organised by RCCs (during 2024 this task is performed by SELENE CC). According to the Report on disconnections of relevant elements in the SEE region for the week 25 (2024-06-15 – 2024-06-21), scheduled topology in the region was as presented in Table 1 and in Figure 1.

Element	Start Date	Start Time	End Date	End Time
400 kV TIE Bekescsaba (MAVIR) – Nadab (TEL) CKT 1	21.05.2024	7:00	12.07.2024	17:00
400 kV TIE Arachthos (IPTO) – Galatina (TERNA) CKT 1	27.05.2024	8:00	23.06.2024	16:00
400 kV OHL Bucuresti Sud (TEL) – Pelicanu (TEL) CKT 1*	28.05.2024	6:00	20.06.2024	17:00
400 kV OHL Tirana 2 (OST) – Koman (OST) CKT 1	01.06.2024	0:00	30.09.2024	23:00
220 kV OHL Kolacem (OST) – Tirana 2 (OST) CKT 1	01.06.2024	0:00	30.09.2024	23:00
400 kV TIE Koman (OST) – Kosovo B (KOSTT) CKT 1	01.06.2024	0:00	30.09.2024	23:00
400 kV OHL Cernavoda (TEL) – Medgidia Sud (TELA) CKT 1**	10.06.2024	6:00	21.06.2024	17:00
400 kV OHL Bucuresti Sud (TEL) – Slatina (TEL) CKT 1	14.06.2024	5:00	20.06.2024	17:00
400 kV OHL Paks (MAVIR) – Sándorfalva (MAVIR) CKT 1	15.06.2024	7:00	16.06.2024	17:00
400 kV OHL KOZLODUY (ESO) – SOFIA ZAPAD (ESO) CKT 2	15.06.2024	7:00	16.06.2024	17:00
400 kV OHL KOZLODUY (ESO) – SOFIA ZAPAD (ESO) CKT 3	15.06.2024	7:00	16.06.2024	17:00
400 kV KOZLODUY (ESO) – SOFIA ZAPAD (ESO) CKT 1	17.06.2024	7:00	21.06.2024	15:30
400 kV OHL Obrenovac (EMS) – Kragujevac 2 (EMS) CKT 1	17.06.2024	7:00	23.06.2024	18:00
400/220 kV TR MARITZA IZTOK 3 (ESO) CKT 1	17.06.2024	7:00	28.06.2024	15:00
220 kV TIE TE Sisak (HOPS) – Prijedor 2 (NOSBiH) CKT 1	17.06.2024	8:00	19.07.2024	17:00
400 kV OHL Tuzla 4 (NOSBiH) – Ugljevik (NOSBiH) CKT 1	20.06.2024	8:00	21.06.2024	16:00

* excluded days: 08–09.06.2024 ** excluded days: 15–16.06.2024

Table 1: List of disconnections for relevant network elements in the SEE region for week 25 and for the voltage levels 220 kV and 400 kV (scheduled disconnections for 21 June highlighted).

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[2] Participating TSOs of the group are CGES, EMS, ESO EAD, HOPS, IPTO, KOSTT, MAVIR, MEPSO, NOSBiH, OST, TEİAS and Transelectrica

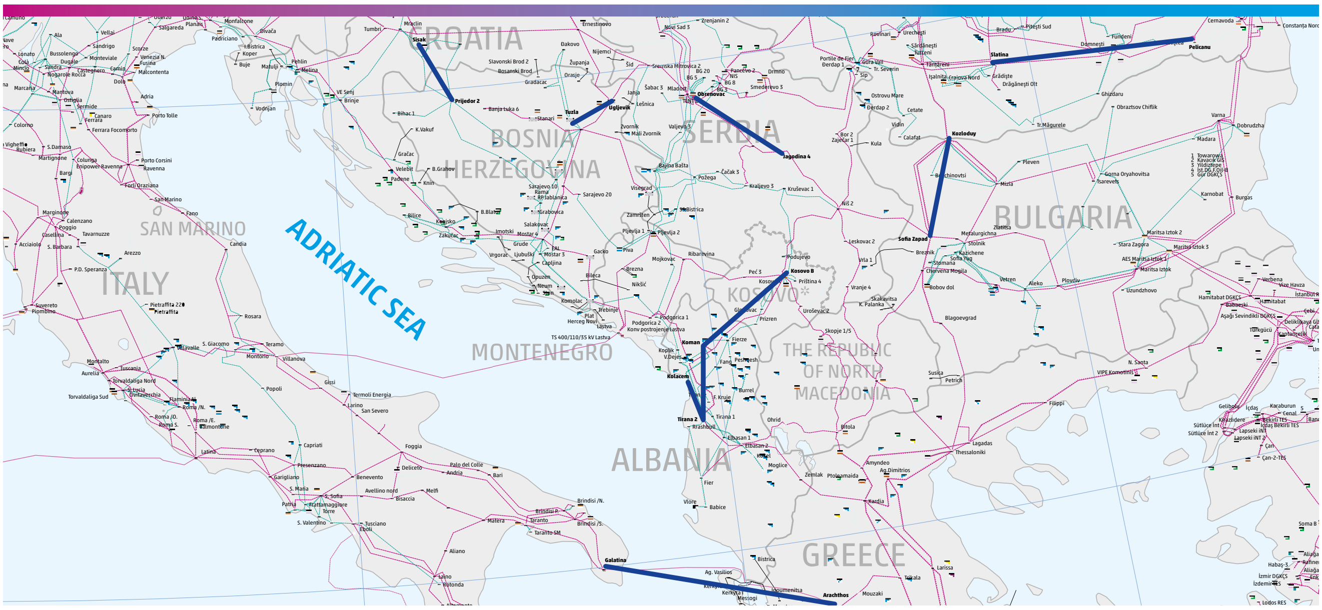

Figure 1: Planned disconnections of relevant elements in the SEE region for the week 25

In the affected area on 21 June, according to the above plan the following lines of interest were disconnected:

- » 220 kV TIE TE Sisak (HOPS) – Prijedor 2 (NOSBiH)
- » 400 kV OHL Tuzla 4 (NOSBiH) – Ugljevik (NOSBiH)
- » 400 kV TIE Koman (OST) – Kosovo B (KOSTT)
- » 400 kV OHL Tirana 2 (OST) – Koman (OST)
- » 220 kV OHL Kolacem (OST) – Tirana 2 (OST)

In addition to the long-term planned disconnections above, within the affected area, there was also a planned disconnection of:

- » 400 kV OHL Melina (HOPS) – Velebit (HOPS)

Due to the high voltage issues[3] in 400 kV node Višegrad (NOSBiH), an additional disconnection was announced within the Day-Ahead-Congestion-Forecast (DACF) individual grid models (IGM) preparation process. This is in line with the formal voltage management procedure established by ENTSO-E and agreed between all TSOs, whereby this is an acceptable measure for managing high voltage magnitudes in the electrical nodes, on the condition that the measure is coordinated with the considered TSOs:

- » 400 kV OHL Tuzla 4 (NOSBiH) – Višegrad (NOSBiH)

While announced in the DACF process as disconnected, the line was announced as connected in the Intraday Congestion Forecasts (IDCF) process through the relevant IGMs.

All mentioned outages were fully implemented in the IGMs of affected TSOs and were the part of the CGM used for the day-ahead and intraday coordinated security analysis.

2.1.2 Unplanned Outages

In addition to weekly and day-ahead announcements, no unplanned outages were reported by the affected TSOs after the delivery time for DACF IGMs, within the timeframe relatively close to the initial outage of the incident (12:09:16).

2.1.3 Affected Area Topology at 12:00

The planned disconnections described in subchapter 2.1.1 were all realised, with the exception of the line 400 kV OHL Tuzla 4 (NOSBiH) – Ugljevik (NOSBiH) that remained in operation.

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[3] The SEE region typically faces high voltages on a seasonal basis. In addition to planned grid reinforcements that are expected to result in a permanent solution of the issue, TSOs are applying topological measures to minimise the effect of this phenomena.

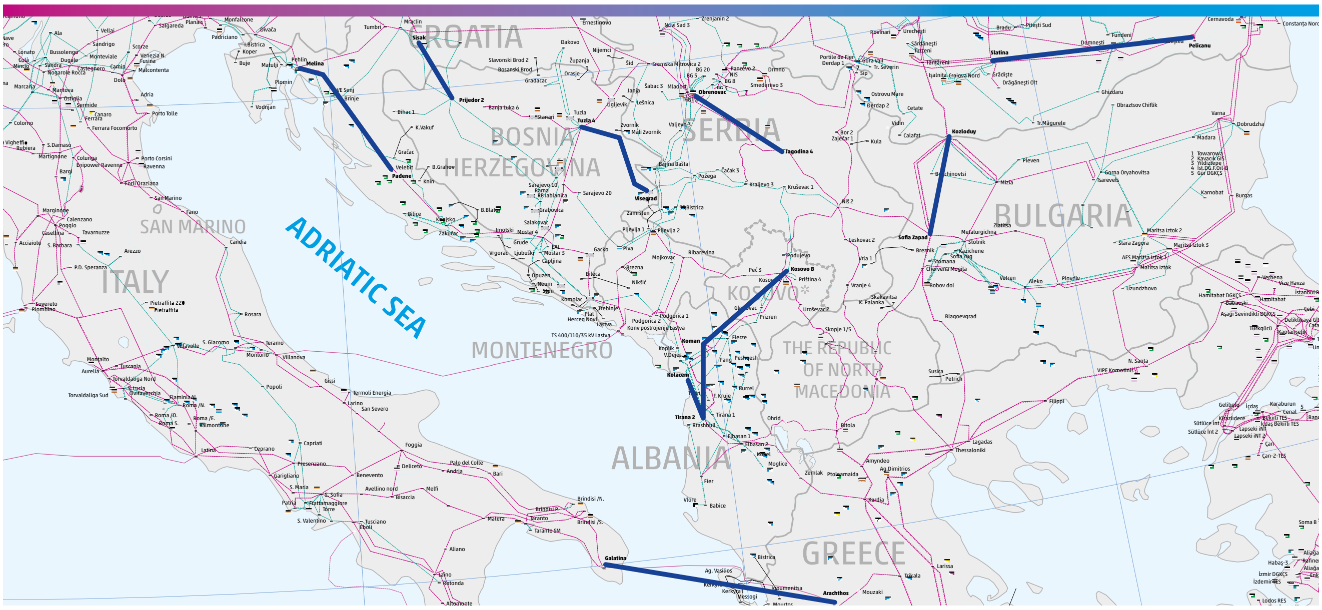

Figure 2: Affected area topology at 12:00

2.2 Weather Conditions

According to the Copernicus climate change service (C3S)[4], the average European temperature for June 2024 was 1.57 °C above the 1991–2020 average for June, making the month the joint-second warmest June on record for Europe.

In June 2024, air temperatures were well above their 1991–2020 average over southern Italy, southeast Europe and Turkey, reflecting the heatwaves that occurred in Cyprus, Greece and Turkey. Temperatures over 40 °C were recorded in many places and Athens had its hottest June in a data record going back to 1860, while Greece had its warmest June since 2010.

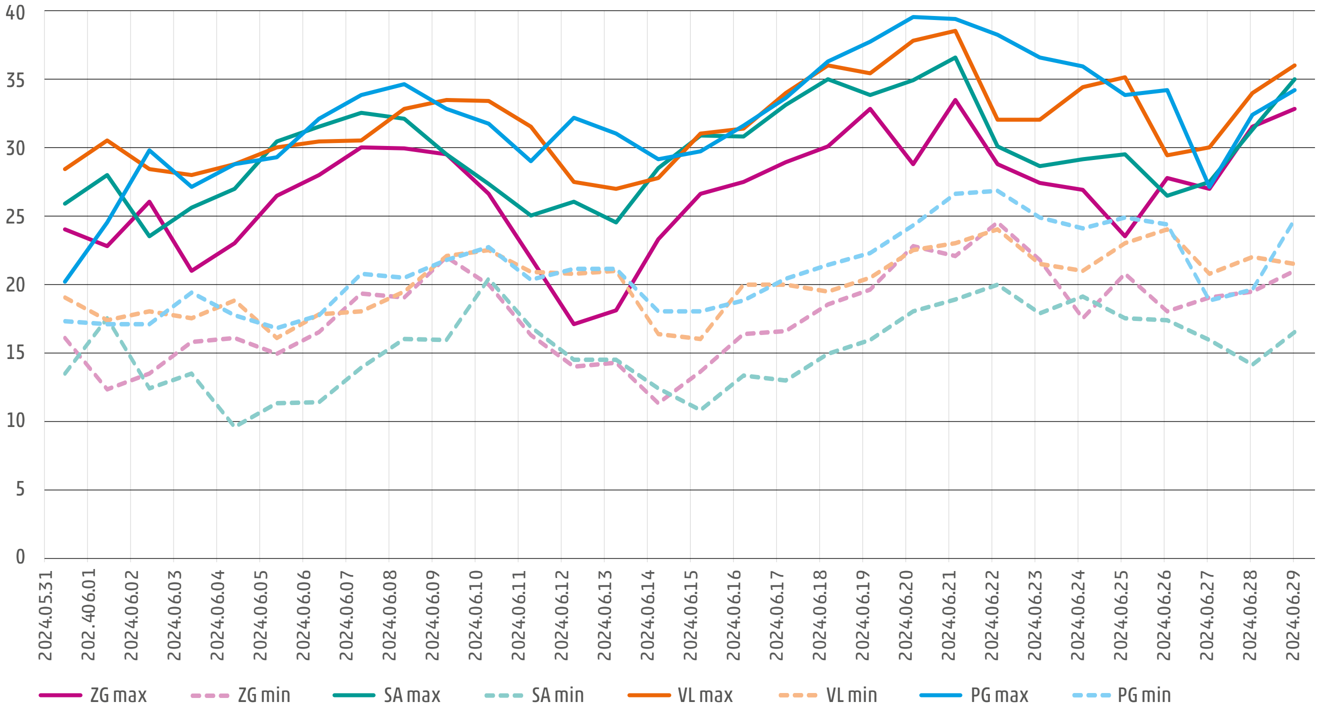

Figure 3: Maximal and minimal daily temperatures during June 2024 in Zagreb (HR), Sarajevo (BA), Podgorica (ME) and Vlore (AL)

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[4] C3S is one of six thematic information services provided by the Copernicus Earth Observation Programme of the European Union (**About us | Copernicus**)

The entire affected area was sharing the conditions present in the SEE region. According to the European Climate Assessment & Dataset (ECA&D)[5], on 21 June 2024 maximum temperatures were between 35 °C and 40 °C in Podgorica (ME), Sarajevo (BA) and Vlore (AL), while daily average temperatures were above 30 °C in Podgorica and Vlore and above 27 °C in Sarajevo and also in Zagreb (HR) (Figure 3).

An illustration of the average daily temperatures in the last 8 years in Podgorica (Figure 4) clearly shows the 21 June (as well as several previous days) was the hottest 21 June in the observed period (2017–2024).

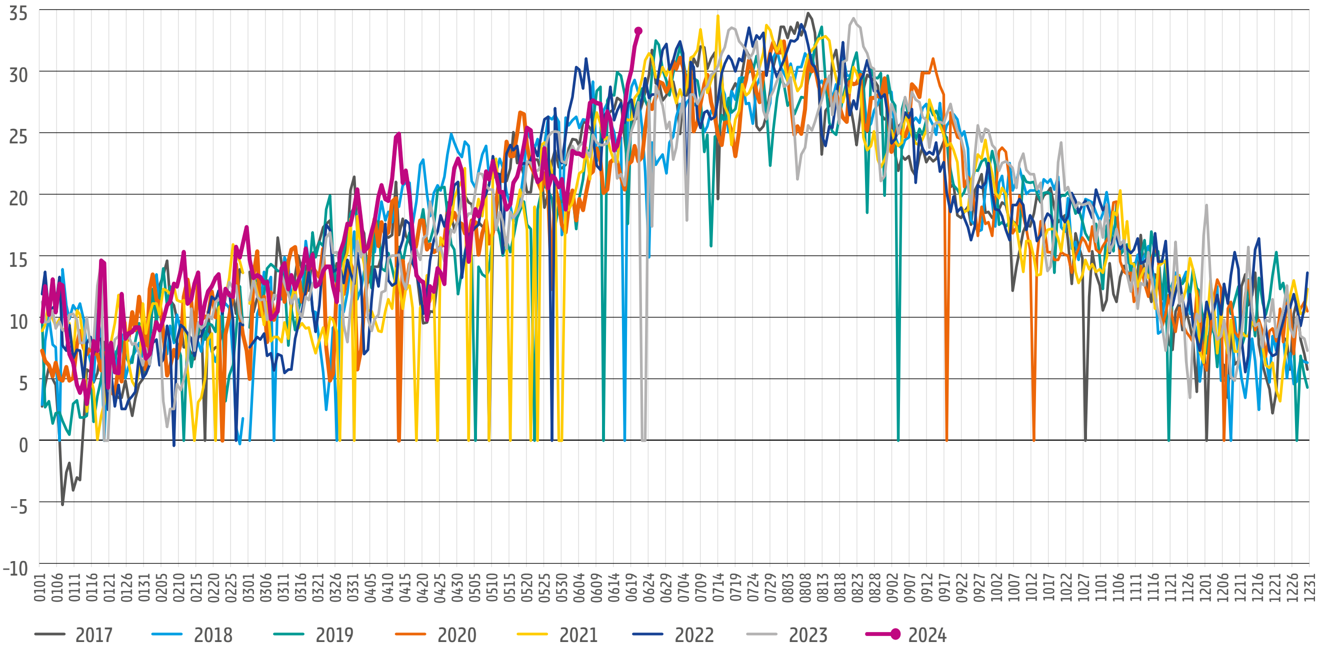

Figure 4: Average daily temperature in last 8 years in Podgorica in °C

While also bearing in mind the high levels of radiation all across the region, combined with very calm air (i. e. average daily wind speeds in Podgorica and Vlora are reported in the range between 1 and 2 m/s), the observed weather conditions were simultaneously a contributing factor to the several aspects of importance for power system operation:

- increased power demand (including additional reactive power demand) due to the increased need for air conditioning system,
- increased production from solar generating units, still unequally distributed across the region,
- increased power flows including cross-border exchange; and
- increased ambient temperature high-voltage overhead lines were operating in.

2.3 Market Information

Day ahead market information is available in 3 out of 4 affected price zones (systems). With the exception of Bosnia and Herzegovina, power exchanges are operational in all other countries, providing spot market price signals as described below.

Cross-border market transactions among affected TSOs (price zones) are based on the explicitly allocated CZCs by the regional coordinated capacity allocation platform SEE CAO.

During the incident, markets were not suspended in the affected areas.

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[5] Data and metadata available at http://www.ecad.eu

2.3.1 DAM Prices

Day ahead spot electricity prices in the region for the 13th hour of 21 June are as shown in Figure 5. The highest price was in Albania price zone reaching 176.32 €/MWh, followed by Montenegrin 124.82 €/MW. Northern and western parts of the region were settled around 100 €/MWh, while the lowest price was reached in Greece with 75 €/MWh.

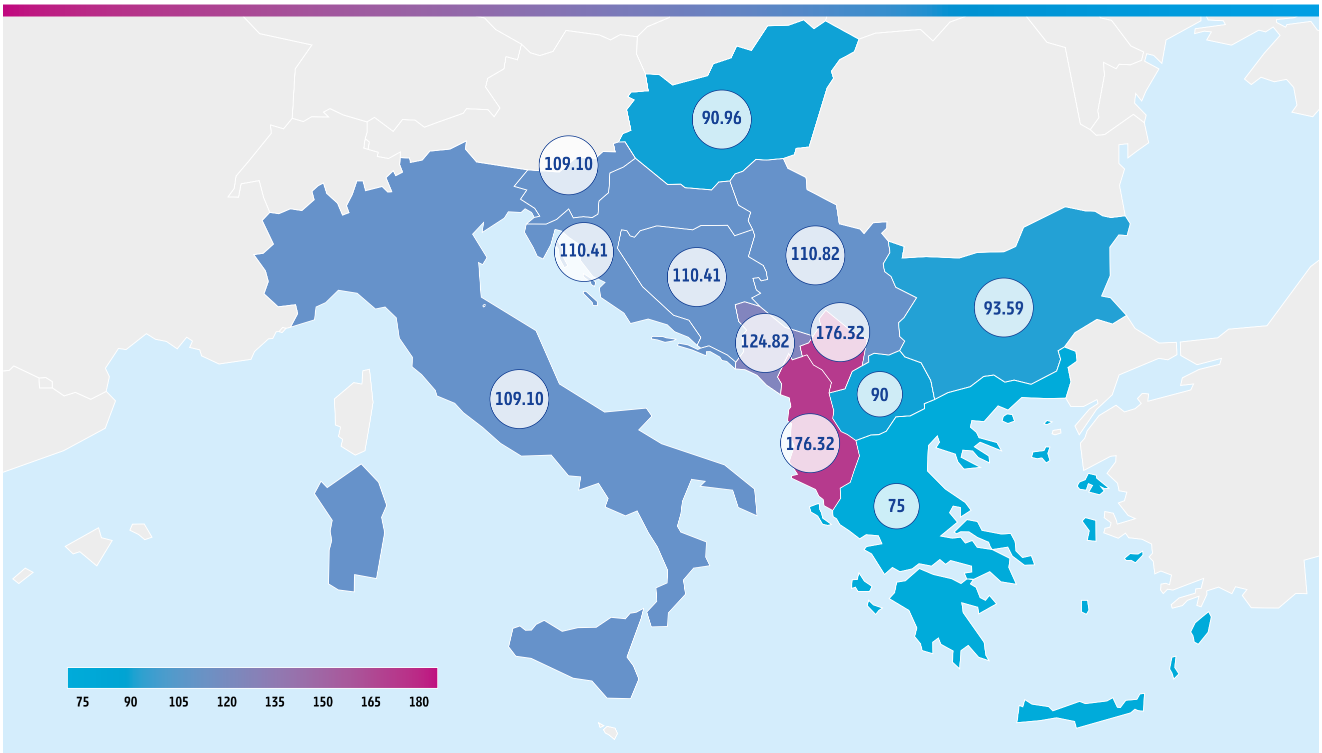

Figure 5: DAM Electricity prices for 13th hour, 21 June 2024

2.3.2 DA CBC Prices

According to the data available from SEE CAO platform, cross-zonal capacities prices allocated on daily level reflected the market conditions and price differences described above. The value of capacities varied from 1.33 €/MW on the Montenegro–Albania direction to 35 €/MW in the Greece–Albania direction.

Delivery period start	Border direction	Time-table	Offered Capacity - Daily auction (MW)	Total Requested Capacity - Daily auction (MW)	Total Allocated Capacity - Daily auction (MW)	Auction Clearing Price (€/MWh)
21.06.2024	HR-BA	12:00-13:00	599	917	599	2.55
21.06.2024	BA-ME	12:00-13:00	394	783	394	10.11
21.06.2024	ME-AL	12:00-13:00	206	335	206	1.33
21.06.2024	GR-AL	12:00-13:00	184	540	184	35.00

Table 2: Cross-zonal capacities prices, SEE CAO results, Day ahead auctions.

2.4 Power Flows before the Incident

Comparing the power flows on several borders of the affected TSOs, one can note a change of historical patterns. According to the comparison of the ENTSO-E Transparency Platform data about flows in June, July and August of 2022, 2023 and 2024, by the date of the incident it is evident that on some borders, total physical energy exchange has been significantly increased or has even changed the historically dominant direction of flows.

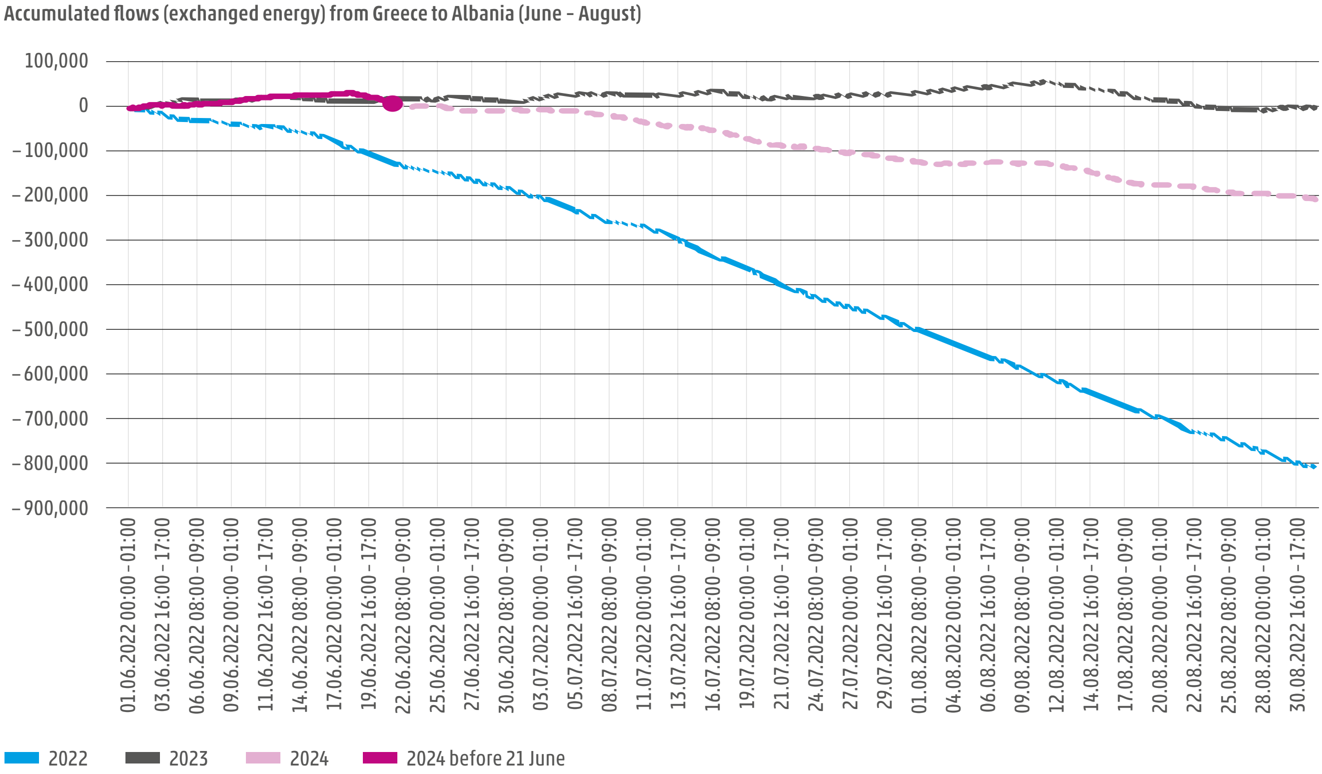

Figure 6: Accumulated flows (exchanged energy) from Greece to Albania (June – August)

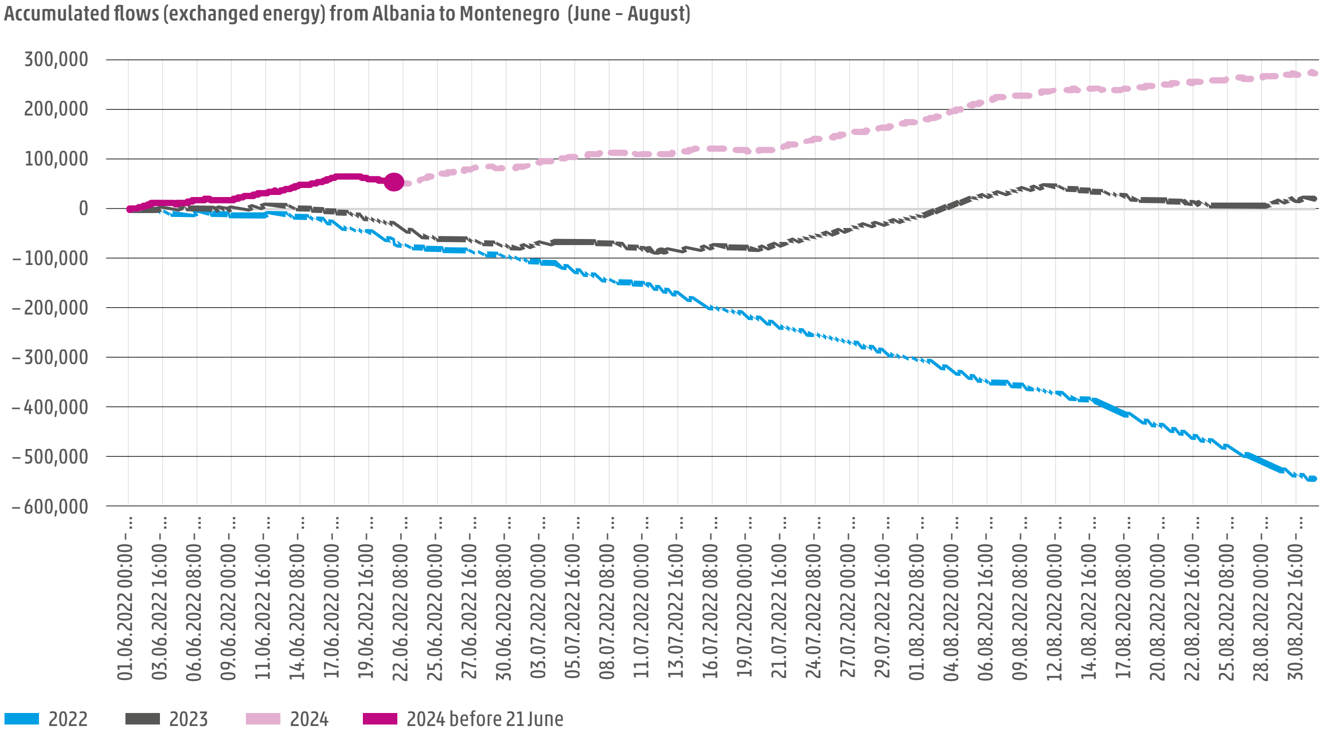

Figure 7: Accumulated flows (exchanged energy) from Albania to Montenegro (June – August)

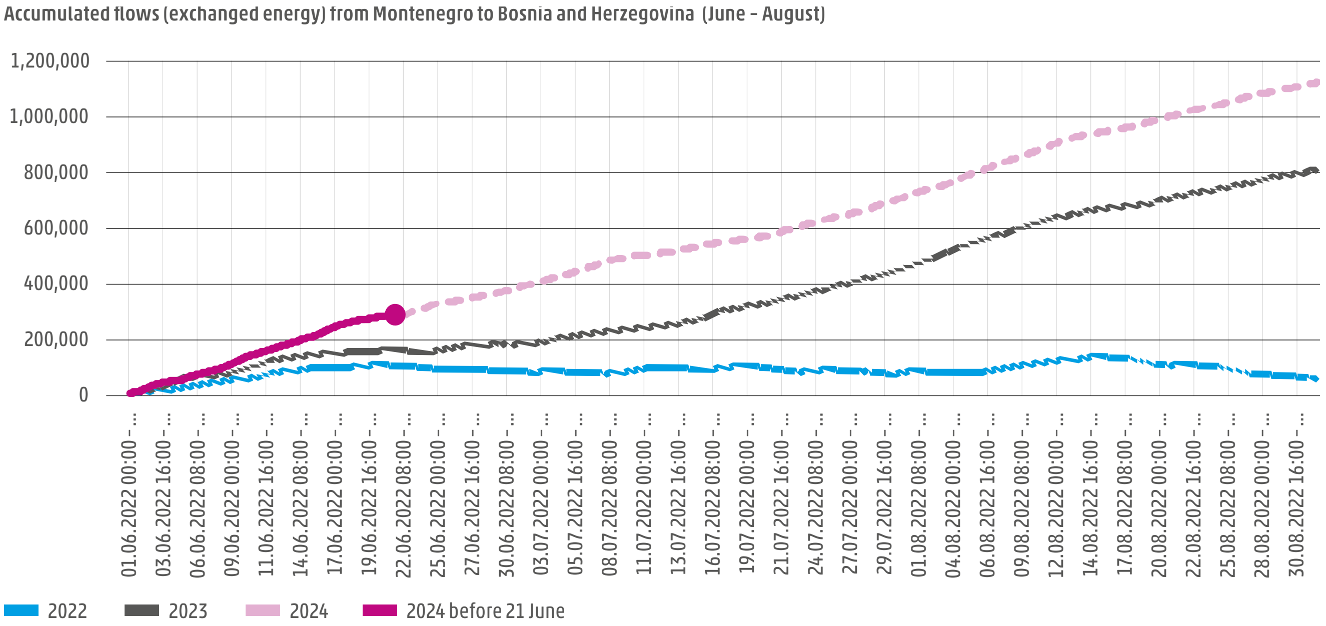

Figure 8: Accumulated flows (exchanged energy) from Montenegro to Bosnia and Herzegovina (June - August)

On the Albania–Greece border maximal daily flows from Albania to Greece were way above 2022 and 2023 levels for the same period of 2024 by 17 June, after which they also exceeded the values from 2022 and 2023 in the opposite direction.

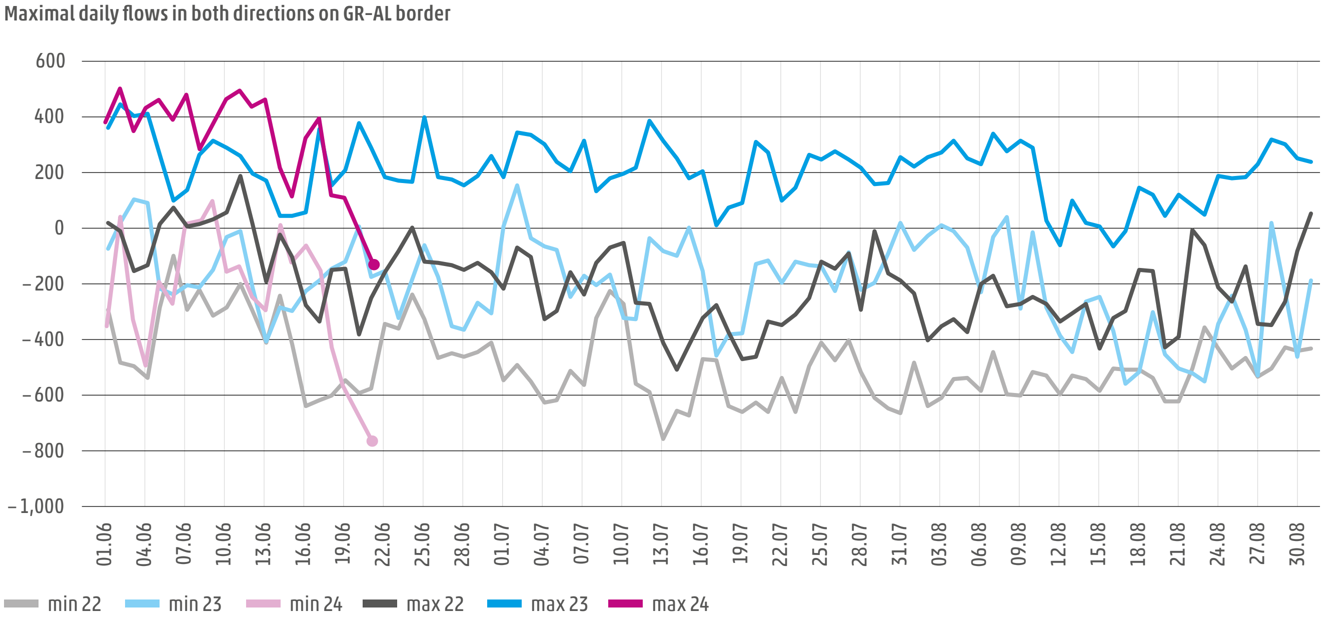

Figure 9: Maximal daily flows in both directions on GR - AL border

2.4.1 Load Patterns

According to the ENTSO-E Transparency Platform data, load patterns in the affected TSOs reflected the seasonal changes in the power systems of Albania, Montenegro, Bosnia and Herzegovina and Croatia. Bearing in the mind the share of tourism in overall economic activities of the affected systems as well as very similar weather conditions all across the region during the observed period, one can explain the daily growth of total consumption in four affected systems together ranging between 4 % and 6 %. The daily load curve on 21 June until the incident was well above the working week average (Figure 10), while total daily consumption, even with the blackout, was 7.8 % higher than on Monday of the same week and 10.3 % above the same day of the previous week (Friday 14 June).

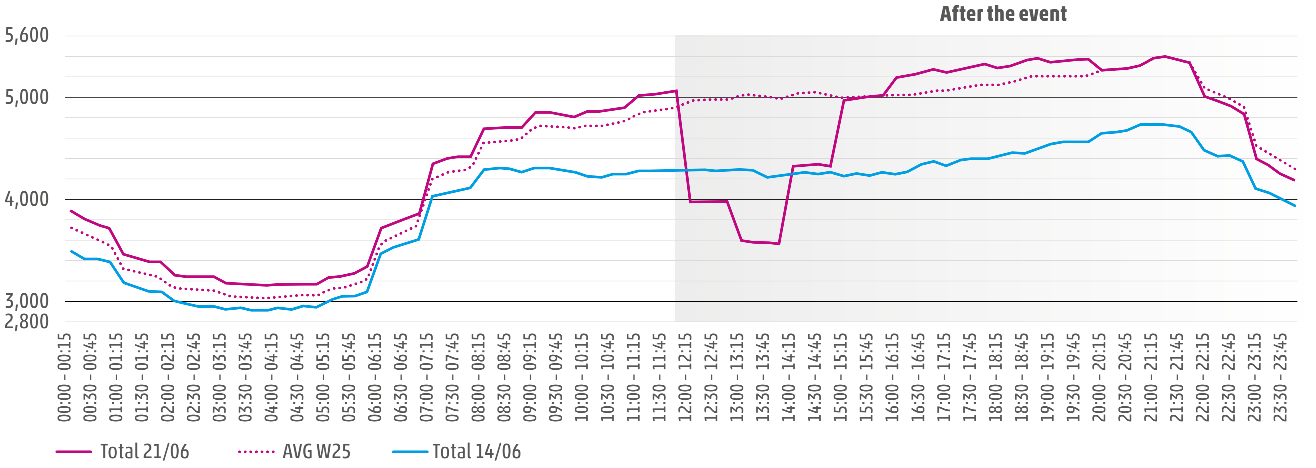

Figure 10: Aggregated daily load curves of 4 affected TSOs (OST, CGES, NOSBiH and HOPS) for the working week 25 (17 June – 21 June 2024) and 14 June 2024.

Individual load patterns in the affected TSOs were not significantly different to the aggregated one, so very similar trends of the load growth were recorded in all four systems.

2.4.2 Production Patterns

The generation structure of the affected systems have not significantly changed in the last several years (Figure 11), hence no unusual production patterns have been observed in the critical period inside the affected area. According to the ENTSO-E Transparency platform data, as updated at the beginning of the year[6], total installed capacity in all four systems has been increased by 558 MW in 2024 compared to 2023 levels. Half of that increase (275 MW) is related to the newly installed solar production, followed by the onshore wind (156 MW).

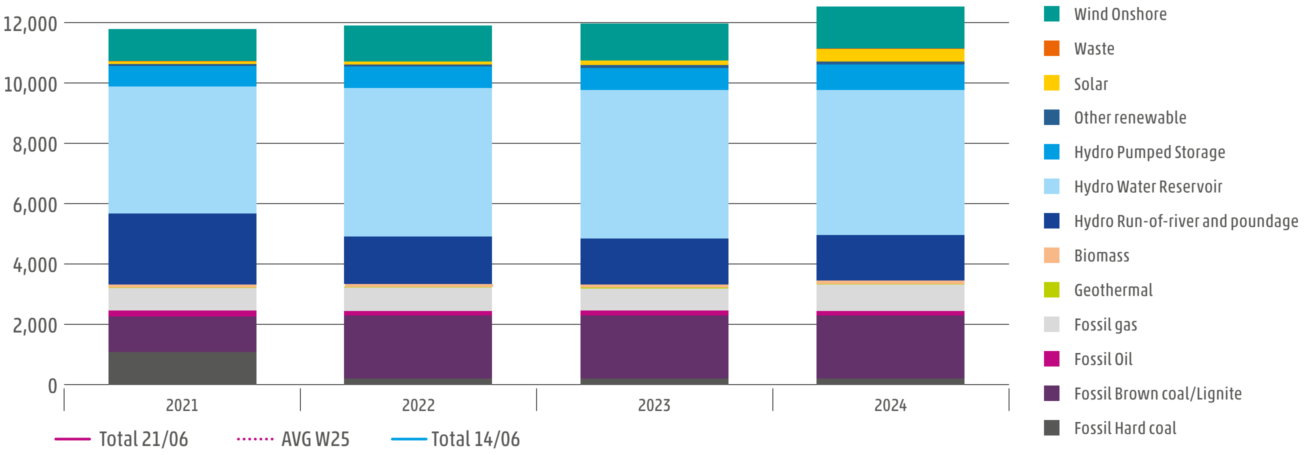

Figure 11: Generation structure of the affected systems during the past years.

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[6] Installed capacity data may differ for some countries depending on how frequently Transparency Platform is updated in that respect.

Geographical distribution of the newly installed production capacities mainly goes to Croatia (onshore wind and solar) and Albania (all solar).

However, aggregated production curves were still extremely responsive to the wholesale market price signals, reaching their maximum during the evening peak hours (Figure 12 and Figure 13).

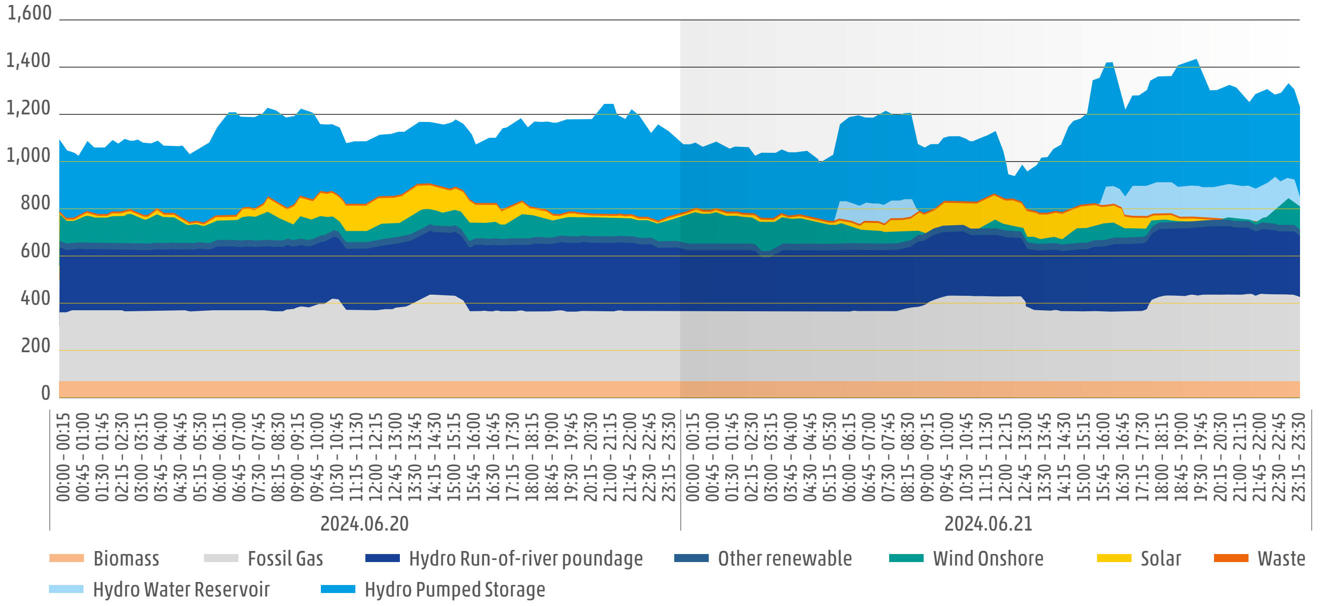

Figure 12: Production pattern in the affected systems – Croatia on 20 and 21 June 2024, by production type (MW)

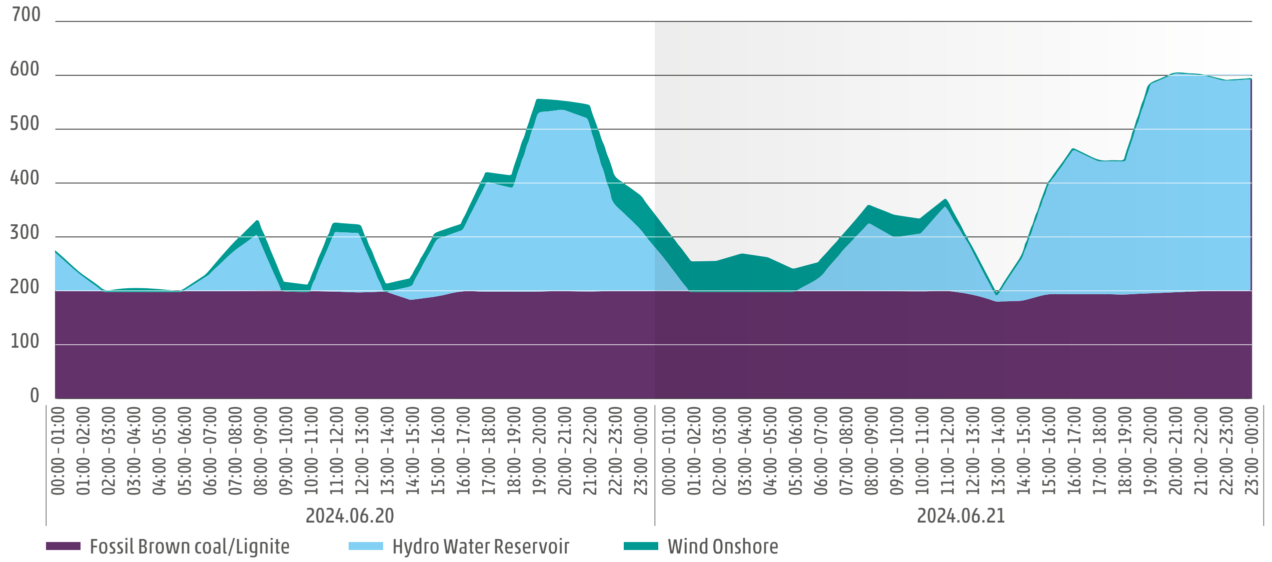

Figure 13: Production pattern in the affected systems – Montenegro on 20 and 21 June 2024, by production type (MW)

Like the affected systems, some neighbouring systems have also seen an increase of the production from solar and wind in 2024. In some cases, the increase is significant, i. e. a capacities increase from 2023 to 2024 in Greece amounts to 2,125 MW, of which 1,600 MW solar. In others it is rather moderate, as in Serbia where total new capacities amount to 139 MW, of which 36 MW is solar.

Consequently, the production curve in Greece followed the weather conditions during 21 June, as well as in the preceding days, reaching its maximum during the 12th and 13th hours local time.

In general, power flow patterns in the affected area were driven by the usual seasonal demand increase and usual seasonal lack of hydro-power production, as well as the predictable but newly established seasonal production increase related to the strong solar production, especially in the southern part of the SEE region.

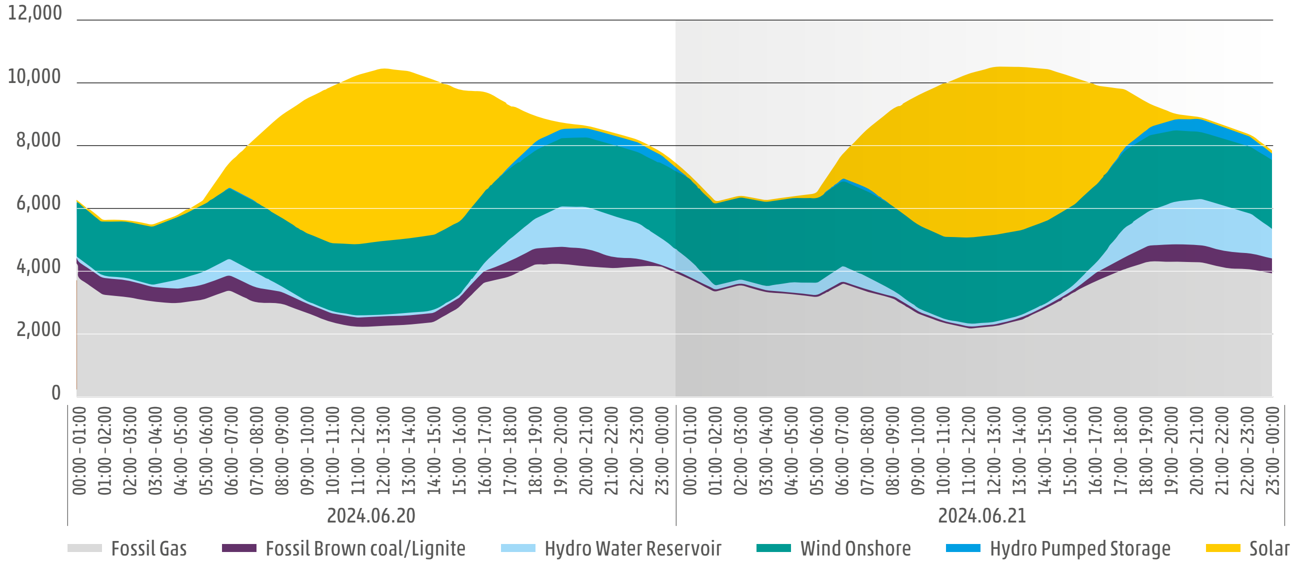

Figure 14: Production patterns in the neighbouring systems – Greece on 20 and 21 June 2024, by production type (MW)

2.4.3 Cross-Border Flows

During the day of the event, as with most of the time in the affected area, a significant difference between scheduled commercial exchanges and physical flows was recorded (up to 500 MW on some borders, as described below). This is explained with a highly meshed grid of SEE, particularly in the affected area, as well as by the fact that the CBC calculation between the affected TSOs is still based on bilaterally agreed results of NTC calculations and is performed mainly on the monthly level. It is assumed that this practice also influences the closest borders that are subject of coordinated capacity calculation

According to the Transparency platform data, from the beginning of 2024 by the date of the event, differences between scheduled and physical flows on several affected TSOs' borders were exceeding 300 MW in nearly 30 % of the time.

Capacity calculations are performed in accordance with established procedure, explained in detail in the Report for System Separation 8 January 2021:

- For the borders not attributed to any of the operational CCRs, TSOs have established a procedure for the creation of a CGM for monthly capacity calculation.
- The NTCs are calculated by each TSO on the SEE regional CGM of the respective border and harmonisation per border, is based on the minimum value proposed by each of the partners.
- The bilateral NTC calculation is conducted for the month ahead.
- The harmonisation of the base-case exchanges of SEE and model merging is performed by one of the involved TSOs in the area (TSO coordinator). The role of TSO coordinator rotates on a monthly basis according to an agreed yearly scheme.

In addition to the monthly calculation of NTCs, some TSOs in the region perform weekly calculations[7], which consider more precise estimations of the system conditions. This is an interim solution applied to improve quality of capacity calculation process and is seen to be used until coordinated capacity calculation on a daily level takes the place.

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[7] Bilateral weekly calculation of NTCs are performed on the EMS–CGES, CGES–KOSTT and OST–CGES borders

2.4.4 Scheduled Commercial Exchanges

Netted values of commercial exchanges between affected TSOs as well as between the affected area and the rest of the region were closely following market signals as reported in the sub-chapter 2.3. Significant commercial exchanges were reported on the East-West route along the Adriatic coast, as a consequence of the lower Day-ahead market prices on the most eastern and the most western price zones, comparing to those in Albania and Montenegro price zones.

Figure 15: Scheduled commercial exchanges for 12th hour, 21 June 2024

2.4.5 Cross-Border Physical Flows

While commercial exchanges followed the market signals, physical flows were significantly different and aligned with the production and load patterns.

Physical flows from Greece to Albania were 518 MW higher than commercial exchange (758 MW comparing to 240 MW). Scheduled export from Montenegro to Albania resulted in physical flows in the opposite direction of 241 MW from Albania to Montenegro. Similarly, the direction was opposite on the Bosnia and Hercegovina – Montenegro border (100 MW from Montenegro to Bosnia and Herzegovina instead of the scheduled 410 MW from Bosnia and Herzegovina to Montenegro), as well as on the Bosnia and Hercegovina – Croatia border (100 MW from Croatia to Bosnia and Herzegovina instead of the scheduled 364 MW from Bosnia and Herzegovina to Croatia). Finally, Croatian import from Slovenia was 617 MW lower than scheduled (406 MW of physical flows compared to 1,023 MW of scheduled commercial exchanges).

In essence, the difference between the scheduled and physical flows (mainly loop-flows, as no significant system disbalances were recorded during the day) alongside the Adriatic coast was present on all the borders in the amount of approximately 500 MW.

Figure 16: Cross-Border physical flows for 12th hour, 21 June 2024 (bold) and corresponding unscheduled loop-flows (underlined) in MW

2.5 Daily Security Analysis

Day-ahead and intra-day analysis are the core of the regional security coordination in the affected area. While security analysis in the medium-term is also performed in a coordinated manner, seasonal outlooks that consider seasonal specifics (such as high temperatures or other seasonal added risks…) are not performed.

The operational security of any power system relies on respecting the operational security limits and on the application of the N-1 Operational Standard, which states that any single contingency should not endanger the system.

Contingency analyses in the affected area are performed by all affected TSOs and respective RCCs pursuant to SOGL Article 34 (Regulation 2017/1485 of the European Commission) that stipulates in particular that:

1. Each TSO shall perform a contingency analysis in its observability area to identify the contingencies which endanger or may endanger the operational security of its control area and to identify the remedial actions that may be necessary to address the contingencies, including the mitigation of the impact of exceptional contingencies.

2. Each TSO shall ensure that potential violations of the operational security limits in its control area which are identified by the contingency analysis do not endanger the operational security of its transmission system or of interconnected transmission systems.

3. Each TSO shall perform a contingency analysis based on the forecast of operational data and on real-time operational data from its observability area. The starting point for the contingency analysis in the N-Situation shall be the relevant topology of the transmission system, which shall include planned outages in the operational planning phases.

According to Agreements on the provision of operational services, which are concluded among SCC and its service users (CGES, OST and NOSBiH from the affected area), CGMs and security analysis results are prepared by SCC and delivered to the TSOs to the dedicated SFTP server.

The results of the security analysis presented in this chapter were extracted from SCCs regular reports, as well as from results for HOPS that belongs to another CCR and SOR.

According to regular procedures, all the elements from the monitoring lists of each TSO that are loaded above 90 % either in base case or after any contingency from the contingency area are listed below.

Presented here are the main results of the conducted security analysis, available to the affected TSOs. A detailed description of the regional security coordination activities and analysis of the results is provided later in the report (chapter 5).

2.5.1 DACF Results

During the critical period (13th hour), no major critical N-1 security violations have been identified in regular daily security analysis in any of the affected TSOs.

The contingency analysis for the Montenegrin system does not identify security violations for the 13th hour. The last contingency is recognised for earlier in the morning (9:30) with the tripping of internal 400 kV OHL Lastva – Podgorica leading to an overload of the tie-line with Albania 220 kV Podgorica 1 – Koplik (107 %), and internal Albanian 220 kV OHL Vau Dejes – Koplik (112 %). However, after that, no contingencies leading to a loading of 90 % and more have been identified until 19:30 of the same day. For all identified contingencies during the day, curative measures have been prepared.

Timestamp	CO Name	CB Name	Loading (%)	L. after (%)	L. after [%]	Snom (MVA)
09:30	400 kV OHL Lastva - Podgorica 2	220 kV OHL Vau Dejes - Koplik	67.52	111.68	710	
09:30	400 kV OHL Lastva - Podgorica 2	220 kV TIE Podgorica 1 - Koplik (AL)	63.81	106.87	720	
09:30	400 kV TIE Tirana 2 - Podgorica 2	220 kV OHL Vau Dejes - Koplik	67.52	96.90	710	
09:30	400 kV TIE Tirana 2 - Podgorica 2	220 kV TIE Podgorica 1 - Koplik (AL)	63.81	92.43	720	
19:30	220 kV TIE Bajina Bašta - Pljevlja 2	220 kV TIE TS Bistrica - Pljevlja 2 (RS)	73.64	94.79	720	
20:30	220 kV TIE Bajina Bašta - Pljevlja 2	220 kV TIE TS Bistrica - Pljevlja 2 (RS)	70.51	90.43	720	

Table 3: DACF Security analysis by SCC for CGES, 21 June 2024, N-1 sorted by time-stamp and loading.

In the Bosnia and Herzegovina system there were some identified overloads in the referent hour, but all referred to the elements at the 110 kV level. No loading after outage higher than 90 % was identified in the 220 kV and 400 kV network, except light overload of 400/220 kV transformers in Obrenovac (102 %), that are within the NOSBiH observability area, but not an internal NOSBiH element. Curative measures have been prepared for the remaining overloads in the 110 kV network.

Time stamp	CO Name	CB Name	Loading_BC (%)	Loading after outage (%)	Imax (A)	Snom (MW)
12:30	400 kV OHL Lastva - Podgorica 2	110 kV OHL Ugljevik - Lopare	83.41	114.26	468	
12:30	400 kV OHL Lastva - Podgorica 2	110 kV OHL Lopare - Tuzla 3	78.14	108.88	470	
12:30	110 kV OHL Ugljevik - Bijeljina 2	110 kVOHLUgljevik - Lopare	83.41	105.75	468	
12:30	110 kV OHL Bijeljina 1 - Bijeljina 2	110 kV OHL Ugljevik - Lopare	83.41	105.37	468	
12:30	110 kV OHL Ugljevik - Zvornik	110 kV OHL Ugljevik - Lopare	83.41	103.79	468	
12:30	220 kV OHL TE Tuzla G6 - Tuzla 4	110 kV OHL Ugljevik - Lopare	83.41	102.90	468	
12:30	400/220 kV TR Obrenovac (3)	400/220 kV TR Obrenovac (2)	71.16	102.23		400
12:30	400/220 kV TR Obrenovac (2)	400/220 kV TR Obrenovac (3)	70.58	101.75		400
12:30	220 kV TIE Međurić - Prijedor	110 kV OHL Ugljevik - Lopare	83.41	100.50	468	
12:30	110 kV OHL Ugljevik - Bijeljina 2	110 kV OHL Lopare - Tuzla 3	78.14	100.26	470	
12:30	110 kV OHL Bijeljina 1 - Bijeljina 2	110 kV OHL Lopare - Tuzla 3	78.14	99.88	470	
12:30	110 kV OHL Ugljevik - Zvornik	110 kV OHL Lopare - Tuzla 3	78.14	98.30	470	
12:30	110 kV OHL Bijeljina 3 - Bijeljina 1	110 kV OHL Ugljevik - Lopare	83.41	98.23	468	
12:30	400/110 kV TR Ugljevik	110 kV TIE Županja - Orašje (HR)	66.65	98.00	439	
12:30	110 kV OHL Ugljevik - Zvornik	110 kV OHL Ugljevik - Bijeljina 2	72.72	97.82	600	
12:30	110 kV OHL Banja L6 - Banja L1 (2)	110 kV OHL Banja L6-Banja L1 (1)	55.16	97.72	468	
12:30	220 kV OHL TE Tuzla G6 - Tuzla 4	110 kV OHL Lopare - Tuzla 3	78.14	97.57	470	
12:30	220 kV TIE Međurić - Prijedor	110 kV OHL Lopare - Tuzla 3	78.14	95.18	470	
12:30	400 kV OHL Ribarevine - Podgorica 2	110 kV OHL Ugljevik - Lopare	83.41	94.82	468	
12:30	400 kV OHL Kosovo B - Peć 3	110 kV OHL Ugljevik - Lopare	83.41	94.67	468	
12:30	400 kV TIE Peć 3 - Ribarevine	110 kV OHL Ugljevik - Lopare	83.41	93.67	468	
12:30	220 kV OHL Međurić - TPP Sisak	110 kV OHL Ugljevik - Lopare	83.41	93.61	468	
12:30	220 kV TIE Sarajevo 20 - HE Piva	110 kV OHL Ugljevik - Lopare	83.41	93.26	468	
12:30	400/220 kV TR Sarajevo 20 (1)	110 kV OHL Ugljevik - Lopare	83.41	93.26	468	
12:30	110 kV OHL Bijeljina 3 - Bijeljina 1	110 kV OHL Lopare - Tuzla 3	78.14	92.87	470	
12:30	110 kV OHL Brčko 2 - Bijeljina 3	110 kV OHL Ugljevik - Lopare	83.41	92.40	468	
12:30	400 kV OHL Bor 2 - HE Đerdap 1	110 kV OHL Ugljevik - Lopare	83.41	92.34	468	
12:30	400/110 kV TR Ugljevik	110 kV TIE Županja - Orašje (BA)	62.26	91.54	470	
12:30	400 kV OHL Bor 2 - Niš 2	110 kV OHL Ugljevik - Lopare	83.41	90.77	468	
12:30	220 kV OHL Konjsko - VE Krš-Pađene	110 kV OHL Ugljevik - Lopare	83.41	90.40	468	
12:30	400 kV OHL TE Gacko - Mostar 4	110 kV OHL Ugljevik - Lopare	83.41	90.29	468	
12:30	220 kV OHL Brinje - VE Krš-Pađene	110 kV OHL Ugljevik - Lopare	83.41	90.18	468	

Table 4: DACF Security analysis by SCC for NOSBiH, 21 June 2024, N-1 sorted by time-stamp and loading.

In the Albanian system, there were some more identified overloads in the referent hour, but again most of them referred to the elements on the 110 kV level. The only loading after an outage higher than 90 % identified in the 220 kV and 400 kV network refers to the 220/110 kV transformers in substation Tirana 2. This overload, as well as the overload of the 150 kV TIE Mourtos (GR) – Bistrica (AL) that was identified in the case of the outage of 400 kV TIE Zemblak – Kardia (133 %), has no propagation potential and only impacts the local consumption. Curative measures have been prepared for all the identified overloads.

It is worth noting that most of the internal 400 kV elements of all affected TSOs are parts of the contingency lists of the neighbouring TSOs (e.g. internal Montenegrin 400 kV OHL Ribarevine-Podgorica 2 is part of the contingency lists of CGES, OST, EMS, NOSBiH and MEPSO).

Time stamp	CO Name	CB Name	Loading_BC (%)	Loading after outage (%)	Imax (A)	Snom (MVA)
12:30	110 kV T OHL irana 1 – Traktora	110 kV I OHL be – Farke	57.65	158.90	336	
12:30	110 kV OHL Tirana 1 – Traktora	110 kV OHL Ibe – Elbasan 1	53.07	142.74	383	
12:30	400 kV OHL Zemblak – Elbasan 2	110 kV OHL Krahes – Memaliaj	49.22	137.78	383	
12:30	400 kV OHL Zemblak – Elbasan 2	110 kV OHL Ballsh – Krahes	47.83	136.44	383	
12:30	400 kV TIE Kardia – Zemblak	150 kV TIE Mourtos – Bistrica (AL)	64.60	133.55	360	
12:30	400 kV TIE Kardia – Zemblak	150/110 kV TR Bistrica	61.73	124.88		100
12:30	110 kV OHL Tirana 1 – Traktora	110 kV OHL Traktora – Farke	29.49	120.92	336	
12:30	220/110 kV TR Tirana 2 (1)	220/110 kV TR Tirana 2 (2)	74.15	111.62		120
12:30	220/110 kV TR Tirana 2 (2)	220/110 kV TR Tirana 2 (1)	74.15	111.62		120
12:30	400 kV TIE Kardia – Zemblak	150 kV TIE Mourtos – Bistrica (GR)	51.91	106.89	450	
12:30	110 kV OHL Tirana 2 – Kombinat	110 kV OHL Selite – Tirana 2	41.77	99.43	645	
12:30	400 kV Elbasan 2 busbar fault	150 kV TIE Mourtos – Bistrica (AL)	64.60	98.68	360	
12:30	400 kV OHL Zemblak – Elbasan 2	150 kV TIE Mourtos – Bistrica (AL)	64.60	97.42	360	

Table 5: DACF Security analysis by SCC for OST, 21 June 2024, N-1 sorted by time-stamp and loading.

In the Croatian power system, no loading higher than 90 % has been identified in the 220 kV and 400 kV network, while curative measures have been prepared for the remaining light overloads in the 110 kV network.

In general, it may be concluded that the day-ahead security analysis process was not implying a more critical than usual system state in the affected area. In particular, DACF analyses have shown that an outage of 400 kV OHL Ribarevine – Podgorica 2 was not causing any critical branch loading in Montenegro as well as in Albania. Hence, the outage was not identified as critical in either of the two concerned systems.

2.5.2 IDCF Security Analysis Results

Following the DACF process, each considered TSO participates in the IDCF process, receiving security analysis based on the intra-day grid models. On 21 June, no major changes in power flows and the results of the IDCF Security analysis were noted. The similarity of the results is checked by comparing final – CB–CO lists of the DACF and IDCF analysis.

2.5.3 Security Analysis accuracy

The accuracy of all the conducted regional security analysis is supported by the results of conducted individual TSOs security analysis as well as by comparison of realised real-time power flows and calculated base-case flows.

Selected examples from 9:30 on 21 June do confirm the quality of the DACF Common Grid Model (Figure 17) as the difference was fairly within the operationally acceptable margin.

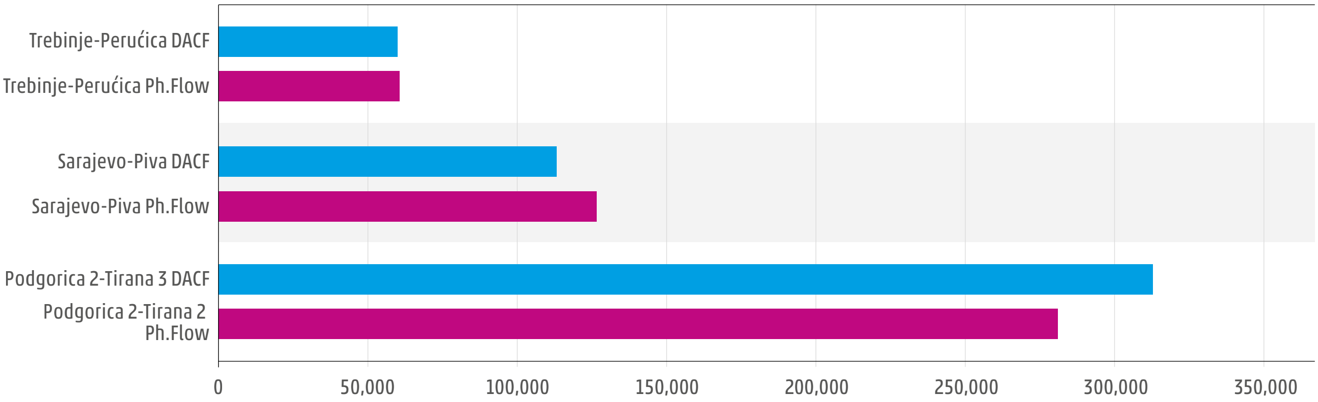

Figure 17: Comparison of realised physical power flows (orange) and DACF calculated base-case flows (green) at 9:30 on 21 June 2024 [MW]

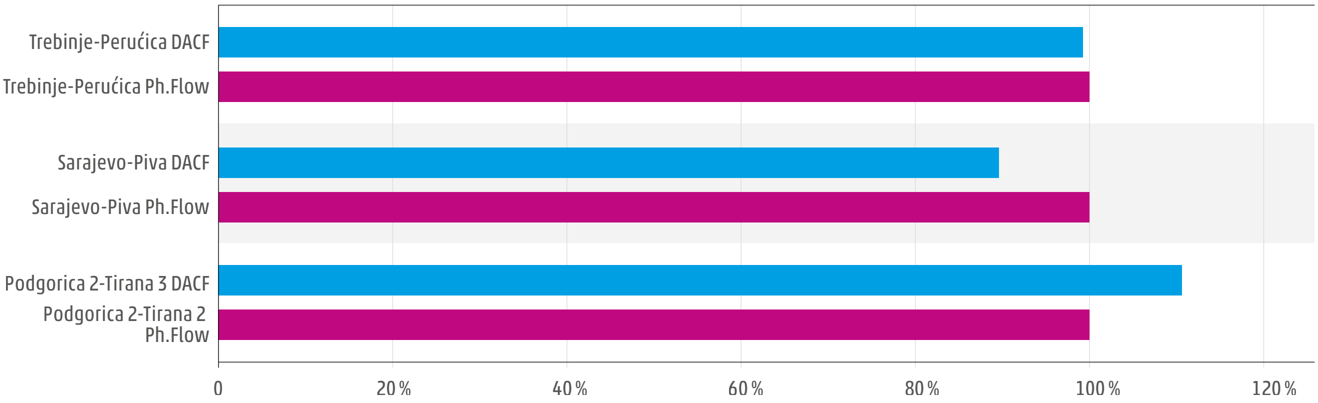

Figure 18: Difference between realised physical power flows and DACF calculated base-case flows at 9:30 on 21 June 2024 (%)

2.5.4 Real-Time Security Analysis Results

Real-time security analysis close to the time of the incident, similarly to the DACF and IDCF analysis, have identified critical overloads only in the 110kV networks of the affected TSOs. Some convergence issues have been observed only after 12:20.

It should be noted here that individual observability zones of the affected TSOs do not cover all the critical elements of the event. In particular, NOSBiH observability area ends on the CGES–OST border, while CGES observability area ends on OST–IPTO interconnection 400 kV Zemblak – Kardia, modelling it only as a power-flow injection to the network equivalent. Hence, in both of those cases the outage of the 400 kV TIE Zemblak – Kardia was not part of the contingency analysis. Internal CGES' 400 kV OHL Ribarevine – Podgorica 2 is within OST's observability area. However, this outage was not indicated as critical in OST's real-time security analysis.

2.5.5 Remedial Actions Coordination for DACF/IDCF/RT

No specific topological measures were implemented as preventive measures to cope with the specific condition described in this chapter before the initial outage.

TSOs of the region that are SCC service users do have an established procedure for extraordinary daily operational planning teleconferences (DOPT) in case critical outages are identified. During 21 June until the incident, the conditions for the organisation of DOPT were not met.

3 EVOLUTION OF SYSTEM CONDITIONS DURING THE EVENT

3.1 Factual Sequence of Events

This section presents the factual evolution of the disturbance that unfolded on 21 June 2024.

Outage ID	Time (CEST)	Substation A (TSO)	Substation B (TSO)	Voltage Level (kV)	Asset Type	Relay Trigger
1--	12:09:16.213	Ribarevine (CGES)	Podgorica 2 (CGES)	400	OHL	DIFF
2	12:21:33:200	Zemblak (OST)	Kardia (IPTO)	400	OHL-TIE	DIST
3	12:21:44:000	Fierze (OST)	Prizren 2 (KOSTT)	220	OHL-TIE	OC
4	12:21:45.774	Podgorica 1 (CGES)	Mojkovac (CGES)	220	OHL	OC
5	12:21:51:446	Lastva (CGES)	Villanova (Terna)	500	DCC-TIE	UV
6	12:22:06:012	Sarajevo 20 (NOSBiH)	Piva (CGES)	220	OHL-TIE	OC
7	12:24:21:587	Brinje (HOPS)	Pađene (HOPS)	220	OHL	DIST
8	12:24:22:341	Prijedor 2 (NOSBiH)	Jajce 2 (NOSBiH)	220	OHL	OC
9	12:24:22:350	Ugljevik (NOSBiH)	Tuzla 4 (NOSBiH)	400	OHL	OC
10*	12:24:22:959	Đakovo (HOPS)	Gradačac (NOSBiH)	220	OHL-TIE	UV
11*	12:24:22:959	Đakovo (HOPS)	TPP Tuzla (NOSBiH)	220	OHL-TIE	UV
12	12:24:23:000	Titan (OST)	Tirana 1 (OST)	220	OHL	DIST
13	12:24:23:089	Međurić (HOPS)	Prijedor 2 (NOSBiH)	220	OHL-TIE	DIST
14	12:24:24:000	Fierze (OST)	Peshqesh (OST)	220	OHL	MAN
15	12:24:26:558	Trebinje (NOSBiH)	Perucica (CGES)	220	OHL-TIE	UV
16	12:24:26:579	Trebinje (NOSBiH)	Hodovo (NOSBiH)	220	OHL	UV
17	12:24:26:583	Trebinje (NOSBiH)	Mostar 3 (NOSBiH)	220	OHL	UV
18	12:24:26:593	Trebinje (NOSBiH)	Plat (HOPS)	220	OHL-TIE	UV
19	12:24:27:694	Prijedor 2 (NOSBiH)	Bihać 1 (NOSBiH)	220	OHL	DIST
20	12:24:28:000	Fierze (OST)	Koman (OST)	220	OHL	MAN
21	12:24:28:000	Fierze (OST)	Fang (OST)	220	OHL	OC

Table 6: Factual sequence of (significant) events; * indicates outages in HOPS on 110 kV network that led to loss of voltage on 220 kV; abbreviations: OHL…overhead line, OHL-TIE…overhead line TIE line, DCC-TIE…DC cable TIE line, UV…under-voltage, OC…overcurrent, DIFF…differential protection, DIST…distance protection, MAN…Manual Disconnection

The draft version of **Blackout sequence video (link1 + link2)** represents the sequence of events as recorded on EMS-SCADA display of JSC EMS during the period between 12:08 and 12:26. Time of recording can be seen on the top of the display.

The geographical map of the region in Figure 19 visualises the sequence of events. The colour indicates the time of disconnection. The number shows the exact order of outages and is linked to the Outage IDs of Table 7. The planned outages disconnected prior to the disturbance are highlighted in grey and designated by the capital letter M (maintenance). The disconnection of OHL Višegrad – Tuzla 4 is marked as O (other), due to the OHL being disconnected because of high voltages in the NOSBiH grid the previous night.

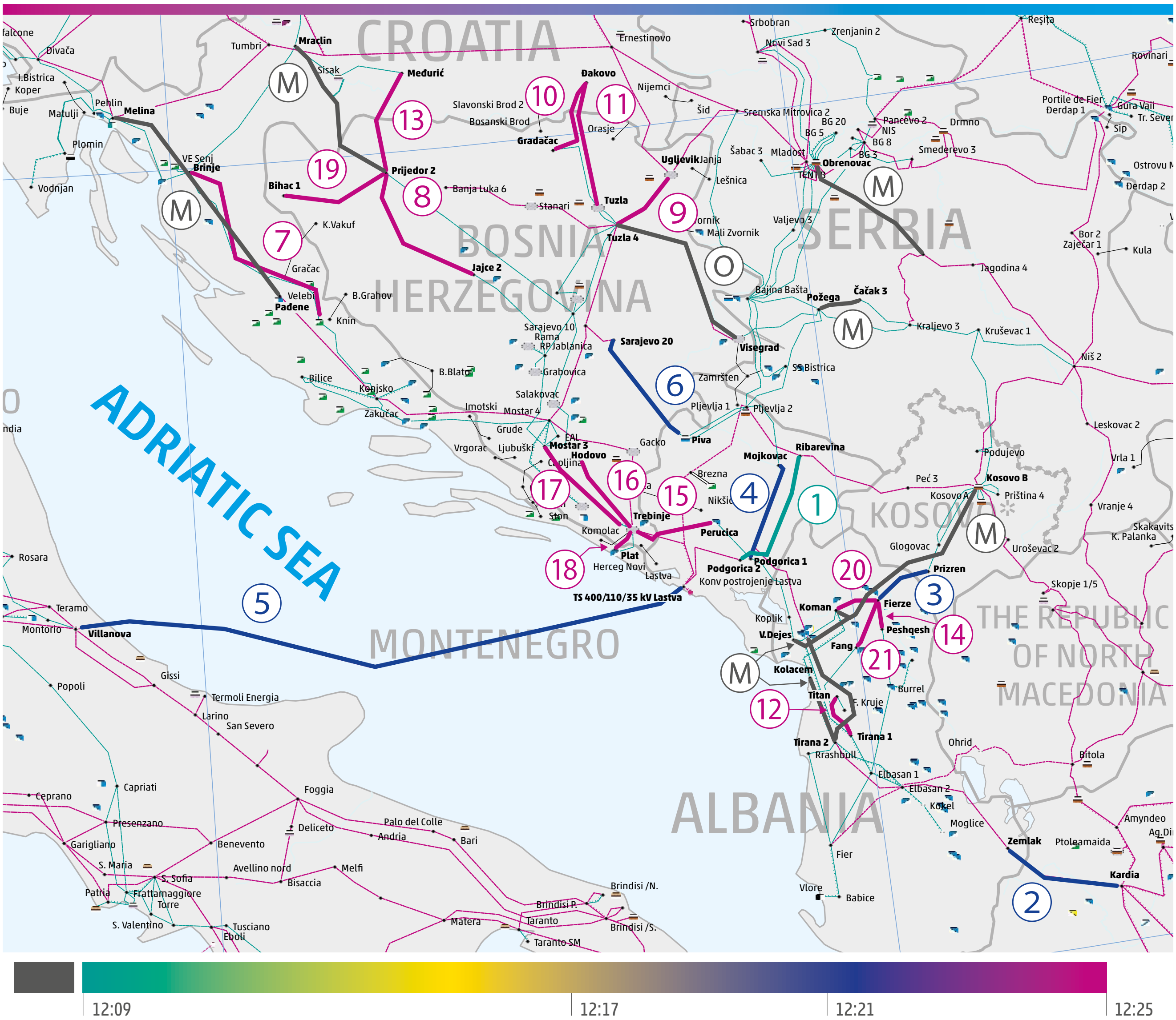

Figure 19: Map with outages indicated in different colours related to their respective outage times; grey means that the lines have already been disconnected prior to the event due to maintenance (M) or other (O) reasons.

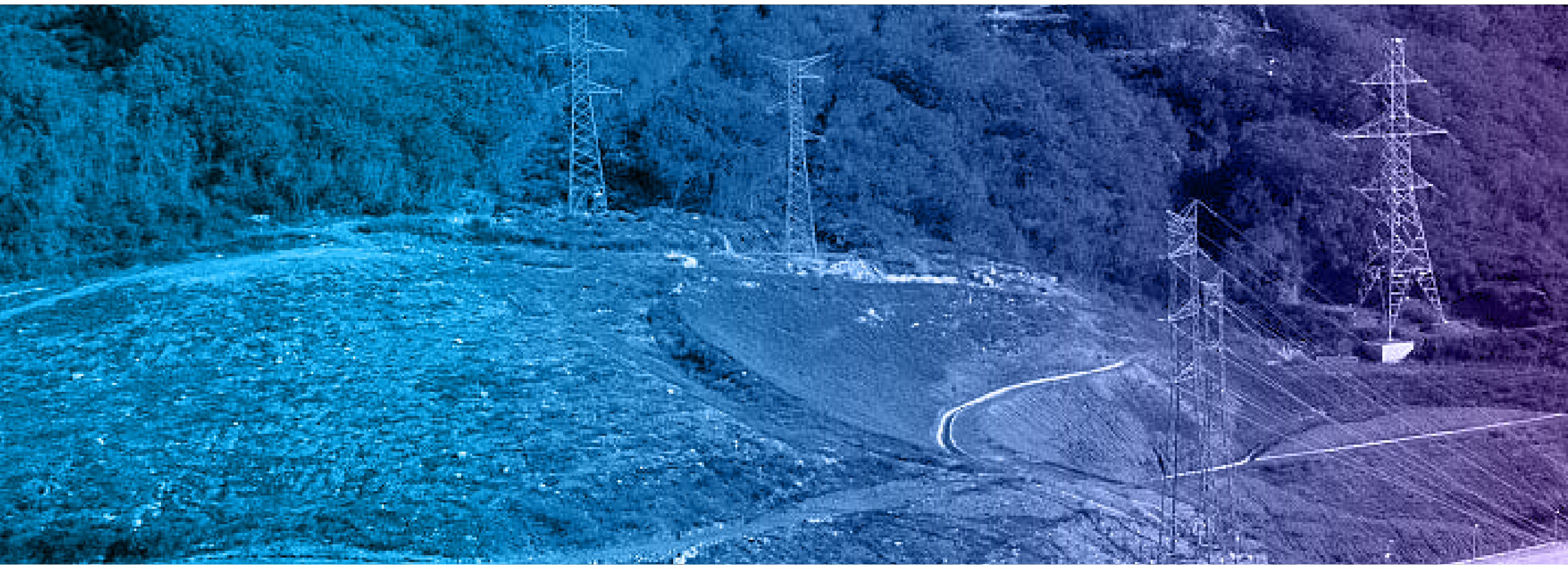

Figure 20 shows the sequence of events together with the voltage trajectory in substation Trebinje (NOSBiH) and in substation Tumbri (HOPS).

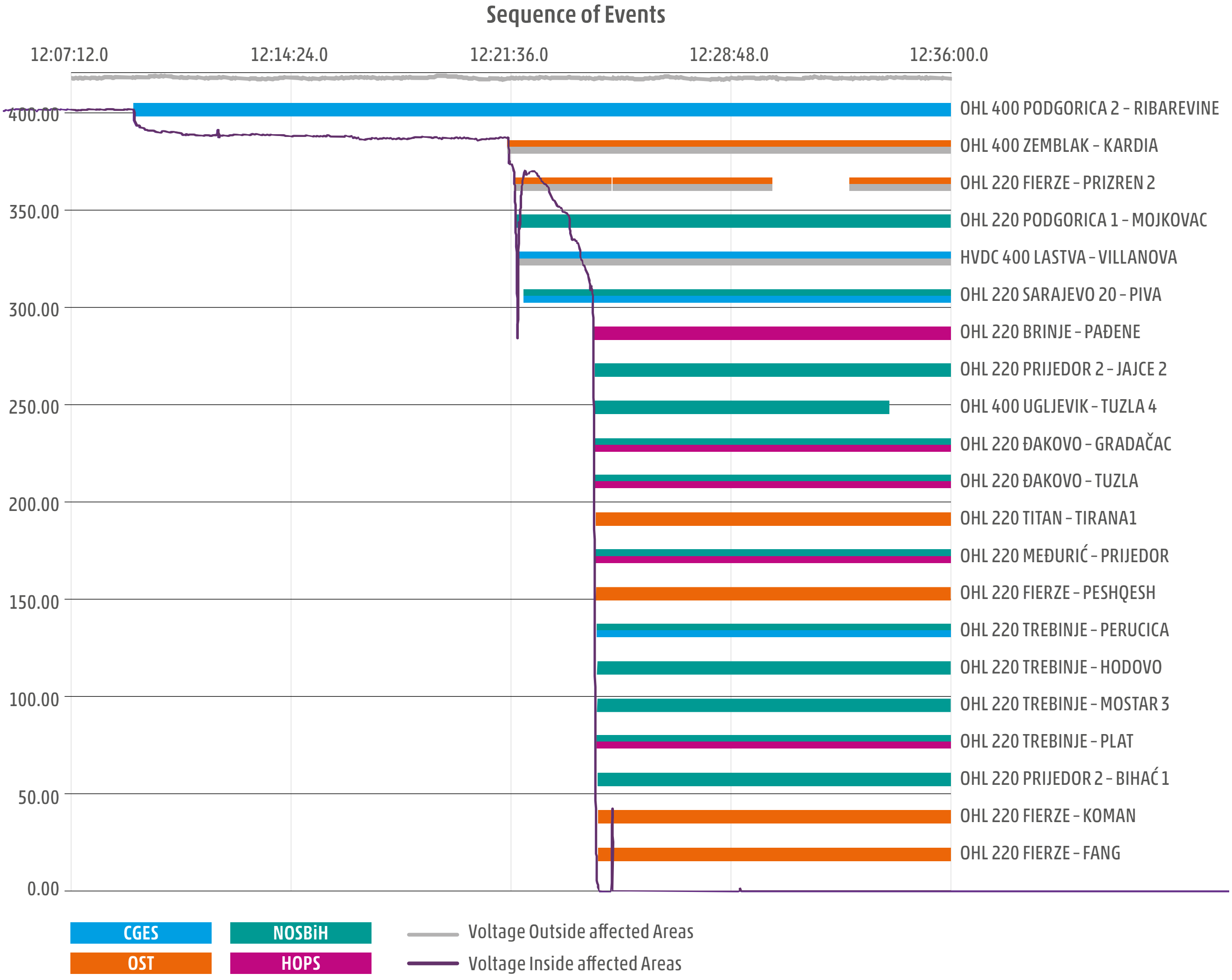

Figure 20: Sequence of Events plotted over voltage in substation Trebinje (NOSBiH) PMU data (purple) and voltage in substation Tumbri (HOPS); the length of the horizontal bars indicates the duration of the outage; two-colour bars indicate tie-lines (220 kV OHL Fierze – Prizren, the separation of the bar indicates switching during restoration).

3.2 Generation and Load

This section presents details on the loss of load and generation during the event. Before the blackout, the affected area had an estimated active power dispatch of 2.2 GW.

Figure 21 shows the loss of generation in a chronological order.

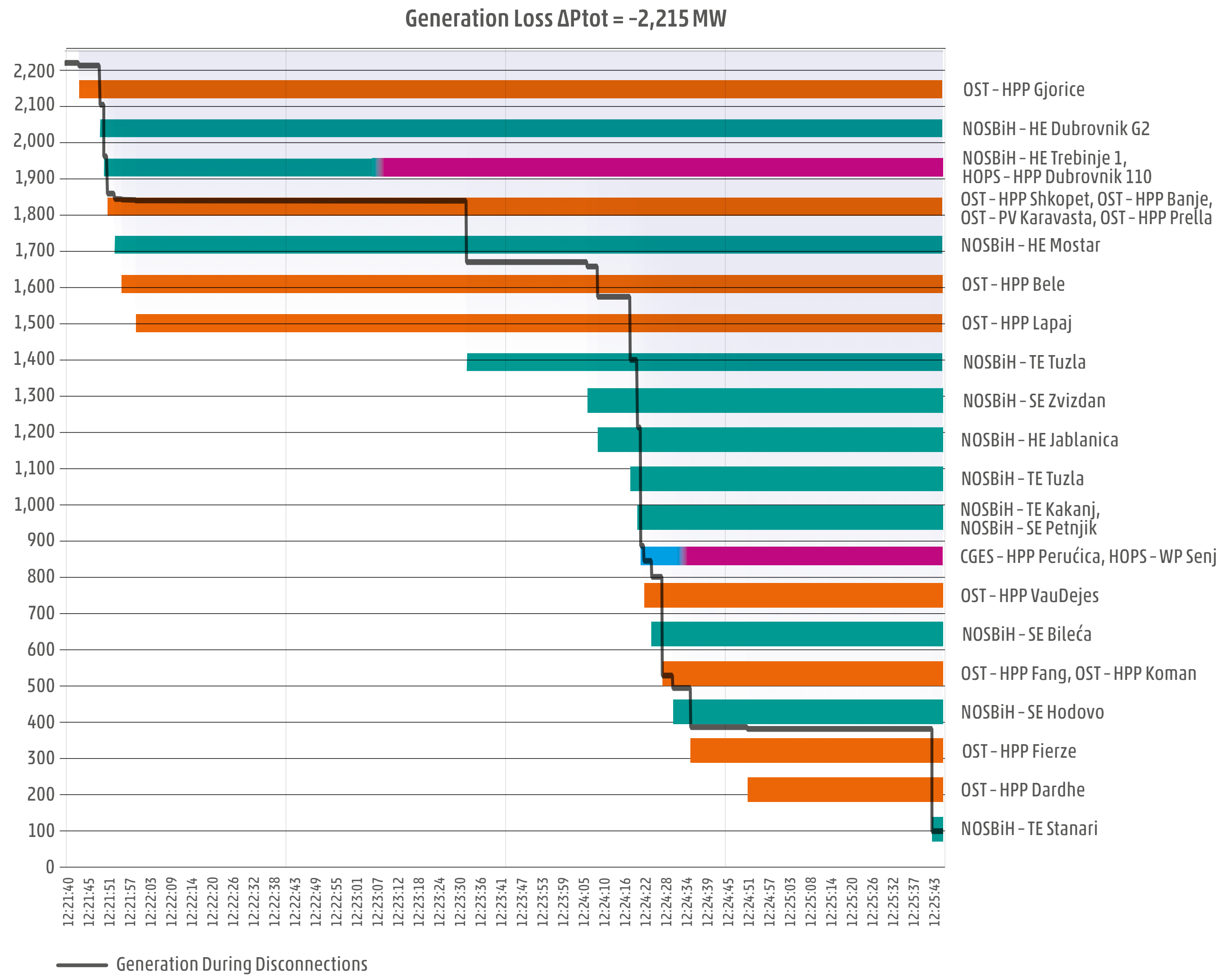

Figure 21: Loss of generation in chronological order.

Figure 22 shows the loss of generation for the affected TSOs.

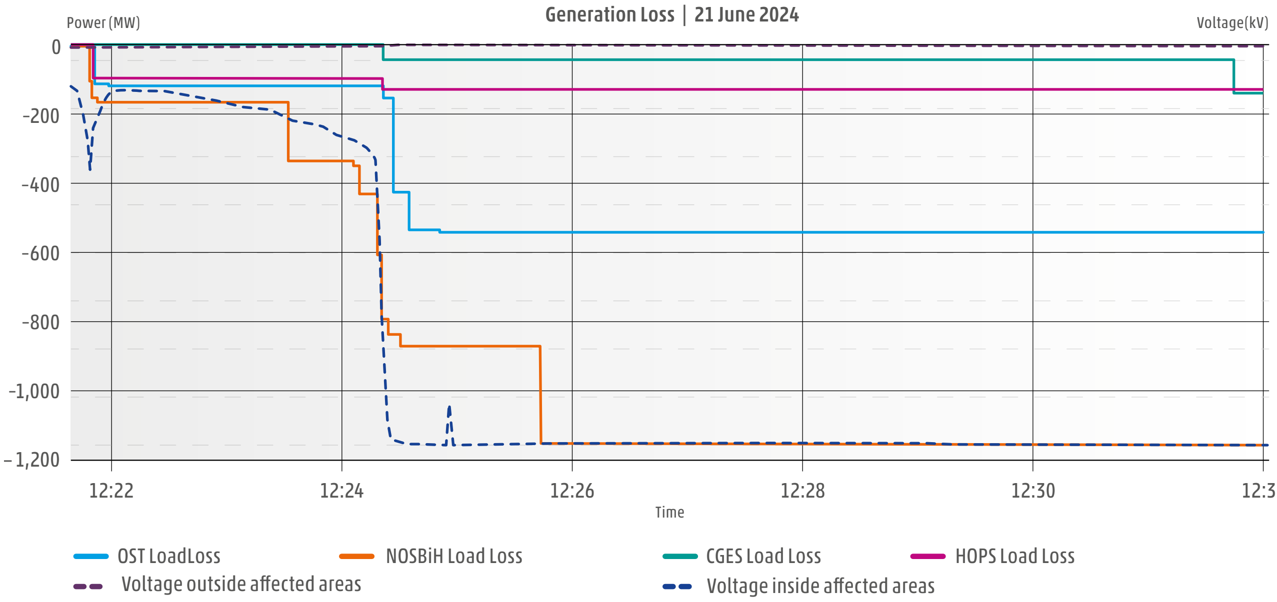

Figure 22: Loss of generation of different affected TSOs; including exemplary voltage within and outside of the affected area.

Following the occurrence of three outages within a brief interval, 400 kV OHL Ribarevine – Podgorica 2 at 12:09:16, 400 kV OHL Zemblak – Kardia at 12:21:33 and Fierze – Prizren at 12:21:43, a rapid voltage drop resulted in a significant loss of generation in the affected area. At 12:21:52, OST had a generation loss of 109 MW and at 12:21:54 NOSBiH recorded a generation loss of 167 MW, while HOPS recorded a generation loss of 97 MW and CGES reported a generation loss of 113 MW.

The voltage drops at 12:24 resulted in a substantial loss of load in the affected area. Subsequently, at 12:24:21, a severe voltage drop that reduced voltage to zero resulted in a generation loss of 2,214 MW in the affected area.

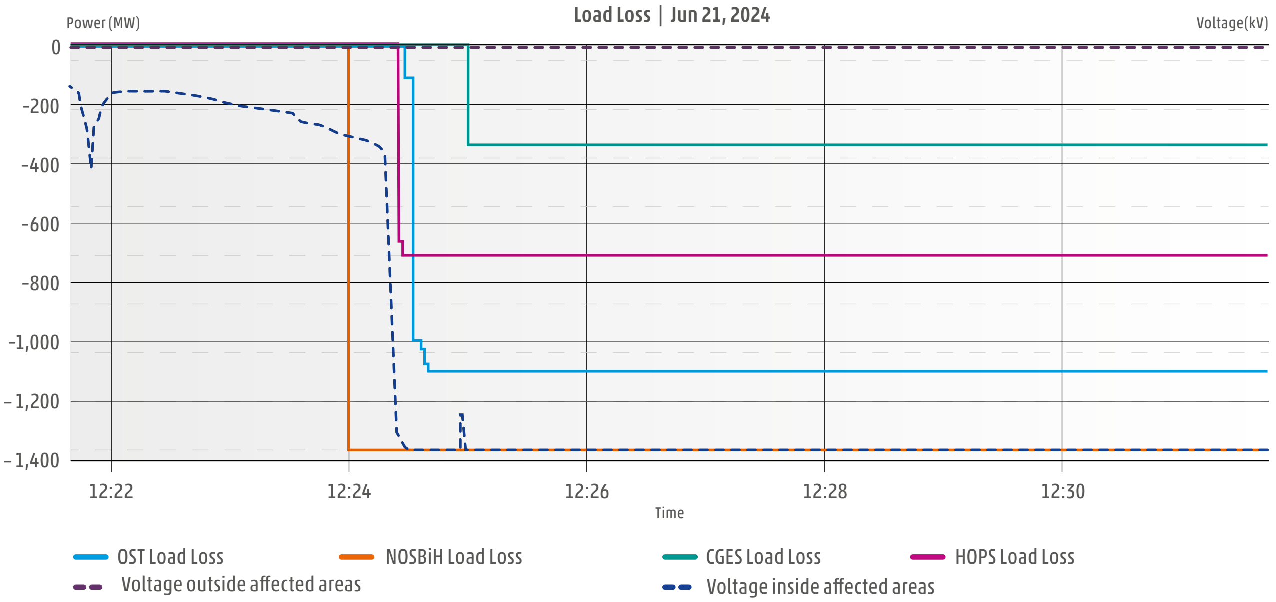

Figure 23: Loss of load of different affected TSOs; including exemplary voltage within and outside of the affected area.

3.2.1 List of Generation Units Disconnected

Table 8 shows the list of generation units with an installed capacity >25 MW, which disconnected during the event.

TSO	Generation Type	Powerplant	Actual Generation (MW)	Gen Unit	Time of disconnection	Reason of disconnection
OST	Hydro	HPP Fierze	109	G1	12:24:36	Voltage Control Overcurrent Protection, Impedance Protection
OST	Hydro	HPP Vau Dejes	40	G5	12:24:23	Pole Slip
OST	Hydro	HPP Fang	61	G1	12:24:28	Impedance Protection, Overcurrent Protection, Undervoltage Protection, Over frequency protection
				G2	12:24:28	Over frequency protection
OST	Hydro	HPP Koman	211	G1	12:24:28	Overcurrent Protection
				G4	12:24:28	Overcurrent Protection
OST	Solar	PV Karavasta	94	N/A	12:21:52	Undervoltage protection
CGES	Hydro	HPP Perucica	113	G2	12:24:22	overcurrent protection
				G3	12:24:22	impedance protection
				G4	12:24:22	overcurrent protection
HOPS	Wind	WPP Senj	33.8	N/A	12:24:22	Undervoltage protection
HOPS	Hydro	HPP Dubrovnik	97	G1	12:21:48	Overcurrent protection of connecting line
NOSBiH	Hydro	HPP Dubrovnik	107	G2 (G2 is working for NOSBiH)	12:21:51	Undervoltage protection
NOSBiH	Hydro	HPP Trebinje 1	46	G3	12:21:51	Undervoltage protection
NOSBiH	Thermal	TPP Tuzla	169	G5	12:23:33	Undervoltage protection
NOSBiH	Hydro	HPP Jablanica	85	G4	12:24:10	Voltage-dependent overcurrent protection
NOSBiH	Thermal	TPP Tuzla	173	G4	12:24:19	Undervoltage protection
NOSBiH	Thermal	TPP Kakanj	81	G5	12:24:21	Undervoltage protection
NOSBiH	Thermal	TPP Kakanj	85	G6	12:24:21	Undervoltage protection
NOSBiH	Solar	SPP Bileća	45	G1	12:24:25	Undervoltage protection
NOSBiH	Solar	SPP Hodovo	34	G1	12:24:31	Undervoltage protection
NOSBiH	Thermal	TPP Stanari	282	G1	12:25:44	Undervoltage protection

Table 7: List of generation units above 25 MW that disconnected.

3.2.2 Loss of Load

NOSBiH experienced a load loss of approximately 1,365 MW at 12:24. At 12:24:21, HOPS reported a load loss of approximately 700 MW. At 12:25, CGES observed a load loss of approximately 338 MW, while OST recorded a load loss of approximately 1,102 MW at 12:24:24. The data indicate that all affected TSOs experienced the load loss within a duration of less than one minute. The total load loss was approximately 3.5 GW.

3.2.3 Other Consequences of the Blackout

The TSOs affected by the blackout did not report any personal injuries or property damages due to the event. None of the TSOs have conducted an economic estimation of the economic loss of the blackout.

3.2.4 Load Shedding

There was no low frequency or undervoltage demand disconnection (LFDD, LVDD) during the incident. Moreover, no manual load shedding was applied.

3.3 Functioning of the Transformers during the Incident

In this chapter, the functioning of the transformer during the incident is analysed, and to do so, some of the most important information related to the voltage levels used in each control area, and for the transformers that connect these levels, are listed.

The transmission network under the control of CGES consists of 400 kV, 220 kV and 110 kV voltage levels, while voltage levels of 35 kV and below are under the responsibility of the distribution system operator. All transformers connecting transmission voltage levels (400/220 kV, 400/110 kV and 220/110 kV) are regulated manually, while transformers connecting transmission and distribution networks (110/x kV) are regulated mostly automatically, whereby the lower voltage level is regulated.

The transmission network under the control of HOPS consists of 400 kV, 220 kV and 110 kV voltage levels, while voltage levels of 35 kV and below are under the responsibility of the distribution system operator. Transformers 400/220 kV are regulated manually, and transformers 400/110 kV are regulated automatically, whereby the lower voltage level is regulated. Transformers 220/110 kV are regulated manually in some substations, and in others automatically (the lower voltage level is regulated), depending on the needs of a specific location in the network. Transformers connecting transmission and distribution networks (110/x kV) are regulated automatically, whereby the lower voltage level is regulated.

The transmission network under the control of NOSBiH consists of 400 kV, 220 kV and 110 kV voltage levels, while voltage levels of 35 kV and below are under the responsibility of the distribution system operators. Transformers 400/220 kV and 400/110 kV are regulated manually. Transformers 220/110 kV are regulated manually in all substations except in SS Mostar 4, where they are regulated automatically, whereby the lower voltage level is regulated. Transformers connecting transmission and distribution networks (110/x kV) are regulated automatically, whereby the lower voltage level is regulated.

The transmission network under the control of OST consists of 400 kV, 220 kV, 150 kV and 110 kV voltage levels, while voltage levels of 35 kV and below are under the responsibility of the distribution system operator. All transformers connecting transmission voltage levels (400/220 kV, 400/110 kV, 220/110 kV and 150/110 kV) and transformers connecting transmission and distribution networks (220/x kV and 110/x kV) are regulated manually

In summary, the reaction of automatic voltage regulation could be expected only at the following transformers:

- » **CGES control area:** the greater part of transformers 110/x kV;
- » **HOPS control area:** all transformers 400/110 kV, some transformers 220/110 kV and all transformers connecting transmission and distribution network;
- » **NOSBiH control area:** transformers 220/110 kV in SS Mostar 4 and all transformers 110/x kV; and
- » **OST control area:** none of the transformers.

In the following, the reaction of the transformer is described in correlation with certain events from the sequence of events, as listed in chapter 3.1. However, not every correlation can be confirmed with complete certainty, considering that some other events with an impact on the system could have occurred at the same time, which do not fall within the scope of the data analysed here.

Before the initial event, it was a steady state situation, with only a few changes in the position of the transformer tap changers, which can be considered normal daily operation.

3.3.1 Outage 1: 12:09:16: 400 kV Ribarevine – Podgorica 2

The consequence of this outage is a drop in the voltage level in the southern part of the CGES control area up to 10 kV in the 400 kV network (SS Podgorica 2: 404 kV → 394 kV), up to 6 kV in the 220 kV network (SS Podgorica 1: 227 kV → 221 kV) and up to 3 kV in the 110 kV network. That caused the change of the position of some transformers 110/x kV tap changers (here and after, it is always a change to a higher position, which means that for a reduced voltage on the high voltage side, an attempt is made to maintain the same voltage on the low voltage side), and the situation stabilised in a new stationary state.

In the HOPS control area, the consequences of this outage were felt only at the southern end of the network around the city of Dubrovnik, which is electrically stronger connected to the southern part of the NOSBiH control area than to the rest of the HOPS control area. Transformer tap changers 220/110 kV in SS Plat changed their position by 2 or 3 steps. In the same substation transformer tap changers 110/35 kV changed their position by 1 step and those were the only changes that can be related with this outage.

In the NOSBiH control area, the transformer tap changers 220/110 kV in SS Mostar 4 responded to a voltage change of about 2 kV moving by one step. Transformer tap changers in substations 110/x kV in the southern part of the NOSBiH control area reacted by changing their position by 1 step and/or they did not react at all.

In the OST control area, a voltage drop was relatively significant, up to 7 kV in the 400 kV network, up to 5 kV in the 220 kV network and up to 3 kV in the 110 kV network, but as none of the transformers are in automatic voltage regulation and also the operators did not change any tap changer manually, there were no changes of the position of any transformer tap changers.

3.3.2 Outage 2: 12:21:33 400 kV Zemblak – Kardia

The consequence of this outage was a drop in the voltage level in the southern part of the CGES control area up to 15 kV in the 400 kV network (SS Podgorica 2: 388 kV → 373 kV), up to 11 kV in the 220 kV network (SS Podgorica 1: 221 kV → 210 kV) and up to 6 kV in the 110 kV network. Transformer tap changers in substations 110/x kV where automatic voltage regulation is applied reacted by changing the tap position, but not more than one step.

In the HOPS control area, the consequences of this outage were a drop in the voltage level in Dalmatia up to 8 kV in the 400 kV network, up to 5 kV in the 220 kV network and up to 2 kV in the 110 kV network. There was a very small voltage drop in the continental part of Croatia. Not a single transformer in automatic voltage regulation reacted to these voltage changes.

In the NOSBiH control area, voltage drop was up to 12 kV in the 400 kV network near to CGES control area (SS Trebinje: 396 kV → 384 kV), up to 4 kV in the 220 kV network (SS Trebinje: 227 kV → 223 kV) and up to 3 kV in the 110 kV network. There was no reaction of transformer tap changers in SS Mostar 4. Transformer tap changers in substations 110/x kV where automatic voltage regulation is applied mostly did not react.

In the OST control area, a voltage drop several seconds after the outage was up to 23 kV in the 400 kV network (SS Zemblak: 414 kV → 391 kV), up to 12 kV in the 220 kV network and up to 7 kV in the 110 kV network. Because one of the transformers are in automatic voltage regulation and also the operators did not change any tap changer manually, there were no changes of the position of any transformer tap changers.

3.3.3 Outages 3, 4, 5 and 6: 12:21:43 220 kV Fierze – Prizren, 12:21:45 220 kV Podgorica 1 – Mojkovac, 12:21:51 Monita cable and 12:22:02 220 kV Sarajevo 20 – Piva

As these four outages occurred in a short period and considering the speed of changing the position of the transformer tap changers, the transformer reaction was analysed as a reaction to all events simultaneously. Furthermore, on the basis of high-resolution data from the PMUs, it is known that the first two outages caused a voltage drop, while the MONITA cable outage briefly increased local voltages.

In the CGES control area there was a further voltage drop in all voltage levels, where, with a local short-term recovery after the MONITA cable outage, by the time of the next outage the voltages dropped slightly to around 310 kV in the 400 kV network, to around 180 kV in the 220 kV network and to around 85–90 kV in the 110 kV network. In almost all substations 110/x kV where automatic voltage regulation is applied, transformer tap changers reacted by changing tap position.

In the HOPS control area, in Dalmatia, voltages decreased; in addition, and with a local short-term recovery after the MONITA cable outage, by the time of the next outage the voltages dropped in the 400 kV network (SS Velebit: 270 kV), to around 150 kV in the 220 kV network, and to levels 80–90 kV in the 110 kV network. Voltage drop also occurred in the continental part of Croatia, so voltages decreased in SS 400/110 kV Ernestinovo to 368 kV and in SS 220/110 kV Međurić to 198 kV. In all substations where automatic voltage regulation is applied, transformer tap changers reacted by changing tap position, often reaching the final step.

In the NOSBiH control area a further voltage drop occurred at all voltage levels as well, to the values slightly higher than in the southern parts of the CGES and HOPS control areas. Transformer tap changers in substations 110/x kV where automatic voltage regulation is applied reacted by changing tap position by several steps.

In the OST control area, an interesting situation occurred that after the voltage drop after outages 3 and 4, the MONITA cable outage (outage 5) recovered voltages locally mostly to levels higher than before the outage 3. Nevertheless, by the time of the next outage the voltages dropped in the 400 kV network to around 340 kV, in the 220 kV network to 175–190 kV and in the 110 kV network to 85–95 kV. Because none of the transformers are in automatic voltage regulation and also the operators did not change any tap changer manually, there were no changes of the position of any transformer tap changers.

3.3.4 Outage 7, 8 and 9: 12:24:22 220 kV Brinje – Pađene, 400 kV Ugljevik – Tuzla 4 and 220 kV Prijedor 2 – Jajce 2

In 3–4 seconds, before the moment of no voltage in all control areas, a sudden drop in voltage occurred. Transformer tap changers in substations where automatic voltage regulation is applied and which were not previously in the final step reacted automatically, but due to the short period this did not happen in all substations.

3.3.5 Post-Blackout

In substations where automatic voltage regulation is applied that remained under voltage and are located near the area where the blackout occurred (the northern part of CGES control area and the bigger part of HOPS control area), the transformer tap changers reacted automatically so that they again took on a new stationary state, ensuring voltage within normal limits.

3.4 Evolution of Electrical Quantities

This chapter shows the evolution of relevant electrical quantities shortly before and during the incident. The plots here are limited to the 220 kV and 400 kV networks.

3.4.1 Active and Reactive Power Flows

This subchapter deals with the flows of active and reactive power on relevant TIE lines in the 400 kV and 220 kV network. Figure 24 shows the line loadings of the lines with outage ID1 and ID2 that triggered the cascading disconnections of the subsequent lines and assets. The loadings of each line are given relative to their maximum thermal capacity. Broadly speaking, apparent power in AC power systems is the total power supplied by the source, combining both the actual usable power (called active power) and the extra power that flows back and forth and cannot be used directly (reactive power).

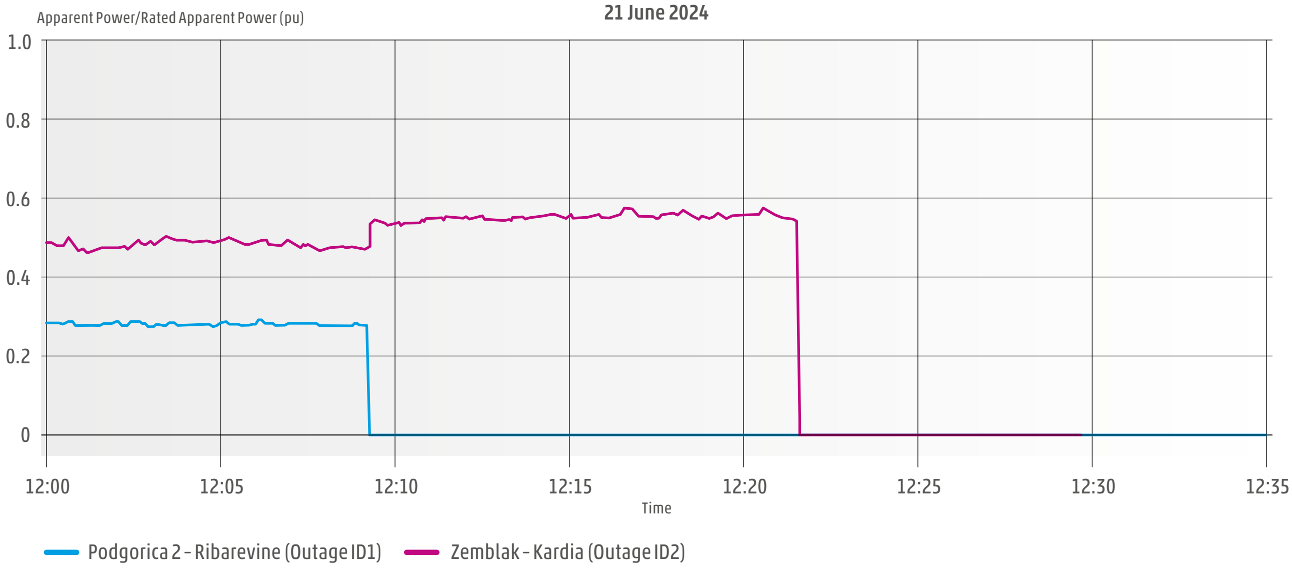

Figure 24: Evolution of line loadings (apparent power) of the lines with outage ID1 and ID2 whose outages triggered the cascading disconnections.

3.4.1.1 CGES (Montenegro)

Figure 25 and Figure 26 show the line loadings within the CGES control area relative to their thermal capacity limits.

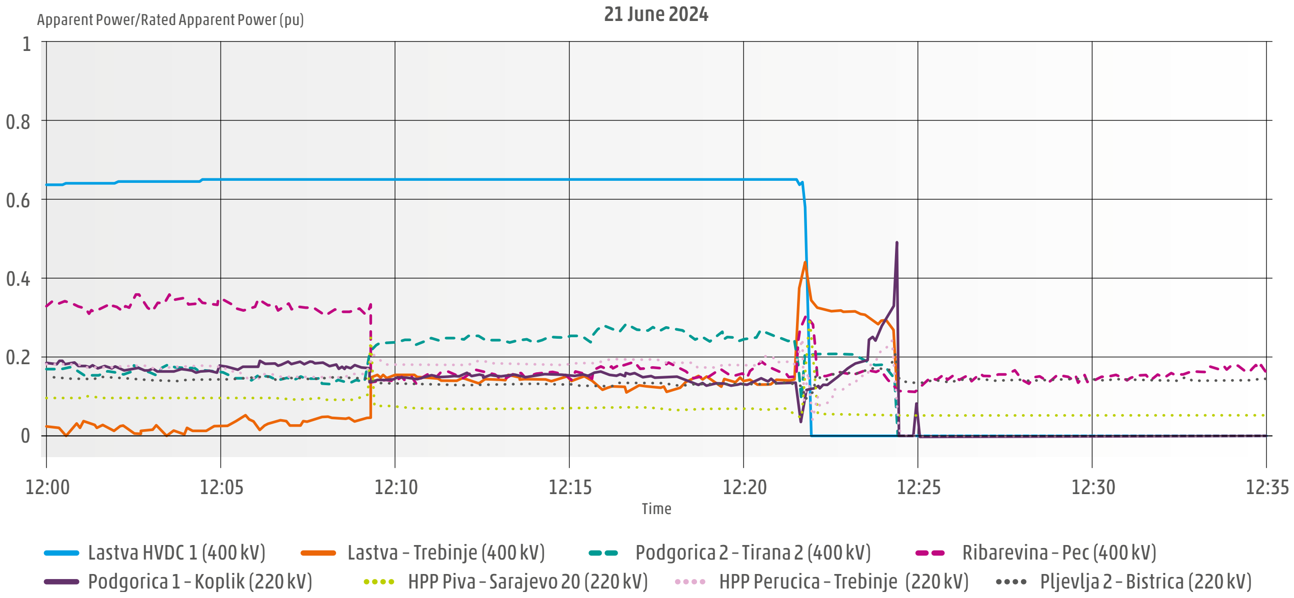

Figure 25: Evolution of line loadings (active power) in the CGES network.

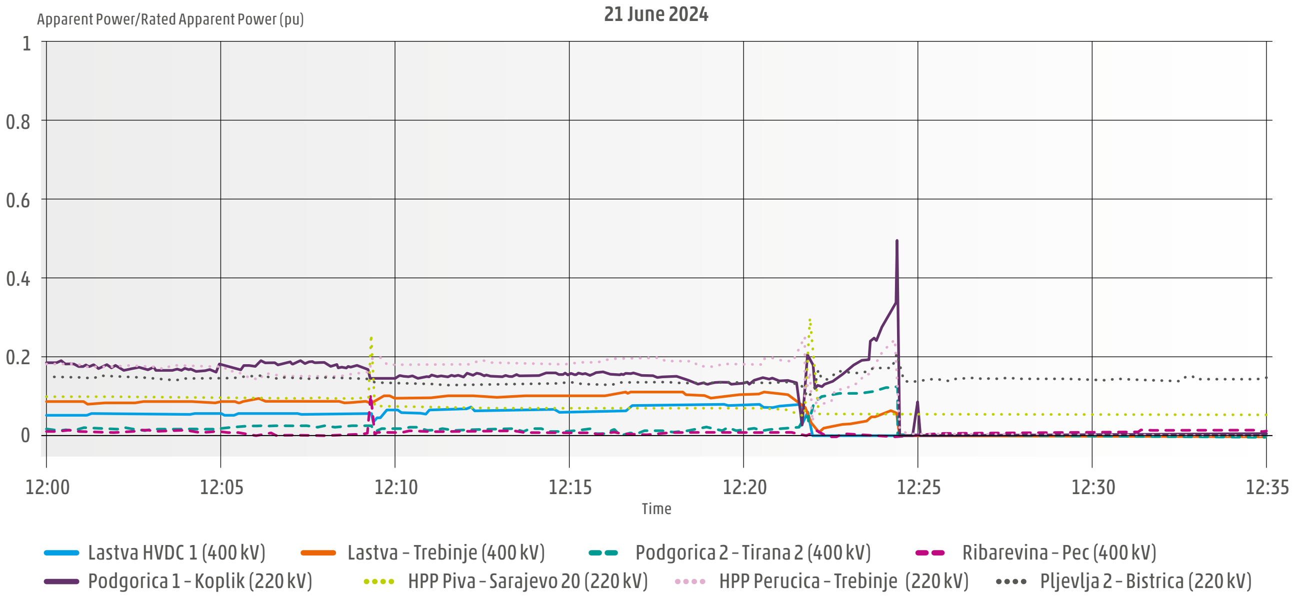

Figure 26: Evolution of line loadings (reactive power) in the CGES network.

3.4.1.2 HOPS (Croatia)

Figures 27 and Figure 28 show the line loadings within the HOPS control area relative to their thermal capacity limits.

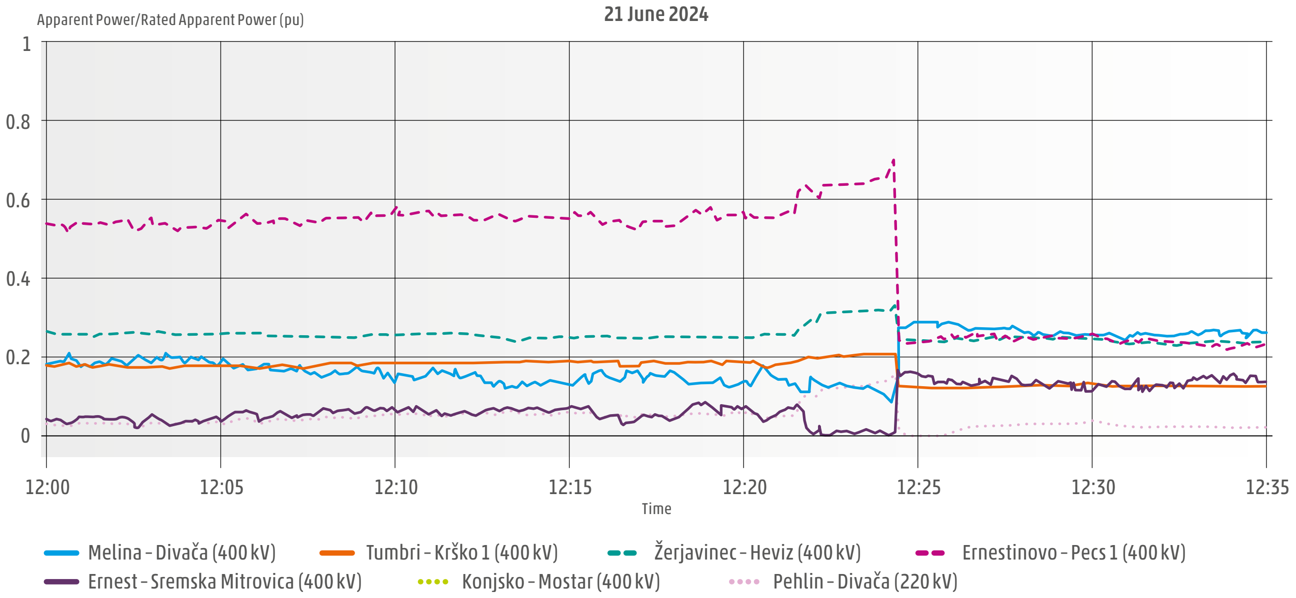

Figure 27: Evolution of line loadings (active power) in HOPS network.

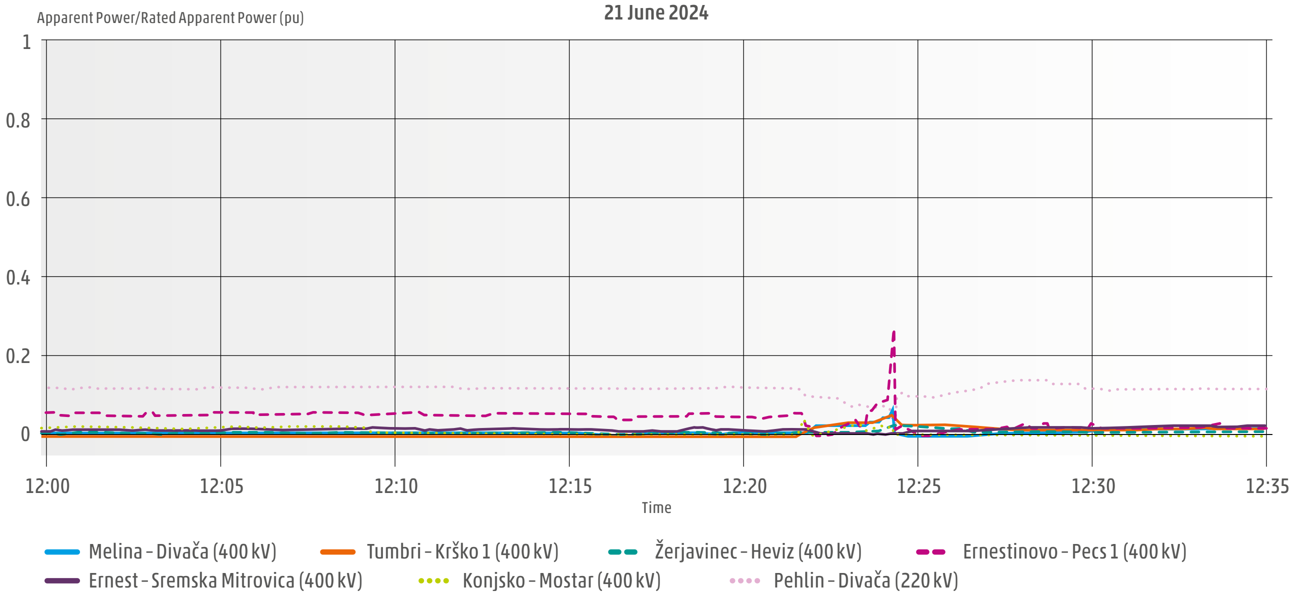

Figure 28: Evolution of line loadings (reactive power) in HOPS network.

A detailed evolution of the system conditions can be seen in the **video recording of HOPS SCADA overview**. The video shows active power flows and significant voltage measurements in the HOPS control area and also the active power flows in parts of the neighbouring systems. The **second video** shows reactive power flows in HOPS SCADA overview during the disturbance.

3.4.1.3 Monita HVDC

The Monita link consists of two poles, each capable of transmitting power independently. When a pole is in operation, the control system manages the reactive power compensation elements to ensure proper functioning of the converter and limit reactive power exchange with the grid. Additionally, the control system automatically adjusts the transformer's tap changer to maintain the correct converter operation. As the Monita link is an LCC[8] HVDC technology, it is unable to provide reactive power support by regulating the reactive power. When a pole is not in active power transmission, the shunt reactors can still be operated for voltage control.

During the event on 21 June, Pole 2 was transmitting active power. Figure 29 illustrates the breaker status at the Kotor station, showing that three of the four shunt reactors were in operation. In contrast, Pole 1, which was not transmitting power, had only the reactor F4 in service.

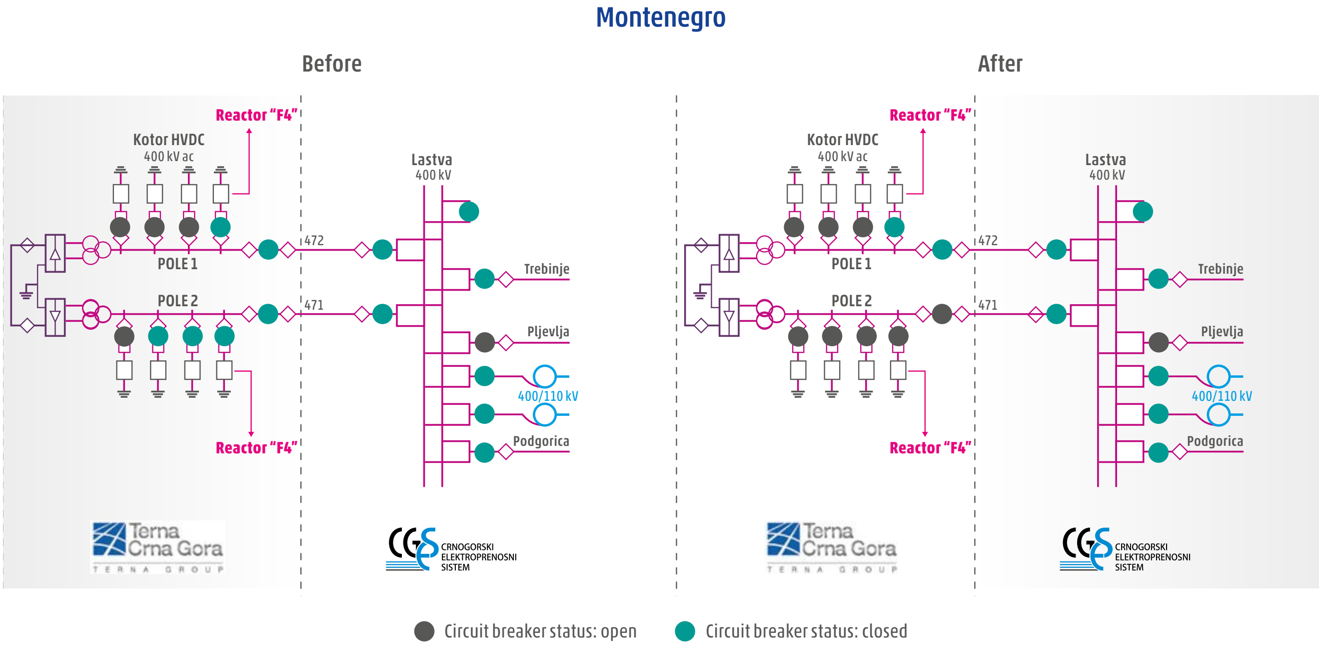

Figure 29: Simplified single line diagram of the Monita link, Kotor station, with the representation of circuit breaker status before and after the Monita trip

Upon the tripping of the Monita HVDC link due to undervoltage protection system intervention in the Kotor substation, reactor "F4" inside the converter facility remained connected to the grid until the end of cascading. Reactor "F4" consumed approximately 72 MVAr (around its nominal power) before the trip of the 400 kV OHL Podgorica 2 – Ribarevine, after which it decreased in value as the voltage continued to drop.

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[8] Line-commutated converter (LCC) HVDC systems cannot regulate reactive power effectively due to their significant reactive power requirements at both the rectifier and inverter sides. This is caused by the delayed firing of thyristors, which leads to a lag between current and voltage waveforms, resulting in high reactive power consumption. LCC HVDC systems require external reactive power compensation devices, such as capacitors and reactors, to manage their reactive power needs. This dependence on external devices limits their ability to regulate reactive power independently.

3.4.1.4 NOSBiH (Bosnia and Herzegovina)

Figure 30 and Figure 31 show the line loadings within the NOSBiH control area relative to their thermal capacity limits.

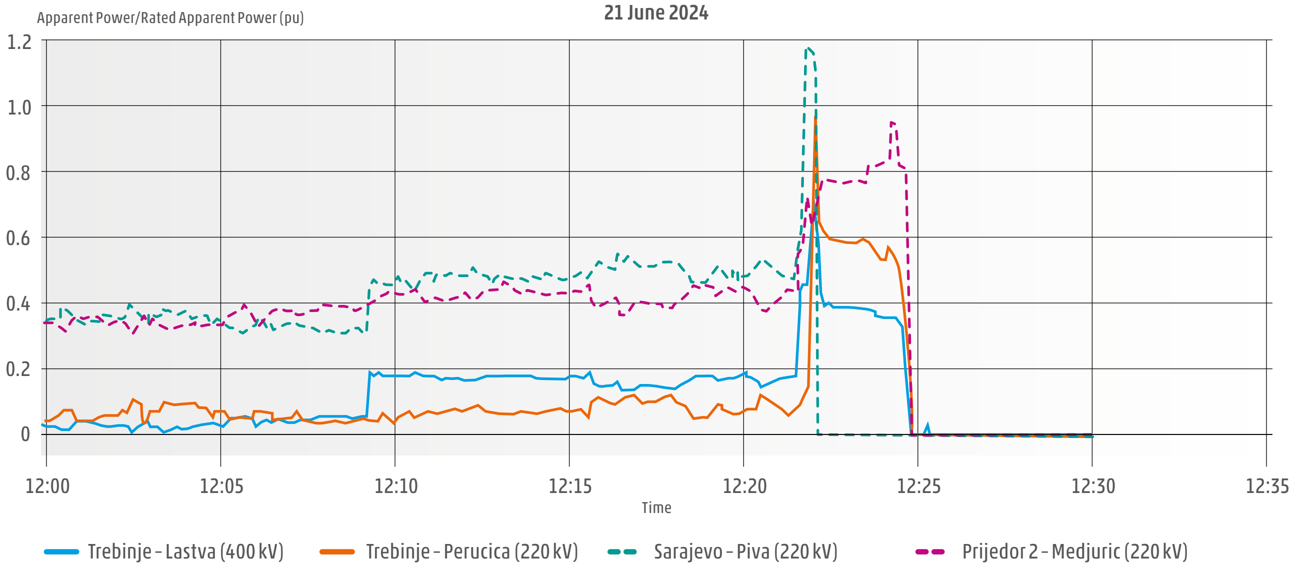


Figure 30: Evolution of line loadings (active power) in NOSBiH network; "Sarajevo" refers to "Sarajevo 20".

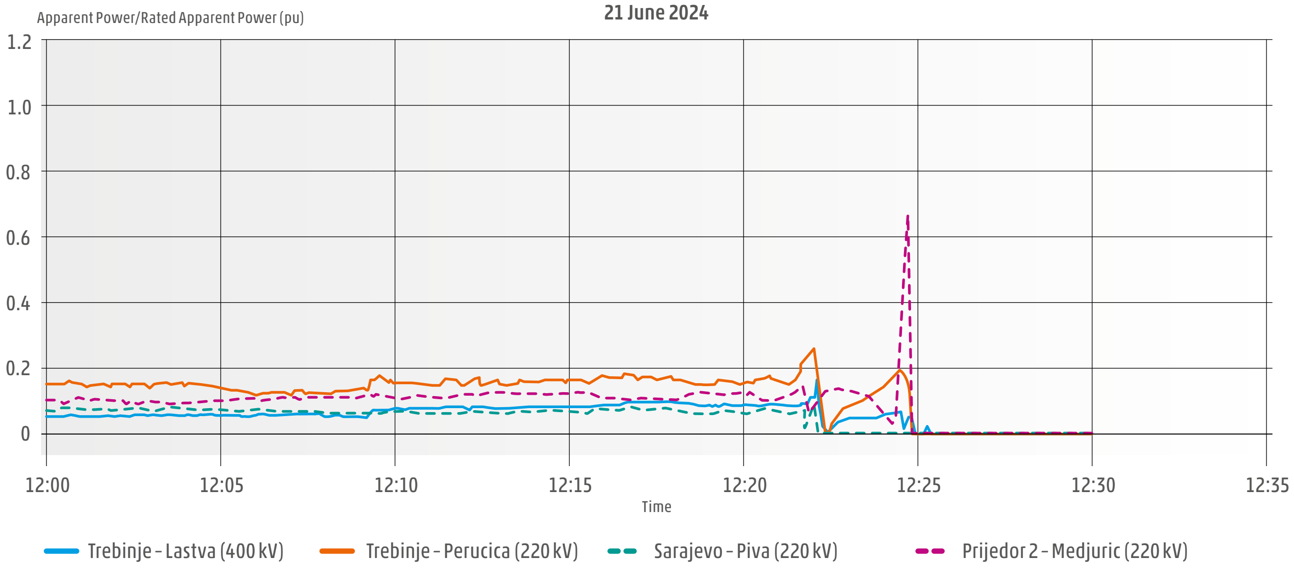


Figure 31: Evolution of line loadings (reactive power) in NOSBiH network; "Sarajevo" refers to "Sarajevo 20".

3.4.1.5 OST (Albania)

Figure 32 and Figure 33 show the line loadings within the OST control area relative to their thermal capacity limits.

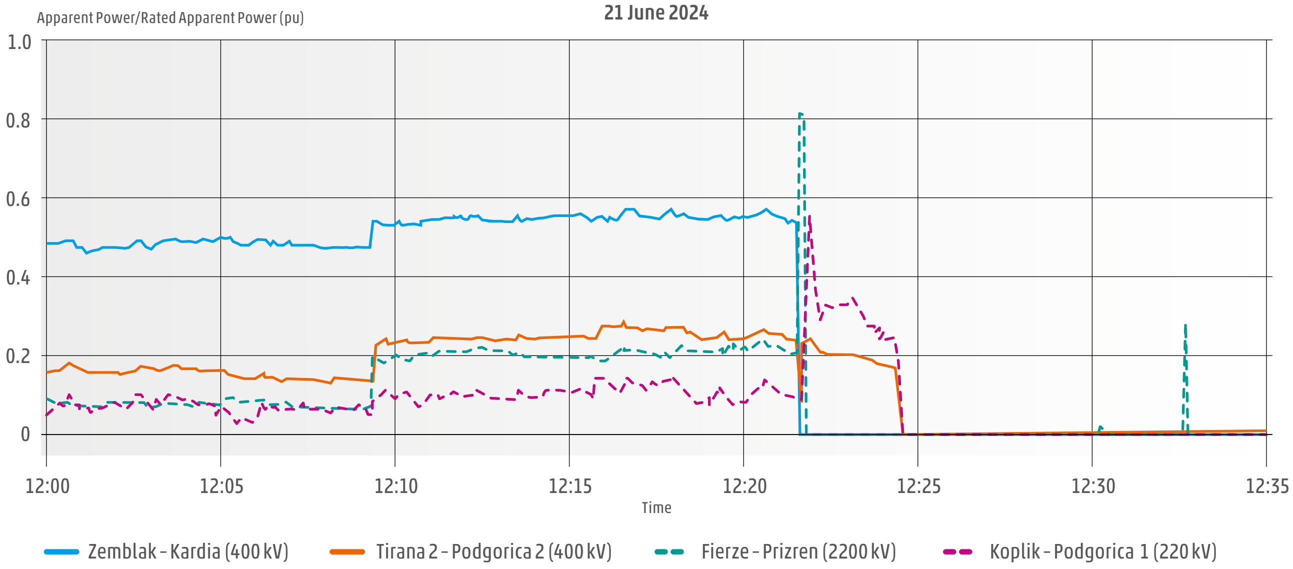


Figure 32: Evolution of line loadings (active power) in the OST network. The value for line Fierze - Prizren (220 kV is estimated, due to pick up time of OC protection, which is shorter than SCADA interval of 4 second)

The outage of 400 kV OHL TIE Zemblak – Kardia due to distance protection caused an overload of 220 kV OHL TIE Fierze – Prizren 2, which resulted in the disconnection of this line due to overcurrent protection. These outages caused a voltage drop that resulted in the disconnection of 400 kV OHL TIE Tirana 2 – Podgorica 2 and 220 kV OHL TIE Koplik – Podgorica 1. Parts of the OST system remained connected to the neighbouring system via TIE line 150 kV Bistrice – Mourtos.

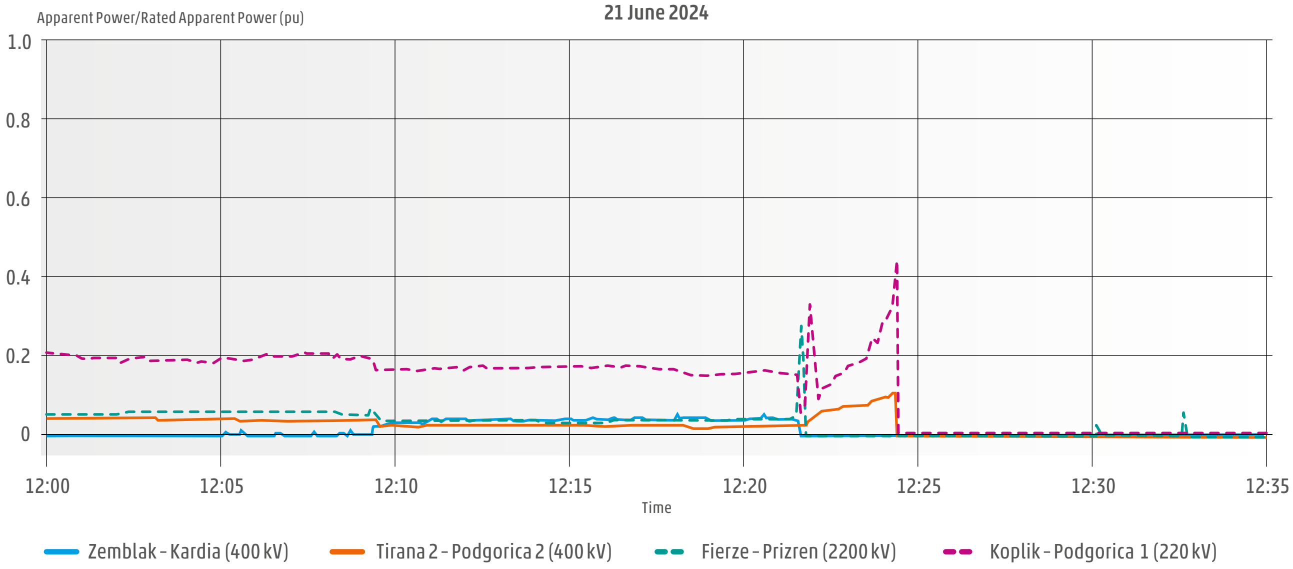


Figure 33: Evolution of line loadings (reactive power) in the OST network.

3.4.2 Voltages

This chapter presents the evolution of the voltages in the different affected areas shortly before and during the incident.

3.4.2.1 CGES (Montenegro)

Figure 34 and Figure 35 represent voltage measurements from selected 400 kV and 220 kV substations within the CGES control area. The initial outage of OHL Podgorica 2 – Ribarevine (ID 1) did not cause a critical drop in voltage in the CGES control area. Although the drop in voltage was 14 kV, voltages remained within the normal range. After the voltage collapse, parts of the CGES system remained connected to neighbouring systems, which can be observed by the presence of voltage in SS Ribarevine even after the disturbance.

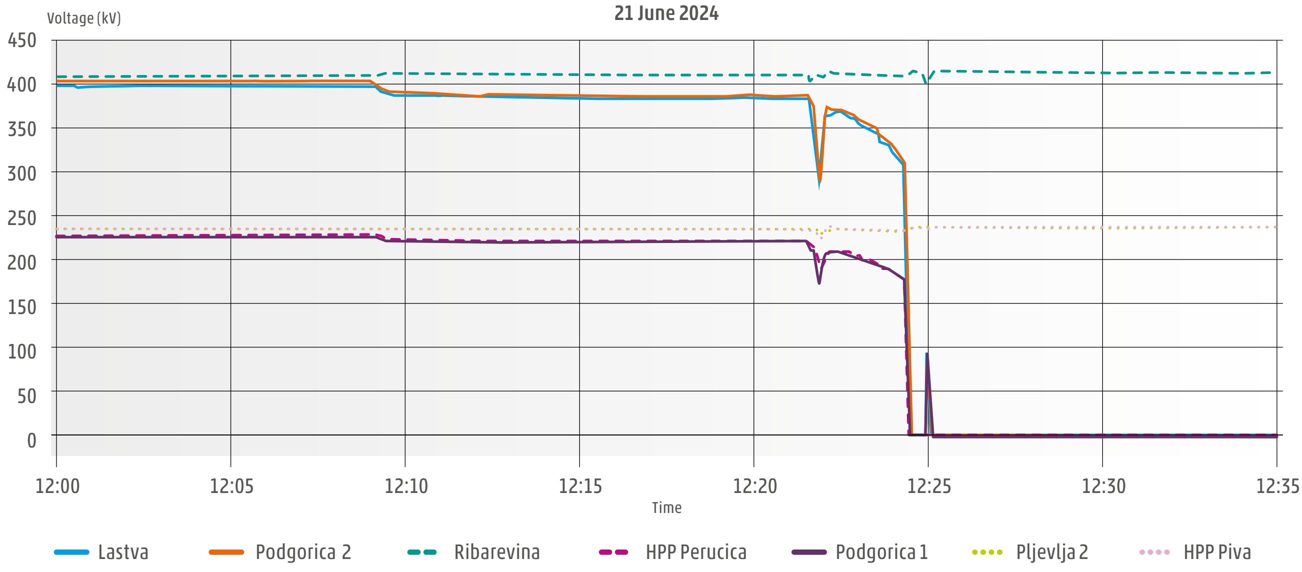


Figure 34: Voltage evolution in CGES network on the 400 kV and 220 kV levels.

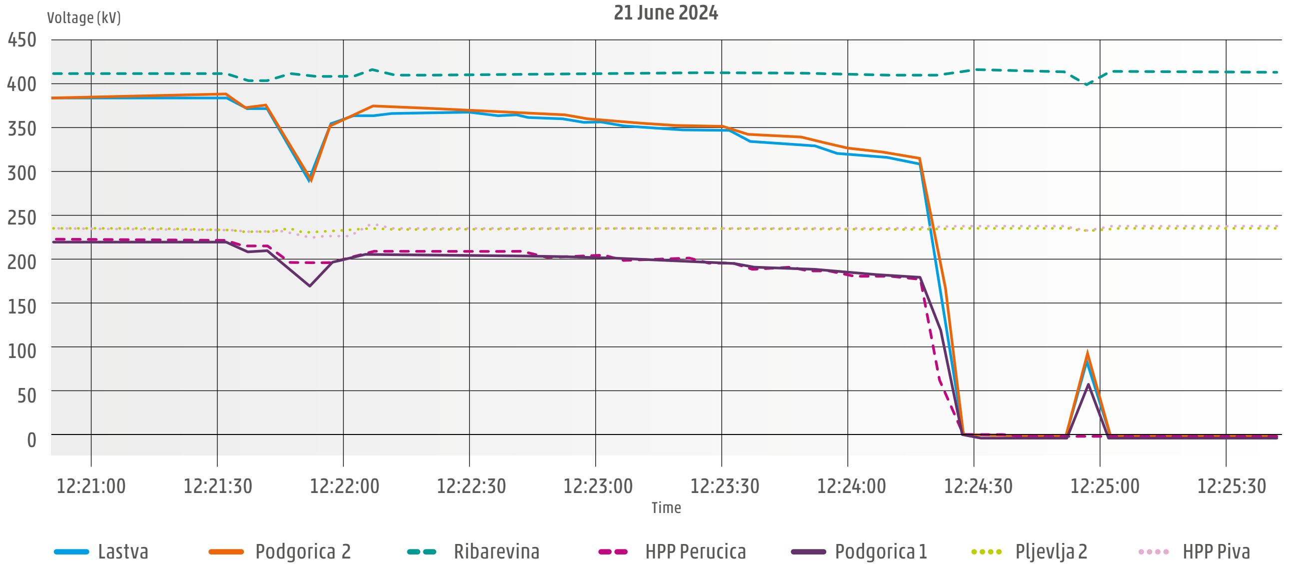


Figure 35: Voltage evolution in the CGES network on the 400 kV and 220 kV levels, the spike in voltage at 12:25:00 shows the reconnection attempts of the TSO (zoomed)

3.4.2.2 HOPS (Croatia)

Figure 36 and Figure 37 show the voltage trajectories in the HOPS control area.

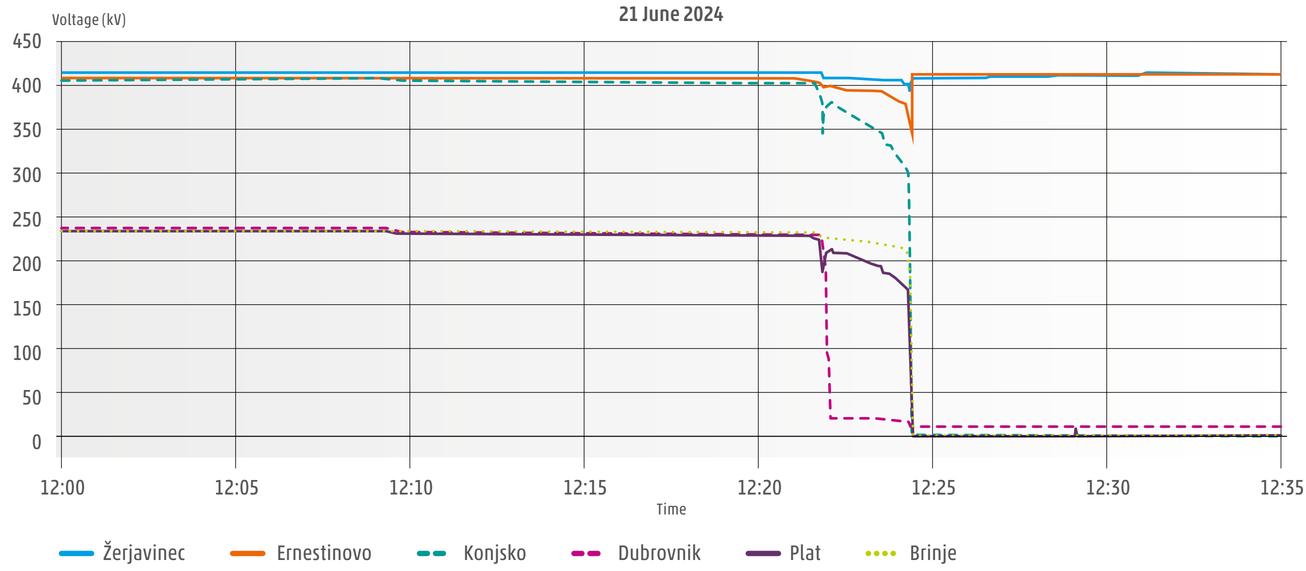


Figure 36: Voltage evolution in the HOPS network on the 400 kV and 220 kV level.

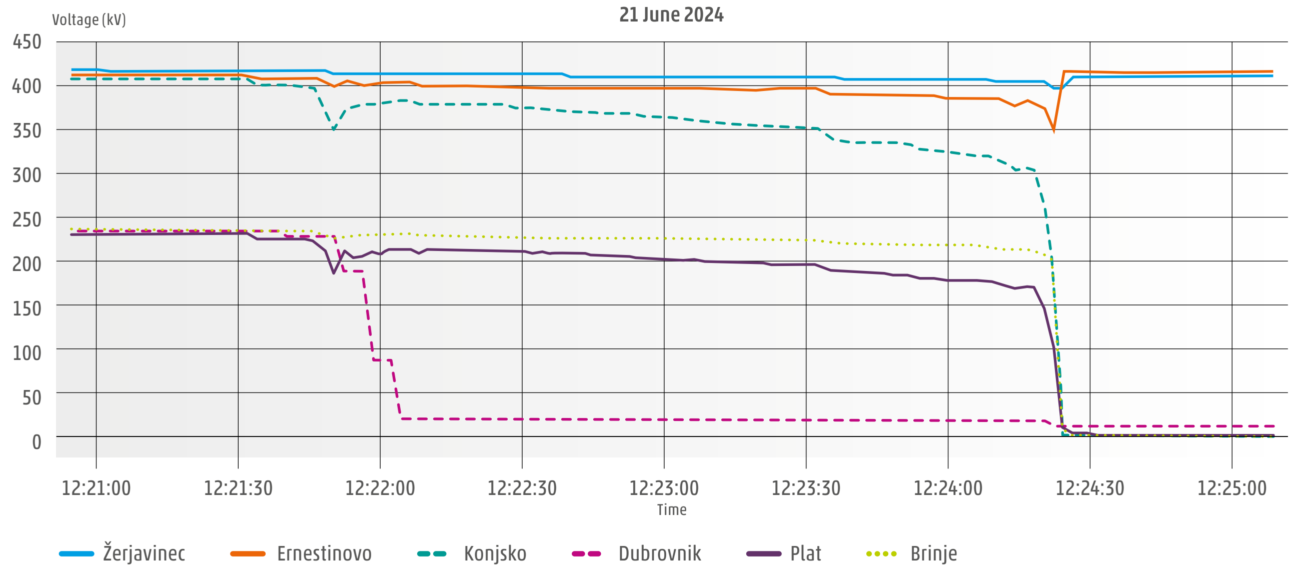


Figure 37: Voltage evolution in HOPS network on the 400 kV and 220 kV level (zoomed)

3.4.2.3 NOSBiH (Bosnia and Herzegovina)

Figure 38 and Figure 39 show the voltage trajectories in the NOSBiH control area.

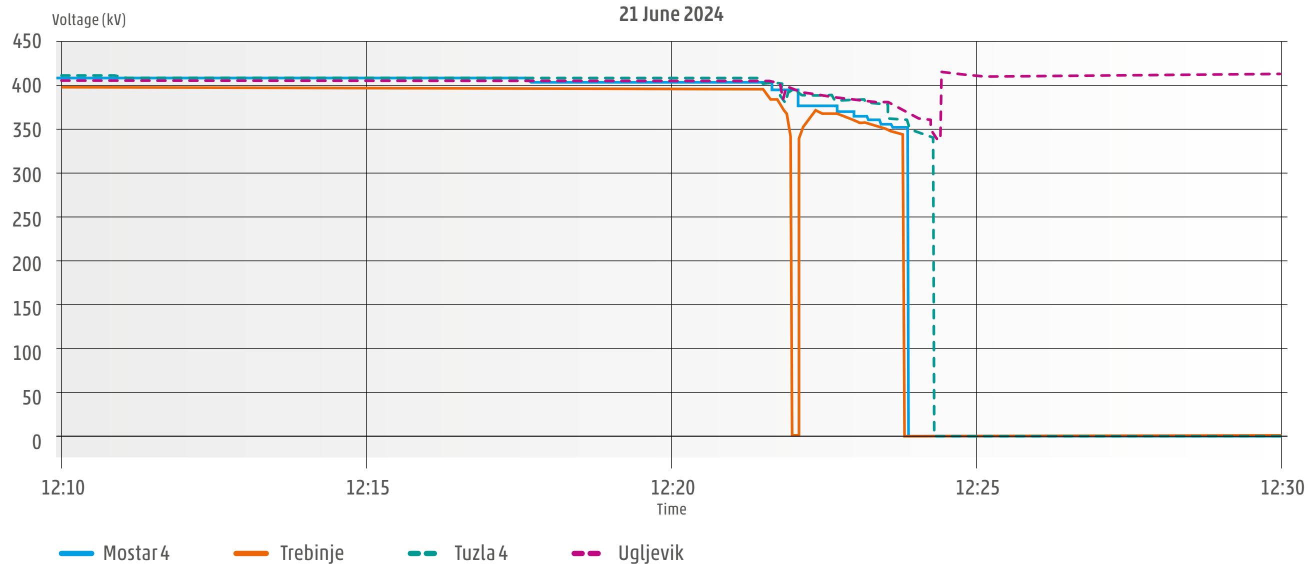


Figure 38: Voltage evolution in the NOSBiH network on the 400 kV and 220 kV levels; the dip to 0 kV at approximately 12:22 (dashed orange line) is due to faulty data and not real.

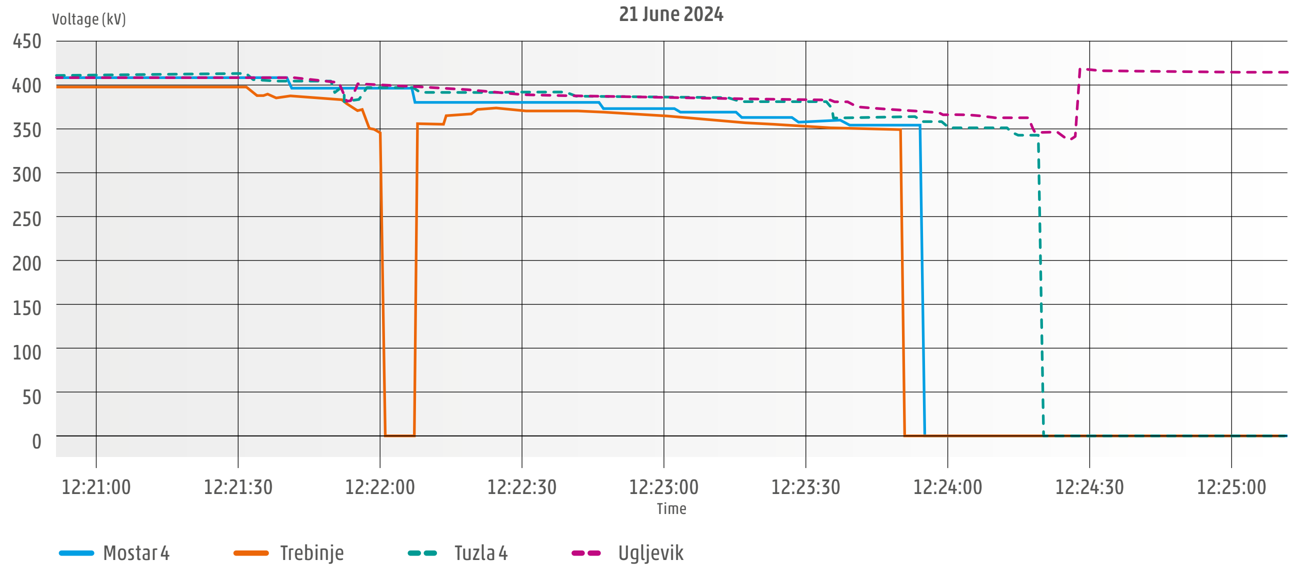


Figure 39: Voltage evolution in the NOSBiH network on the 400 kV and 220 kV levels (zoomed); the dip to 0 kV at approximately 12:22 (dashed orange line) is due to faulty data and not real. Substation Ugljevik remained with voltage in 400 kV busbars

3.4.2.4 OST (Albania)

Figure 40 and Figure 41 show the voltage trajectories in the OST control area.

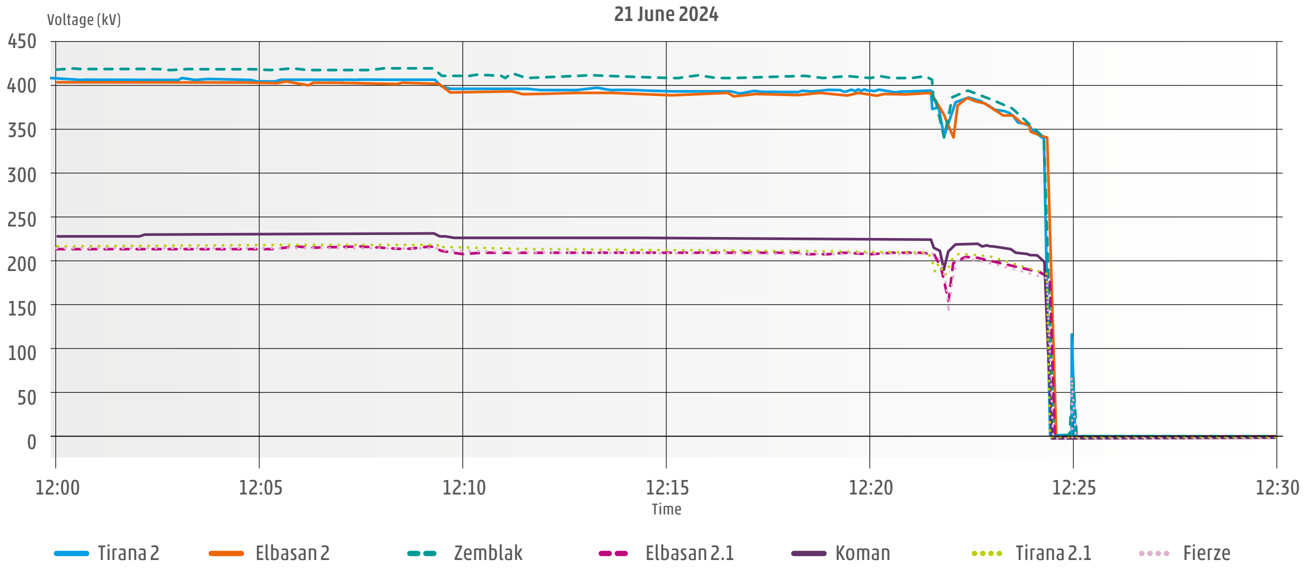


Figure 40: Voltage evolution in the OST network on the 400 kV and 220 kV levels.

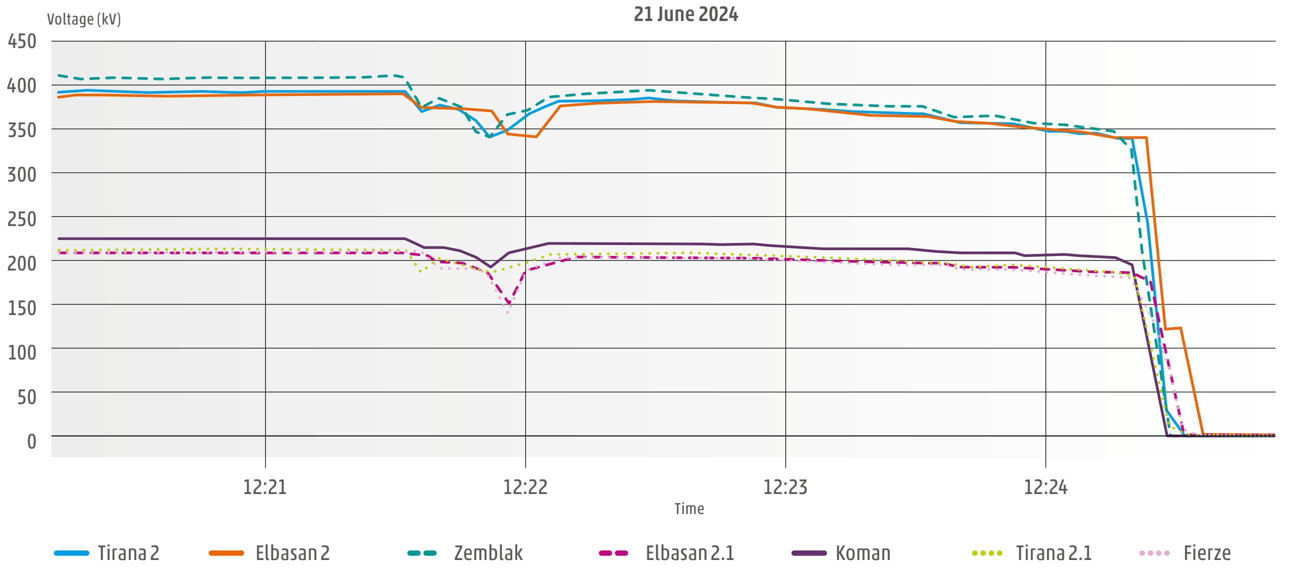


Figure 41: Voltage evolution in the OST network on the 400 kV and 220 kV levels (zoomed)

3.4.3 Voltage Angles

Figure 42 and Figure 43 show the voltage angles of some selected nodes with different temporal zooms. For plotting purposes, the voltage angles were unwrapped (not toggling between –180° and +180°) and put in relation to a distant voltage angle in Switzerland (Soazza). Thereby, it is easier to identify relative movements of certain nodes to each other. It can be seen that there is a change in voltage angles around 12:24 with a maximum of approx. 50° in substation "Sarajevo 20". Voltage angles changes were observed in the whole CE area, even in Portugal.

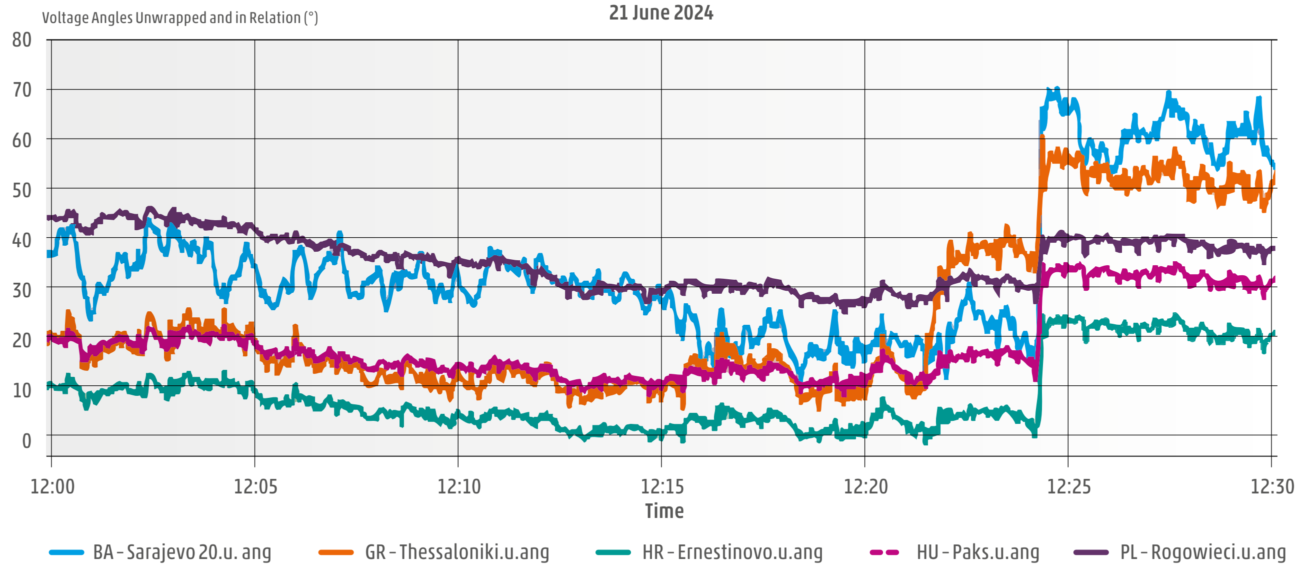


Figure 42: Unwrapped voltage angles relative to Soazza (CH)

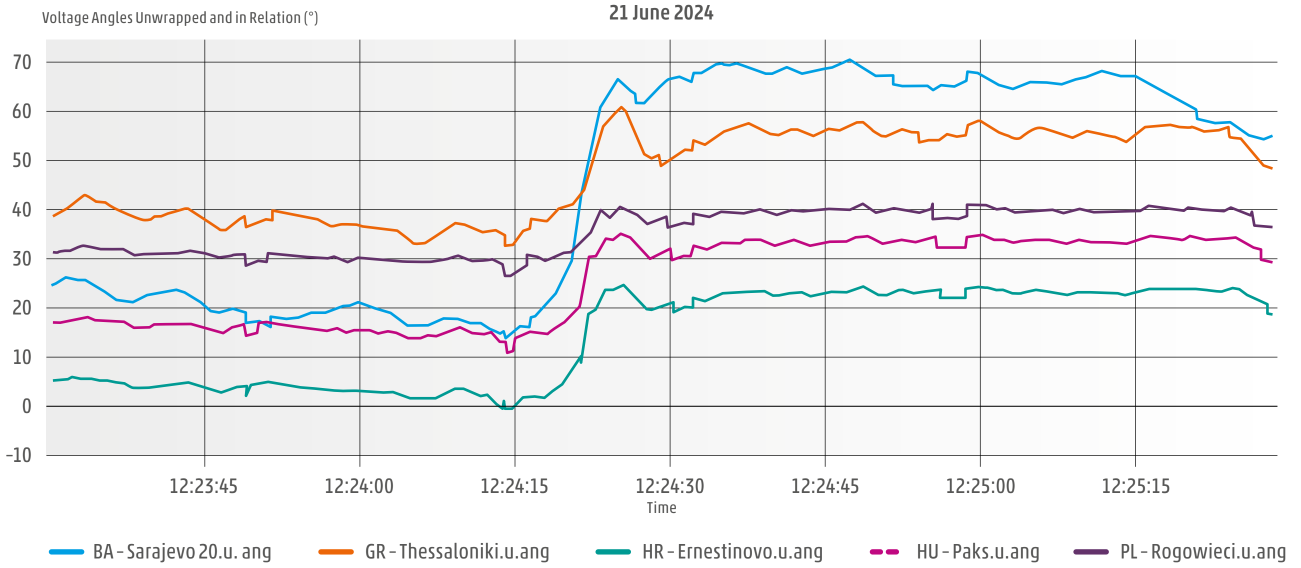


Figure 43: Unwrapped voltage angles relative to Soazza (CH) (zoomed)

3.4.4 Frequency

Figures 44 to Figure 45 show the frequency trajectory of some selected nodes with different temporal zooms. Though it is visible that frequency is affected by the incidents in the grid (e. g. around 12:24), the event was not triggered by frequency stability issues and did not result in any. The frequency inside and outside the affected area always remained in an uncritical range and synchronous.

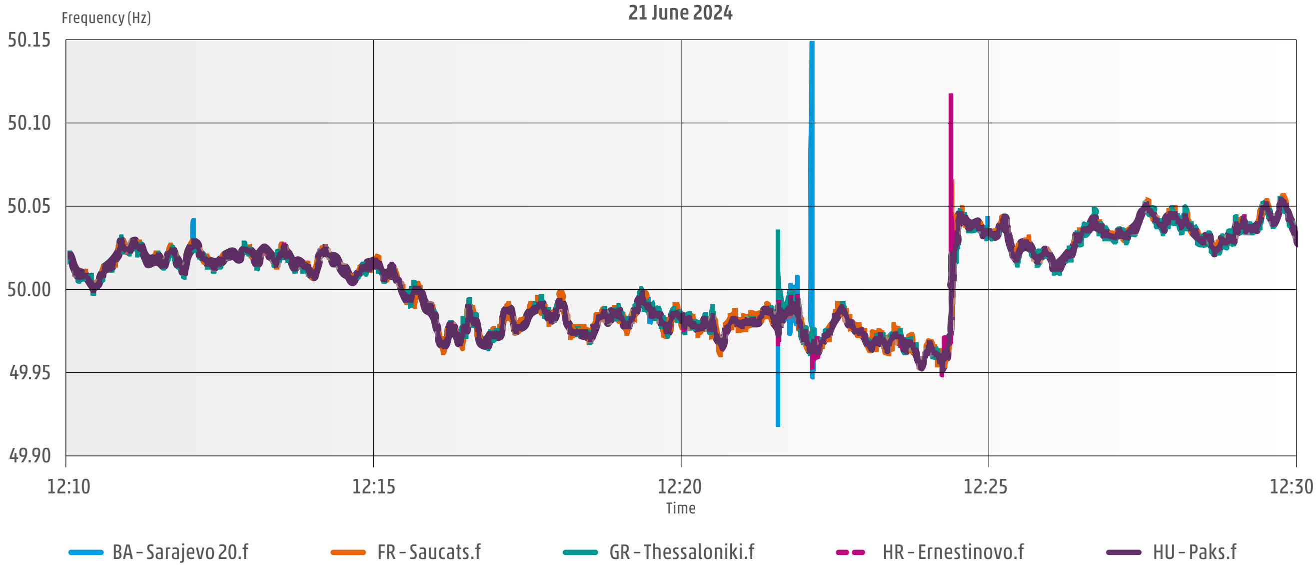


Figure 44: Frequency.

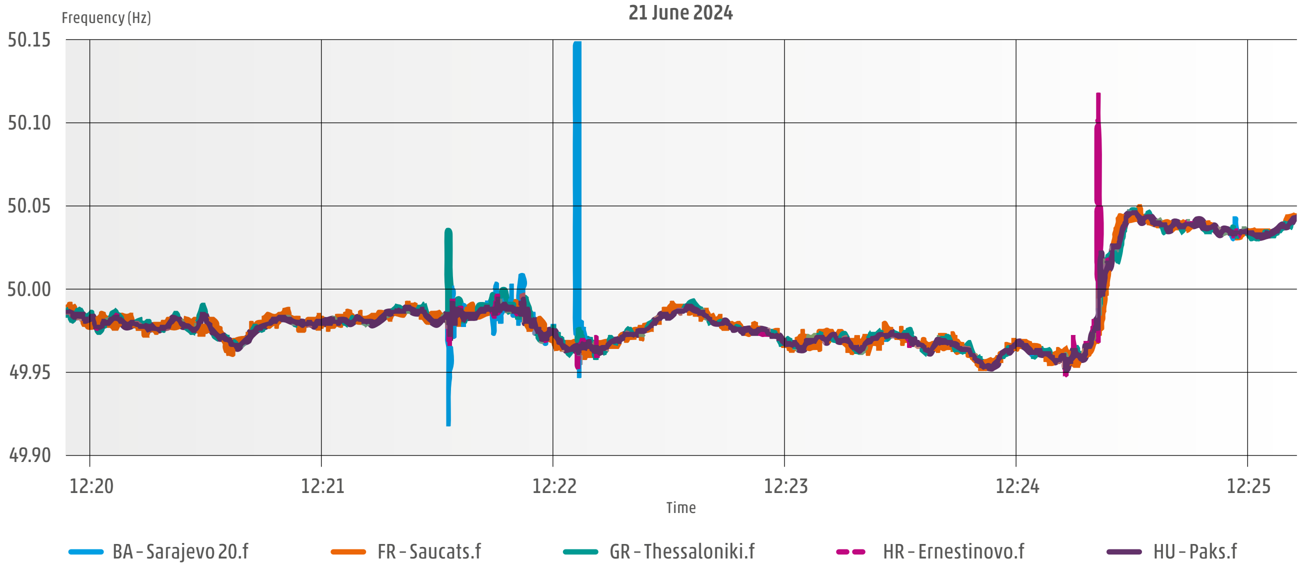


Figure 45: Frequency (zoomed)

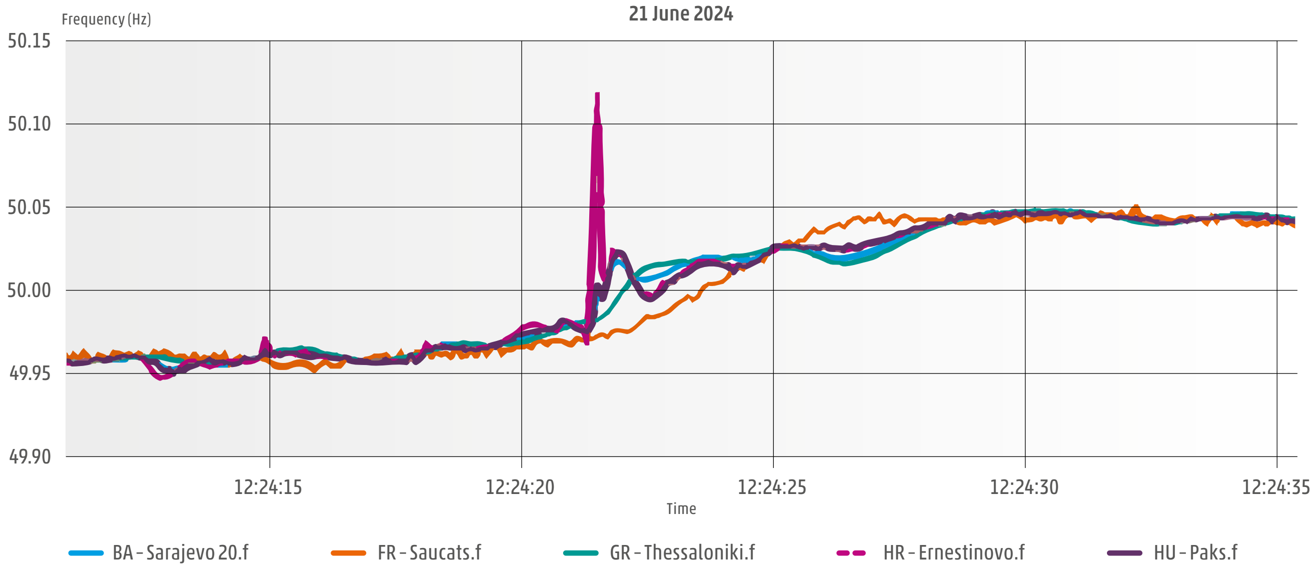


Figure 46: Frequency (zoomed to frequency jump)

3.5 Performance of the Protection System

In large interconnected power systems, just as in any electrical system, the basic objectives that one aims to achieve with the design, setup and maintenance of a protection system are: to avoid dangerous situations for people, to limit the damage to the components of the electrical system when an anomaly or failure occurs, to minimise the consequences of the discontinuity of service in any network situation and to mitigate the risk of transient instability in the transmission network.

Reconstructing the operation and checking it in relation to the expected calibration and the settings of the devices is critical in the case of the analysis. Events such as the blackout on the 21 June 2024 shall be analysed and investigated to understand the causes, the events and finally to determine the corrective actions, if any, that can be taken to avoid such events in the future.

In this section the protection's operation (tripping) will be analysed, using the available data: mainly the SCADA event lists and the disturbance fault recordings (DFRs).

The events which will be analysed are listed in Table 8. The outage IDs in this table and in the following subchapters are in line with the outage IDs from Table 6.

Outage ID	Time (CEST)	Voltage Level (kV)	Asset Type	Relay Trigger	Cause of Tripping	Tripped Phases	Relay Parameter Settings	Relay Tripped According its Settings
1	12:09:16:213	400	OHL	DIFF	vegetation – line to ground fault	first only L3; secondly all 3 phases	Stage 1 = 480 A; 0 ms time delay	YES
2	12:21:33:200	400	OHL-TIE	DIST	vegetation – line to ground fault	first only L2; secondly all 3 phases	Zemblak: Z1 – R1 = 7.66 Ω X1 = 23.86 Ω 0 ms; Kardia: Main 1 Time EF stage IN1 > = 3I0 = 165 % *Inom = 2,640 A, 300 ms	YES
3	12:21:44:000	220	OHL-TIE	OC	overload	all 3 phases	I = 720 A, 10 s time delay	YES
4	12:21:45:774	220	OHL	OC	overload	all 3 phases; tripped only in Podgorica 1	Stage 1 = 840 A, 1700 ms time d.	YES
5	12:21:51:446	500	DCC-TIE	UV	voltage drop	tripped only in Kotor	UV function V = 400 kV DC with a t = 2 s time delay	YES
6	12:22:06:012	220	OHL-TIE	OC	overload	all 3 phases; tripped only in Sarajevo 20	Stage 3 = 808 A; 20 s time delay	YES
7	12:24:21:587	220	OHL	DIST	voltage drop	all 3 phases	Z3 of the distance relay X = 107.9 Ω	YES
8	12:24:22:341	220	OHL	OC	overload	all 3 phases; tripped only in Prijedor 2	Zone 3 of OC = 786 A; 1,200 s time delay	YES
9	12:24:22:350	400	OHL	OC	overload	all 3 phases; tripped only in Ugljevik; manual CB switch off in Tuzla 4	trip by directional earth fault protection: I0 = 11 % *Inom = 176 A, U0 = 55 % *Unom = 220 kV; 3 s time delay	YES
10	12:24:22:959	220	OHL-TIE	UV	voltage drop	all 3 phases	Automatic CB opening in no voltage condition	YES
11	12:24:22:959	220	OHL-TIE	UV	voltage drop	all 3 phases	Automatic CB opening in no voltage condition	YES
12	12:24:23:000	220	OHL	DIST	voltage drop	all 3 phases, tripped only in Titan	Z1 of the distance relay R1 = 13.567 Ω X1 = 7.97 Ω with 0 ms time delay	YES
13	12:24:23:089	220	OHL-TIE	DIST	voltage drop	all 3 phases	Međurić: Z3 are X = 99.9 Ω; RFPP = 92.4 Ω with 1000 ms time delay	YES
14	12:24:24:000	220	OHL	MAN	manual CB switch off	3 phases manual CB switch off	no protection trip	N/A
15	12:24:26:558	220	OHL-TIE	UV	voltage drop	all 3 phases; tripped only in Trebinje; manual CB switch off in Perucica	no protection trip in Perucica; in Trebinje the settings for Loss of Voltage function is U < 0.7 *Un time delay 10 s	YES
16	12:24:26:579	220	OHL	UV	voltage drop	all 3 phases; tripped only in Trebinje; manual CB switch off in Hodovo	no protection trip in Hodovo; in Trebinje the settings for Loss of Voltage function is U < 0.7 *Un time delay 10 s	YES
17	12:24:26:583	220	OHL	UV	voltage drop	all 3 phases; tripped only in Trebinje; manual CB switch of in Mostar 3	no protection trip in Mostar 3; in Trebinje the settings for Loss of Voltage function is: U < 0.7 *Un time delay 10 s	YES
18	12:24:26:593	220	OHL-TIE	UV	voltage drop	all 3 phases; tripped only in Trebinje	no protection trip in Plat; in Trebinje the settings for Loss of Voltage function is U < 0.7 *Un time delay 10 s	YES
19	12:24:27:694	220	OHL	UV	voltage drop	all 3 phases; tripped only in Prijedor 2; manual CB switch off in Bihać 1	no protection trip in Bihać 1; in Prijedor Zone 3 of distance protection tripped	YES
20	12:24:28:000	220	OHL	MAN	N/A	3 phases manual CB switch off	no protection trip	N/A
21	12:24:28:000	220	OHL	DIST	voltage drop	3 phases; tripped only in Fierze	Z1 of the distance relay R1 = 4.82 Ω X1 = 24.85 Ω with 0 ms time delay	YES

Table 8: Performance of the protection system in the sequence of events

3.5.1 Outage ID 1: 400 kV OHL Ribarevine (CGES) – Podgorica 2 (CGES)

At **12:09:16.213 CEST the Ribarevine (CGES) – Podgorica 2 (CGES)** 400 kV OHL tripped. Line differential protection function tripped the OHL; the cause was a line-to-ground fault which occurred in phase L3 because of vegetation under the OHL. The relay protection system of the OHL operated according to its settings, the Stage1 of the line differential protection (settings 480 A) operated without any time delay (0 ms). As this was a permanent fault, after the failed auto reclosing there was a definite three phase trip and the OHL remained out of service.

3.5.2 Outage ID 2: 400 kV OHL Zemblak (OST) – Kardia (IPTO)

At **12:21:33:200 the Zemblak (OST) – Kardia (IPTO)** 400 kV OHL-TIE line tripped. The distance protection function tripped the OHL first from Zemblak (OST) side in phase L2 and IN1> earth-fault over current protection function of Main 1 protection from Kardia (IPTO) side in all three phases, then at Zemblak (OST) substation there was an unsuccessful auto reclosing in the L2 phase which ended with a three-phase definite trip. The cause of the relay protection trip was the distance shortening to vegetation under the line, with this causing a fault in phase L2 near Zemblak (OST) substation – at 19.2 % of the line. At the time of the event, the CB 1-pole auto reclosure at Kardia P940 (Zemblak) bay was out of service. Due to this, all trips were 3-pole. The parameter settings are: Zemblak (OST): Z1 function – R1 = 7.66 Ω × 1 = 23.86 Ω 0 ms time delay; Kardia (IPTO): in Main 1 protection device the Time EF stage IN1> function IN1> = 3I0 = 165 % × (1,600 A/1 A) = 2,640 A, 300 ms. At the time of the fault, the tele-protection scheme of the line was also out of service. Therefore, at the Kardia (IPTO) substation no transfer trip could be received from Zemblak (OST); thus, the trip of the Z2 function which started was not accelerated. The IN1> earth-fault overcurrent function at Kardia (IPTO) has approximately the same reach as the Z2 distance protection function and has a shorter time delay than the Z2, which is why it operated before the Z2 function. We can state that the relay protection system of the OHL operated according to its settings.

3.5.3 Outage ID 3: 220 kV OHL Fierze (OST) – Prizren 2 (KOSTT)

At **12:21:44:000 the Fierze (OST) – Prizren 2 (KOSTT)** 220 kV OHL-TIE line tripped. The overload protection function (overcurrent protection with lower amper settings) tripped the OHL in three phases. The settings of the overload protection in Fierze (OST) substation are I = 720 A with a 10 s time delay. The relay protection system of the OHL operated according to its settings.

3.5.4 Outage ID 4: 220 kV OHL Podgorica 1 (CGES) – Mojkovac (CGES)

At **12:21:45.774, the Podgorica 1 (CGES) – Mojkovac (CGES)** 220 kV OHL line tripped. The overload protection function (overcurrent protection with lower amper settings) tripped the OHL in three phases in the Podgorica 1 (CGES) substation. The settings of the overload protection in Podgorica 1 (CGES) substation are Stage 1 = 840 A with a 1,700 ms time delay. The overload protection function is only installed on one side of the line, which is the usual situation in the area. The relay protection system of the OHL operated according to its settings.

3.5.5 DCC 500 kV Lastva (CGES) – / Kotor DC convertor station (Terna) /– Villanova (Terna)

At **12:21:51:446, the Lastva (CGES) – / Kotor DC convertor station (Terna) / Villanova (Terna)** 500 kV DCC-TIE cable was blocked in Kotor Convert SS. On the Lastva (CGES) side (AC), there was no protection trip. The DC converter was blocked by undervoltage (UV) protection of the DC cable. The cause of this was the voltage drop on the AC side from Lastva. The settings of the UV are V = 400 kV DC with a t = 2 s time delay. The relay protection system of the DC operated according to its settings. The DC link is a LCC converting system which cannot support voltage, in the event of voltage drop on the AC side the power flow is blocked.

3.5.6 Outage ID 6: 220 kV OHL-TIE Sarajevo 20 (NOSBiH) – Piva (CGES)

At **12:22:06:012, the Sarajevo 20 (NOSBiH) – Piva (CGES)** 220 kV OHL-TIE tripped. The overload protection function (overcurrent protection with lower amper settings) tripped the OHL in three phases in Sarajevo 20 (NOSBiH) substation. The settings of the overload protection in Sarajevo 20 (NOSBiH) substation are Stage 3 = 808 A with a 20 s time delay. Overload protection function is only installed on one side of the line, which is the usual situation in the area. The relay protection system of the OHL operated according to its settings.

3.5.7 Outage ID 7: 220 kV OHL Brinje (HOPS) – Pađene (HOPS)

At **12:24:21:587, the Brinje (HOPS) – Pađene (HOPS)** 220 kV OHL tripped in three phases. The distance protection function in Zone 3 on the Brinje (HOPS) side of the line tripped because of voltage drop. The settings of Z3 of the distance relay are X = 107.9 Ω. There was no protection trip on the Pađene (HOPS) side of the line. The relay protection system of the OHL operated according to its settings.

3.5.8 Outage ID 8: 220 kV OHL Prijedor 2 (NOSBiH) – Jajce 2 (NOSBiH)

At **12:24:22:341, the Prijedor 2 (NOSBiH) – Jajce 2 (NOSBiH)** 220 kV OHL tripped. The overload protection function (overcurrent protection with lower amper settings) tripped the OHL in three phases in the Prijedor 2 (NOSBiH) substation. The settings of the overload protection in Prijedor 2 (NOSBiH) substation are Zone 3 = 786 A with a 1,200 s time delay. Overload protection function is only installed on one side of the line; this is the usual situation in the area. The relay protection system of the OHL operated according to its settings.

3.5.9 Outage ID 9: 400 kV OHL Ugljevik (NOSBiH) – Tuzla 4 (NOSBiH)

At **12:24:22:350, the Ugljevik (NOSBiH) – Tuzla 4 (NOSBiH)** 400 kV OHL tripped. Directional earth fault protection tripped the OHL in three phases in the Ugljevik (NOSBiH) substation. The settings of the directional earth fault protection in Ugljevik (NOSBiH) substation are I0 = 11 % × Inom = 176 A, U0 = 55 % × Unom = 220 kV; with a 3 s time delay. In Tuzla4 (NOSBiH) the circuit breakers were switched off manually. The relay protection system of the OHL operated according to its settings.

3.5.10 Outage ID 10 and 11

At **12:24:22:959** there were outages in HOPS' 110 kV network which led to a no voltage condition of 220 kV OHL TIE Đakovo – Tuzla and 220 kV OHL TIE Đakovo – Gradačac. Recognising zero voltage condition in SS Đakovo all circuit breakers opened automatically.

3.5.11 Outage ID 12: 220 kV OHL Titan (OST) – Tirana 1 (OST)

At **12:24:23:000 Titan (OST) – Tirana 1 (OST)** the 220 kV OHL line tripped in three phases in the Titan (OST) substation. The distance protection Zone 1 (Z1) tripped the line in Titan (OST), and in Tirana 1 (OST) substation there was no protection trip. The parameter settings of the distance protection Z1 are R1 = 13.567 Ω X1 = 7.97 Ω with a 0 ms time delay. The cause of the trip was the voltage drop on the line. The relay protection system of the OHL operated according to its settings.

3.5.12 Outage ID 13: 220 kV OHL Međurić (HOPS) – Prijedor 2 (NOSBiH)

At **12:24:23:089 the Međurić (HOPS) – Prijedor 2 (NOSBiH)** 220 kV OHL-TIE line tripped in three phases. The distance protection Zone 3 (Z3) in Međurić (HOPS) substation tripped the line in three phases. In Međurić (HOPS) substation the parameter settings of the distance protection Z3 are X = 99.9 Ω; RFPP = 92.4 Ω with a 1,000 ms time delay. The relay protection system in Međurić (HOPS) substation operated according to its settings.

3.5.13 Outage ID 14: 220 kV OHL Fierze (OST) – Peshqesh (OST)

At **12:24:24:000 the Fierze (OST) – Peshqesh (OST)** 220 kV OHL was switched off manually. No protection tripping occurred.

3.5.14 Outage ID 15: 220 kV OHL-TIE Trebinje (NOSBiH) – Perucica (CGES)

At **12:24:26:558 the Trebinje (NOSBiH) – Perucica (CGES)** 220 kV OHL-TIE line tripped. There was no relay protection trip on the Perucica (CGES) side of the line; the line was manually switched off there.

In Trebinje (NOSBiH) on the 220 kV voltage level in the event of loss of voltage the UV (undervoltage) function of the bay trips the line in all three phases. This is a definite trip (no auto reclosing). The settings of the UV function are: U < 0.7 × Un with a 10 s time delay The disturbance records show that there was a sever voltage drop. The relay protection system in Trebinje (NOSBiH) substation operated according to its settings.

3.5.15 Outage ID 16: 220 kV OHL Trebinje (NOSBiH) – Hodovo (NOSBiH))

At **12:24:26:579 the Trebinje (NOSBiH) – Hodovo (NOSBiH)** 220 kV OHL line tripped. There was no relay protection trip on the Hodovo (NOSBiH) side of the line; the line was manually switched off there.

In Trebinje (NOSBiH) on the 220 kV voltage level in the event of loss of voltage the UV (undervoltage) function of the bay trips the line in all three phases. This is a definite trip (no auto reclosing). The settings of the UV function are: U < 0.7 × Un with 10 s time delay The disturbance records show that there was a sever voltage drop. The relay protection system in Trebinje (NOSBiH) substation operated according to its settings.

3.5.16 Outage ID 17: 220 kV OHL Trebinje (NOSBiH) – Mostar 3 (NOSBiH))

At **12:24:26:583 the Trebinje (NOSBiH) – Mostar 3 (NOSBiH)** 220 kV OHL line tripped. There was no relay protection trip on the Mostar 3 (NOSBiH) side of the line; the line was manually switched off there.

In Trebinje (NOSBiH) on , the 220 kV voltage level in the event of loss of voltage the UV (undervoltage) function of the bay trips the line in all three phases. This is a definite trip (no auto reclosing). The settings of the UV function are: U < 0.7 × Un with 10 s time delay. The disturbance records show that there was a sever voltage drop. The relay protection system in Trebinje (NOSBiH) substation operated according to its settings.

3.5.17 Outage ID 18: 220 kV OHL-TIE Trebinje (NOSBiH) – Plat (HOPS)

At **12:24:26:593 the Trebinje (NOSBiH) – Plat (HOPS)** 220 kV OHL-TIE line tripped. There was no relay protection trip on the Plat (HOPS) side of the line.

In Trebinje (NOSBiH) on the 220 kV voltage level in the event of loss of voltage the UV (undervoltage) function of the bay trips the line in all three phases. This is a definite trip (no auto reclosing). The settings of the UV function are: U < 0.7 × Un with 10 s time delay. The disturbance records show that there was a sever voltage drop. The relay protection system in Trebinje (NOSBiH) substation operated according to its settings.

3.5.18 Outage ID 19: 220 kV OHL Prijedor 2 (NOSBiH) – Bihać 1 (NOSBiH)

At **12:24:27:694 the Prijedor 2 (NOSBiH) – Bihać 1 (NOSBiH)** 220 kV OHL line tripped. There was no relay protection trip on the Bihać 1 (NOSBiH) side of the line; the line was manually switched off there. Distance protection function Zone 3 (Z3) tripped the line in three phases in Prijedor 2 (NOSBiH) substation. The cause of the distance protection Z3 trip was the voltage drop on the line. The relay protection system of the OHL operated according to its settings.

3.5.19 Outage ID 20: 220 kV OHL Fierze (OST) – Koman (OST)

At **12:24:28:000 the Fierze (OST) – Koman (OST)** 220 kV OHL was switched off manually. No protection tripping occurred.

3.5.20 Outage ID 21: 220 kV OHL Fierze (OST) – Fang (OST)

At **12:24:28:000 the Fierze (OST) – Fang (OST)** 220 kV OHL tripped. Distance protection function Zone 1 (Z1) tripped the line in three phases in Fierze (OST) substation. There was no relay protection trip in Fang substation. In Fierze (OST) substation the parameter settings of the distance protection Z1 are R1 = 4.82 Ω X1 = 24.85 Ω with a 0 ms time delay. The distance protection tripped because of the voltage drop. The relay protection system of the OHL operated according to its settings.

3.6 Important Alarms in Control Centres

All voltage violations referenced are based on alarm thresholds defined by each TSO, not on the thresholds defined in Annex II of the SO GL. All the affected TSOs used 380 kV as the low voltage limit for issuing alarms, which gave out alerts before reaching the low voltage limit of 360 kV defined in SO GL.

3.6.1 HOPS

The HOPS alarm list shows no significant alarms prior to the start of cascading outages.

The first instance of a low voltage alarm in the 220 kV part of the grid happened at 12:21:49:644 in substation Plat, measuring a voltage of 192.6 kV.

Real Time Security Analysis

HOPS N-1 results for the period between 12:00 and 12:23 show no N-1 violations for the 400 kV and 220 kV grid elements. Only after the outage do ID6 potential overloads of 220 kV grid elements appear on the list inside of HOPS EMS-SCADA real time calculations. After this outage there are also multiple divergences within the HOPS EMS-SCADA, but most are for the outages near the endpoint of the HOPS observability area, located in nodes in other control areas and not important for the analysis of the event.

3.6.2 NOSBiH

The NOSBiH alarm list shows that the first instance of a low voltage alarm happened in HPP Višegrad at 12:09:16, measuring the voltage of 377.8 kV, but his alarm was deactivated one second later after the voltage recovered to 386.6 kV. Only after the outages of OHL Zemblak – Kardia and OHL Piva – Sarajevo multiple low voltage alarms were issued during the period between 12:21:33 and 12:22:03.

Real Time Security Analysis

There are no real time N-1 results available for the NOSBiH control area during the period between outage ID1 and ID2 because there is no possibility to archive the N-1 results after each run of the real time contingency analysis. The NOSBiH observability area ends on the CGES–OST border and, therefore, does not include outage ID2 as a part of the contingency analysis.

3.6.3 CGES

The CGES alarm list shows that the first alarm issued regarding low voltage on 400 kV level happened in substation Lastva at 12:12:02; the voltage measured was 376.7 kV. Shortly after that, the voltage in substation Lastva recovered to 385 kV. Next low voltage alarms started appearing at 12:21:33 after the ID2 outage.

Outage ID1 generated appropriate alarms about the nature of the fault and the time of the OHL disconnection.

Real Time Security Analysis

CGES had no N-1 violations in the 400 kV and 220 kV parts of the grid. In addition, CGES observability zone ends on the OST–IPTO border and OHL Zemblak – Kardia is modelled as an equivalent power flow injection, which was not included as a part of the real time contingency analysis.

3.6.4 OST

The OST alarm list shows that the first alarm issued regarding 220 kV low voltage value was at 12:21:33 in substation Fierze. The voltage measured was 195.5 kV. From that point on there were many low voltage alarms issued as the voltage collapse started.

Real Time Security Analysis

The EMS-SCADA system inside the OST control room did not show any real time N-1 violations for the OST control area during the period between outage ID1 and ID2. The OST observability area includes CGES network but does not include the NOSBiH and HOPS network.

3.6.5 IPTO

There were no significant alarms for the 400 kV and 150 kV grid elements between 12:00 and 12:30.

Real Time Security Analysis

IPTO real time N-1 calculations showed no significant results for the affected area between outage ID1 and ID2.

3.6.6 EMS

There were no significant alarms for the 400 kV and 220 kV grid elements between 12:00 and 12:30.

Real Time Security Analysis

Real time N-1 calculations within EMS-SCADA applications of NCC showed no significant results for the affected area between outage ID1 and ID2, as the outages of elements outside the JSC EMS control area are used to calculate the loadings of internal JSC EMS elements and TIE lines only. After the cascading started there was a divergent estimation solution at 12:25 for the affected part of the grid model used inside of EMS-SCADA system. The following state estimation at 12:26 converged without issues.

3.7 Conclusion

The sequence of events started with the outage of OHL Podgorica 2 – Ribarevine at 12:09 (outage ID1) which tripped due to the short circuit caused by s the hortening of the distance to the vegetation beneath the OHL. This outage caused an initial drop in voltages across the affected region, but the voltages stabilised quickly.

The second outage was the tripping of OHL TIE Zemblak – Kardia at 12:21. The short circuit that led to the outage was caused by shortening the distance to the vegetation beneath the OHL, same as the first outage.

The cascading event continued with 220 kV lines and HVDC Monita disconnected also due to under voltage protection at Lastva side, then the affected areas lost voltage at 12:24.

During the incident, automatic voltage regulation was applied as written in subchapter 3.3 and all transformers reacted properly, considering regulated voltage set points. There was no manual change of transformer tap changers nor manual disconnection of loads.

The relay protection systems of each high voltage element affected operated according to its parameter settings, based on information collected.

Based on the information gathered from the TSOs of the affected region. there were no real time N-1 violations detected in the 400 kV and 220 kV grid during the period between outage ID1 and ID2.

Furthermore, there were no remedial actions identified or applied in any of the affected TSOs during the period between the first two outages.

4 RCC ANALYSIS BEFORE THE INCIDENT

4.1 RCC Tasks

There are five RCCs and one Regional Security Coordinator (RSC) in Europe, covering different regions and serving different groups of TSOs. The RCCs are: Baltic RCC, TSCNET, SEleNe CC, Coreso and Nordic RCC, and the RSC is SCC.

The services delivered by the RSC are described in System Operational Guidelines (EU Reg 2017/1485). The tasks for RCCs are described in the Electrical Regulation (EU Reg 2019/943 art 37). In this report, both RSC and RCCs will be referred to as RCC for ease of reading the document, and the word "task" will be used for both RSC services and RCC tasks.

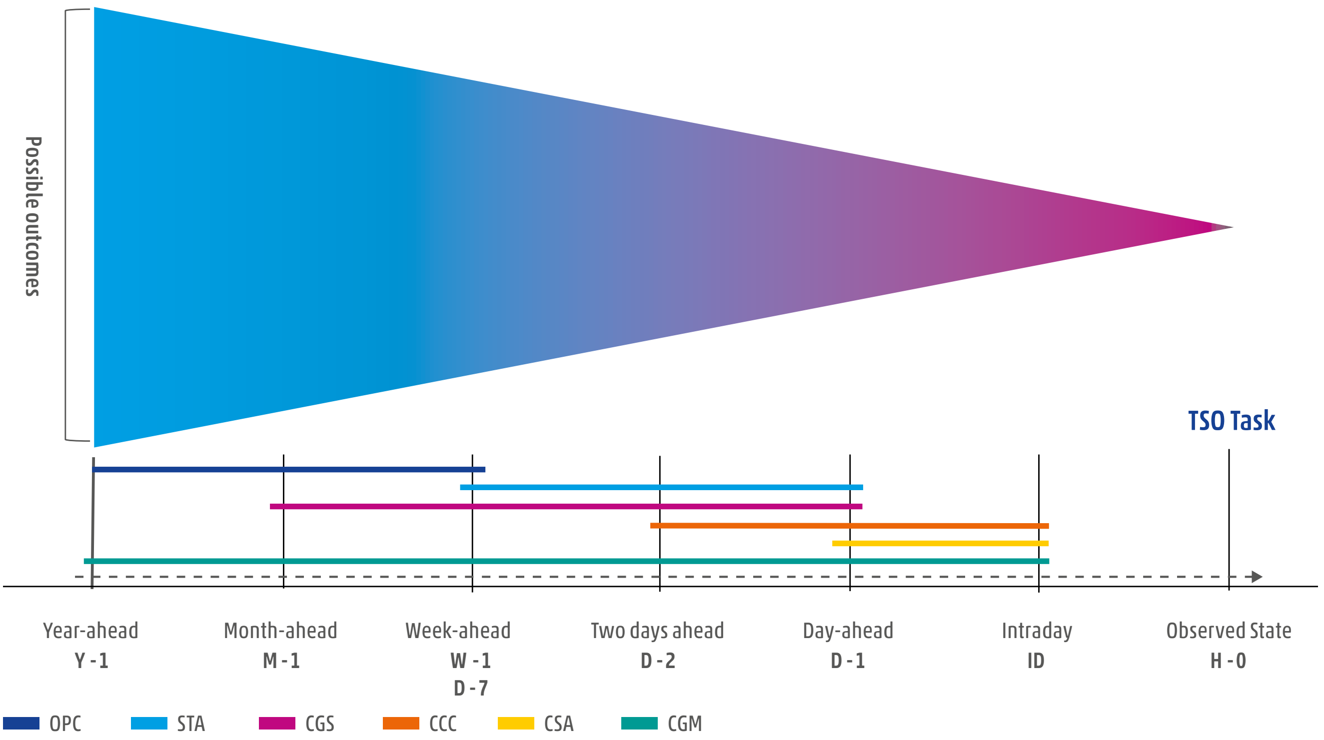
SCC delivers the following tasks mentioned in this report (the 4 out of 5 services from SOGL: OPC, STA, CGM and CSA but not CCC (Coordinated Capacity Calculations)) and the tasks CGS (Critical Grid Situations, decided by SOC in September 2017) and consistency assessment of defence and restoration plans (EU Reg 2019/943 art 37.1(d)). The Security Analysis provided by SCC is not a Coordinated Security Analysis according to EU Reg 2017/1485 but a Security Analysis which is used until the Coordinated Security Analysis goes live.

The RCC for the region affected by the Balkan Blackout is SCC. SCC thereby joins the task described in EU Reg 2019/943 art 37.1(i) (post-operation and post-disturbance analysis and reporting), which is chapter 4 in this report. The RCCs involved in the event were SCC, TSCNET, CORESO and SEleNe CC as they cover the regions where the event originated and propagated.

4.1.1 High Level Description on RCC Tasks

The tasks of RCCs have different time horizons, ranging from several years ahead to close to real-time operation. For the purpose of this investigation, we will focus on the tasks relevant for the specific hour of the event, which occurred on 21 June 2024 around 11.20 UTC. These tasks include outage planning coordination, short-term and very short-term operational security analysis.

4.1.2 Time Horizon of the Tasks and the Focus on the Specific Hour



The provided tasks from the RCCs have a few regional differences, but in general we can identify the following:

- **OPC:** As it is necessary to perform maintenance of the electricity grid, outages are a condition of the operation of the grid. Outages of grid elements and production units affect neighbouring countries and must be coordinated to ensure the secure operation of the grid. The OPC task coordinates the outages to optimise the availability of the Regional and European Power Grid.
  - Time horizon: Y-1 to W-1.
- **STA:** RCCs investigates whether the reliable available expected production capacity can meet the expected consumption at any given time while also considering restrictions in the transmission grid. If there is insufficient reliable available production capacity to meet the consumption, measures need to be taken by TSOs to avoid an adequacy situation.
  - Time horizon D-7 to D-1.
- **CSA:** The possibility to highlight and visualise possible operational security risks in advance gives the operators additional time during the preparation and planning phase to investigate possibly needed remedial actions, thus aiding operators in their decision-making in real time. This service provides operational support to the TSOs to identify operational security risks and recommends preventive remedial actions to the individual TSOs.
  - Time horizon D-1 to ID.
- **CGM:** Based on IGMS, a CGM representing the power system is created, which can be used for performing further analysis through the tasks performed by RCCs.
  - Time horizon Y-1 to ID.
- **CCC:** Electricity is freely traded across borders in the internal energy market. However, the limits of transmission capacity must be respected. The service calculates the secure power market capacities to maximise the transmission capacity offered to the market, while maintaining grid security.
  - Time horizon Y-1 to M-1; and D-2 to ID.
- **CGS:** When the grid is experiencing extraordinary conditions that cannot be resolved through national countermeasures, the TSOs have the option to trigger a communication protocol to enhance collaboration with neighbouring TSOs/RCCs with the objective of mitigating the risk to the security of supply.
  - Time horizon M-2 to D-2.

4.2 RCC Tasks Relevant for the Investigation

Task	RCC/RSC	Area	Timeframe	Result	References
OPC	SEleNe CC	SEleNe CC area (incl. GR)	Week ahead	OK	See chapter 4.2.1 for details
	SCC	SCC region	Week ahead	OK	
	TSCNET	TSCNET area (incl. HR)	Week ahead	OK	
STA	All RCCs (Main: SCC)	Pan-EU	Week ahead	OK	See chapter 4.2.2 for details
Security Analysis	TSCNET	TSCNET area (incl. HR)	Day ahead (23:22 CEST)	OK	See chapter 4.2.3 for details
			Intraday (11:25 CEST)	OK	
	SCC	SCC area (incl. BA, ME, AL)	Day ahead (20:27 CEST)	OK	
			Intraday (08:25 CEST)	OK	
	SEleNe CC	SEleNe CC area (incl. GR)	Day ahead (20:15 CEST)	OK	
CCC	TSCNET & Coreso	Core CCR (incl. HR-SI, HR-HU)	Day ahead	OK	See chapter 4.2.4 for details
E&R	SCC	SCC region	Every 5th year, done in 2019 and is ongoing in 2024	OK	See chapter 4.2.5 for details
	TSCNET	TSCNET area (incl. HR)		OK	

Table 9: Overview of the status from RCC tasks – For all processes, no issues were foreseen for the region.

4.2.1 Outage Planning Coordination (OPC)

4.2.1.1 Overview

The process consists of annual, monthly and weekly, where TSOs are obliged to report all planned outages of relevant elements defined by calculations based on the Relevant Assets for Outage Coordination (RAOC) methodology.

The regional OPC process is implemented by each RCC/RSC for its region, i.e. its TSOs. The W-1 OPC process covers a seven-day planning period beginning on Saturday and ending on the following Friday. TSOs are obliged to report preliminary planned disconnections on Wednesdays by 12:00 CEST. They receive a report from the OPC tool after the 1st Merge (on Wednesdays at 12:00 CEST) with detected possible tie-line inconsistencies with neighbours. TSOs are obliged to correct these tie-line inconsistencies by 16:00 CEST, when the 2nd Merge is triggered.

The results of the 2nd Merge are used by RCCs as input data for regional calculations.

After the security analysis performed by RCCs and analysis by the TSOs, the TSOs have the right to change the disconnection plan and submit an updated one until Thursday at 16:00 CEST, when the 3rd Merge is triggered. In addition to changing the disconnection plan, TSOs have the right to request the repetition of security analyses if they consider that between the 2nd and 3rd Merge they have reported some significant changes that have a major impact on the results.

The results of the 3rd Merge are presented at the regular weekly operational teleconference (WOPT) held for the SEE region every Friday at 09:00 CEST. The moderator of the meeting is SCC/Selene CC on the yearly rotational basis since both RCC are operating in the SEE region. Further details are described in 4.2.1.3 SEE MG WOPT. On WOPT, the final reconciliations of the disconnection plan for the next week are made, and TSOs are obliged to submit all changes to the OPC tool by 13:00 CEST when the last, final 4th Merge is triggered, which is used as the relevant disconnection plan for the next week.

Therefore, planned disconnections are considered to be only those that were reported to PE OPC tool before Friday 13:00 CEST. Disconnections reported after that moment are considered unplanned.

RCCs use week ahead (and year ahead) CGMs to assess all combinations of upcoming outage plans and possible N-x contingencies to evaluate grid security.

In the case of identified issues, remedial actions and/or cancelling of outage tasks are proposed.

4.2.1.2 W-1 OPI Results

OPI (Outage Planning Incompatibilities) Assessment[9] performed regularly two times per week after TLI (Tie line Inconsistencies) Errors Identification/Notification of affected TSOs.

The week ahead OPI assessment process uses the merged preliminary unavailability plan (.xml) and merged OPC Element List (.xml) from the PE OPC process, performs a regional security assessment on predefined scenarios (seasonal CGMs) and allows for the application of imported remedial actions on the CGM. The regional security assessment is performed by SEleNe CC in close cooperation with SEleNe CC TSOs.

SEleNe CC has performed week ahead OPI covering the period from 16/06 to 21/06. According to the results, on CW25, SEleNe CC initial and final OPI did not detect any contingencies for TIE line Zemblak – Kardia. For the other lines related to the incident there are no findings as the coverage does not include elements outside the SEE CCR (GR, BG, RO). The TS closer to the incident is on 21 June 10:30 and the results can be found in Table 10. No overloading is observed in this timestamp.

Critical Outage identification			Critical Network Element identification			CNE After CO result		
Elements in outage	Base voltage (kV)	Area	Monitored element	Type	Base voltage	U	Loading I	Loading
						(kV)	(A)	%
Gutinas - Smardan OHL	380	RO	Barbosi - Filesti OHL	line	220	220.39	–669	**84**
lineGutinas - Smardan OHL	380	RO	Lacu Sarat - Filesti OHL	line	220	219.97	607	**76**
Brazi Vest transformer	380/220	RO	Bucuresti Sud - Fundeni c2	line	220	220.20	630	**72**
Brazi Vest transformer	380/220	RO	Bucuresti Sud - Fundeni c1	line	220	220.55	629	**72**

Table 10: SeleneCC OPI Results for CW25

OPI in SCC was performed for BD 18 June TS 07:30 as this date had the highest number of outages in the SEE region. Compared to 21 June, on Tuesday 18 June there was 46 outages planned and for Friday 21 June there were 43 outages planned. OPI performed for the 18 June did not detect any contingencies.

The results show that no contingencies are detected. In the 220 kV and 400 kV network, overloads greater than 100 % were detected for the following elements:

Critical Outage identification			Critical Network Element identification			CNE After CO result		
Elements in outage	Base voltage (kV)	Area	Monitored element	Type	Base voltage	U	Loading I	Loading
						(kV)	(A)	%
400 kV OHL Gelibolu 2 - Bekirli Tes - I	400	TR	400 kV OHL GELİBOLU2 - BEKİRLİ TES - II	line	400	403.21	1062.0	**104.7**
400 kV OHL Gelibolu 2 - Bekirli Tes - II	400	TR	400 kV OHL GELİBOLU2 - BEKİRLİ TES - I	line	400	403.21	1060.0	**104.6**
400 kV TIE Trebinje - Lastva	400	ME	220 kV OHL Podgorica 1 - HE Perućica	line	220	226.14	102.80	**102.9**

Table 11: SCC OPI Results for CW25

TSCNET performs an OPI assessment for three timestamps per day one week before real-time. For any foreseeable congestion TSCNET assesses different available remedial action including the cancelation of outages. The results from this assessment are an early indicator for the grid security and are closer to real-time complemented by the day-ahead and intraday congestion forecasts.

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[9] The state in which a combination of the availability status of one or more relevant grid elements, relevant power generating modules, and/or relevant demand facilities and the best estimate of the forecasted electricity grid situation leads to a violation of operational security limits considering any remedial actions without costs at the TSO's disposal.

For 21.06.2024 12:30 the outage plans available until 13.06.2024 16:00 were considered. Based on this data, TSCNET foresaw some possible minor congestions in Switzerland and Germany but did not foresee any congestions in Croatia. As measures for reducing these congestions, TSCNET had considered topological measures in France, Italy, Belgium and Switzerland, as well as the cancelation of one outage in Switzerland.

None of the foreseen congestions and the proposed measures had a direct influence on the incident in the Balkan area and the grid situation for Croatia considered in the scenario can be considered as secure based on TSCNET's week-ahead OPI assessment.

4.2.1.3 SEE MG WOPT

All TSOs from the SEE region (AL, BA, BG, GR, HR, HU, KS, ME, NMK, RO, RS, TR) regularly participate in the pan-European OPC Process.

In the SEE region, the coordination of Week ahead and Year ahead disconnections is the task of the South East Europe Maintenance Group (SEE MG).

SEE MG is a dedicated regional group of EU and non-EU TSOs and RCCs whose obligation is to plan and coordinate outages in SEE.

For 2024, SEleNe CC has been assigned as a coordinator of SEE MG. Topics covered within role MG are:

1. Harmonisation of the yearly procedure for the annual maintenance plan in the SEE region;

2. Confirmation of planned outages and information exchange on a weekly basis;

3. Short term scheduling and information exchange on outage planning; and

4. Real time outages and information exchange.

Planned Outages for CW25 (2024-06-15 to 2024-06-21) are shown in the following Table:

Element	Start Date	Start Time	End Date	End Time	Daily / Permanently	Restitution Time [h]
400 kV TIE Bekescsaba (MAVIR) – Nadab (TRANSELECTRICA) CKT 1	21.05.2024	07:00	12.07.2024	17:00	P	N
400 kV TIE Arachthos (IPTO) – Galatina (TERNA) CKT 1	27.05.2024	08:00	23.06.2024	16:00	P	N
400 kV OHL Bucuresti Sud (TRANSELECTRICA) – Pelicanu (TRANSELECTRICA) CKT 1*	28.05.2024	06:00	20.06.2024	17:00	P	24
400 kV OHL Tirana 2 (OST) – Koman (OST) CKT 1	01.06.2024	00:00	30.09.2024	23:00	P	N
220 kV OHL Kolacem (OST) – Tirana 2 (OST) CKT 1	01.06.2024	00:00	30.09.2024	23:00	P	N
400 kV TIE Koman (OST) – Kosovo B (KOSTT) CKT 1	01.06.2024	00:00	30.09.2024	23:00	P	N
400 kV OHL Cernavoda (TRANSELECTRICA) – Medgidia Sud (TRANSELECTRICA) CKT 1**	10.06.2024	06:00	21.06.2024	17:00	D	2
400 kV OHL Bucuresti Sud (TRANSELECTRICA) – Slatina (TRANSELECTRICA) CKT 1	14.06.2024	05:00	20.06.2024	17:00	D	1
400 kV OHL Paks (MAVIR) – Sándorfalva (MAVIR) CKT 1	15.06.2024	07:00	16.06.2024	17:00	D	2
400 kV OHL KOZLODUY (ESO) – SOFIA ZAPAD (ESO) CKT 2	15.06.2024	07:00	16.06.2024	17:00	D	1
400 kV OHL KOZLODUY (ESO) – SOFIA ZAPAD (ESO) CKT 3	15.06.2024	07:00	16.06.2024	17:00	D	1
400 kV OHL KOZLODUY (ESO) – SOFIA ZAPAD (ESO) CKT 1	17.06.2024	07:00	21.06.2024	15:30	D	1
400 kV OHL Obrenovac (EMS) – Kragujevac 2 (EMS) CKT 1	17.06.2024	07:00	23.06.2024	18:00	D	1
400/220 kV TR MARITZA IZTOK 3 (ESO) – MARITZA IZTOK 3 (ESO) CKT 1	17.06.2024	07:00	28.06.2024	15:00	P	2
220 kV TIE TE Sisak (HOPS) – Prijedor 2 (NOSBiH) CKT 1	17.06.2024	08:00	19.07.2024	17:00	D	0.5
400 kV OHL Tuzla 4 (NOSBiH) – Ugljevik (NOSBiH) CKT 1	20.06.2024	08:00	21.06.2024	16:00	D	N

Table 12: Planned Outages for CW25 (2024-06-15 to 2024-06-21)), as it was available at Friday June 14th at 1 PM CEST

The map below shows the planned disconnections for CW25 (2024-06-15 to 2024-06-21)

Figure 47: Map of planned disconnections for CW25 (2024-06-15 to 2024-06-21)

It should be noted that because of the incident there are some planned outages that are practically changed as follows:

Element	Planned Status	Final Status
400 kV OHL Tuzla 4 (NOSBiH) – Ugljevik (NOSBiH) CKT 1	OFF	ON
400 kV OHL Tuzla 4 (NOSBiH) – Višegrad (NOSBiH)	ON	OFF
400 kV OHL Melina (HR) – RHE Velebit (HR)	ON	OFF
REN	49.8	185

Table 13: Differences between planned and actual outages

4.2.2 Short Term Adequacy (STA)

All South-East Europe (SEE) TSOs and RCCs (EU and non-EU) participate in the Pan-European (also known as Cross-Regional) STA process.

All SEE TSOs are obliged to submit input data for the STA process. The process is triggered daily on the Pan-European level, which is executed automatically and monitored by the Main or Back-up RCC. Deterministic and probabilistic calculations of STA are performed daily.

If necessary, the Regional STA process is also triggered, which is a rare situation in SEE. A regional STA process is triggered if the results of deterministic calculation show inadequacy, for a time horizon on D+3 or less.

SCC was the Main Adequacy Assessment Agent (AAA) for the pan-EU process in the week when incident happened.

4.2.2.1 Input data

All input data (NTC files, Week Ahead Generation and Week Ahead Load files) relevant for all affected and neighbouring TSOs received on the STA tool on 20.06.2024 (the day before the incident) successfully passed validation and were considered during STA calculation.

CZC for affected and neighbouring TSOs for three timestamps

CZC values for all affected and neighbouring TSOs are presented in the next figures for timestamps 11:30, 12:30 and 13:30 CET which are relevant for the incident. Figures also display initial Remaining Capacities (RCs) for the bidding zones of the affected region. According to input data, all TSOs except HOPS and one bidding zone in Italy are initially adequate (when the bidding zone is green on the map than adequacy is satisfied, and vice versa a red colour indicates that the zone is initially inadequate and needs energy import). When a bidding zone is initially adequate, this means that zone can cover all its load with production in that bidding zone and there is no need for an import of energy. MEPSO had a long-term issue with the delivery of input data, and that region in the calculation is neglected. In that case, CZC capacities are available for the exchange of energy in calculations, but that region has neither load nor generation. Based on input data, the conclusion is that the adequacy situation in the region was good. CZC values for the import and export of energy presented on the maps indicates usual capability for energy exchange between bidding zones and, based on that, the situation for the analysed timestamps was usual and normal.

Figure 48: CZC values from the STA tool for all affected and neighbouring TSOs for 11:30

Figure 49: CZC values from the STA tool for all affected and neighbouring TSOs for 12:30

Figure 50: CZC values from the STA tool for all affected and neighbouring TSOs for 13:30

Initial Remaining Capacities

Initial RCs per bidding zone for timestamps 11:30, 12:30 and 13:30, before STA calculation, are presented in the figures below. As described in 1.3, the adequacy situation in the region was good, and in this step, based on the input data for the region, even before calculations it could be concluded that after calculations the region will also be adequate.

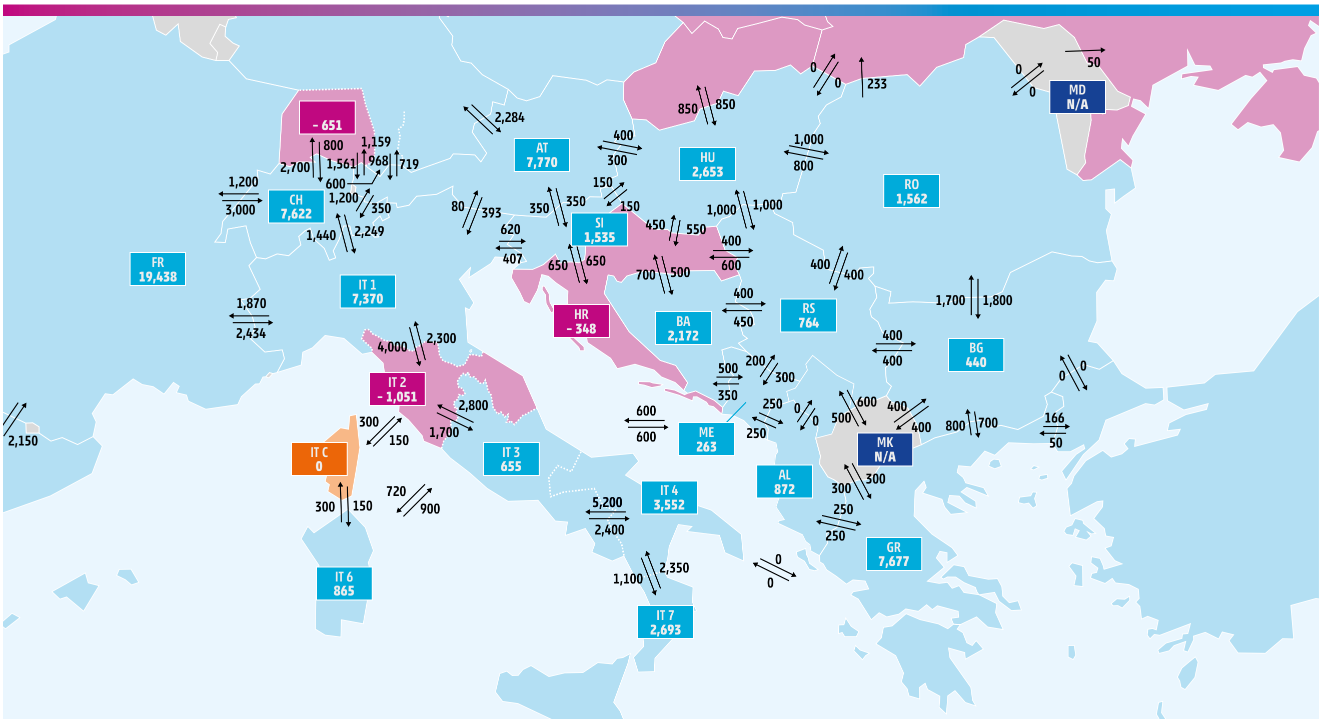

Figure 51: Initial RC values from the STA tool for all affected and neighbouring TSOs for 11:30

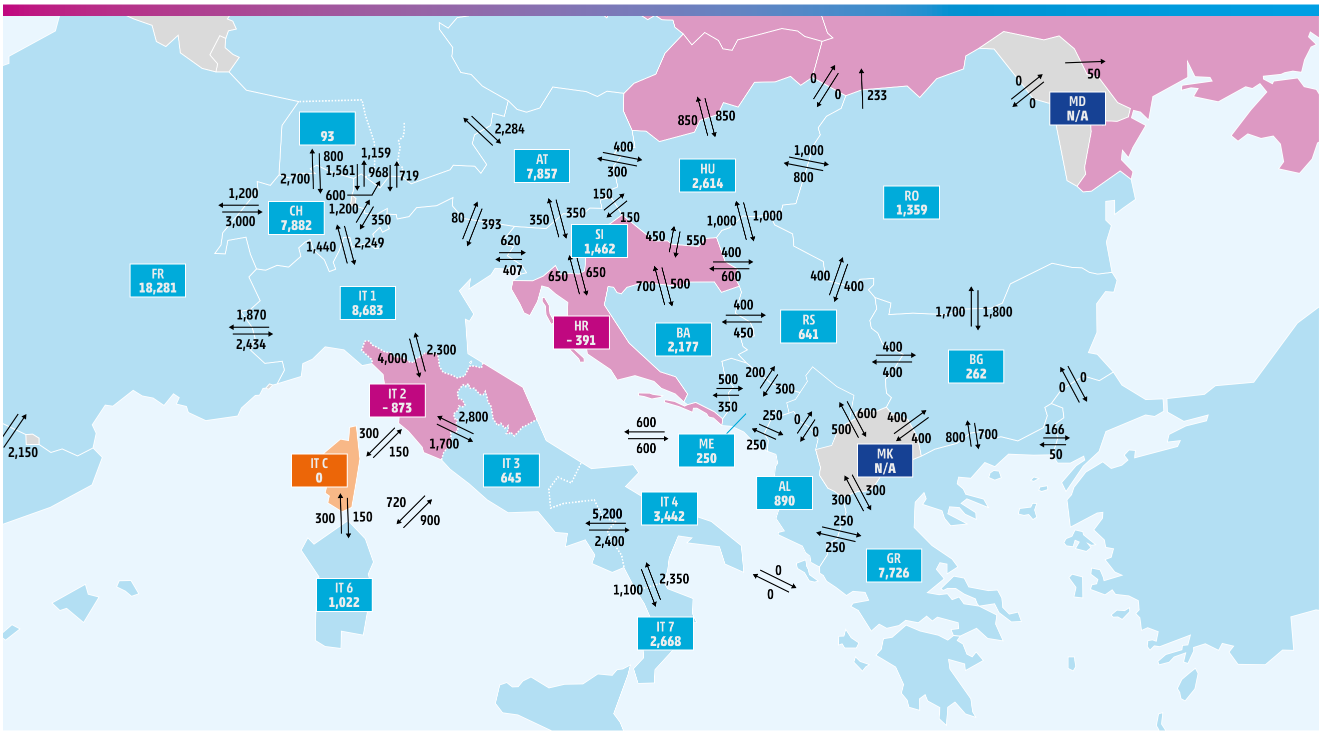

Figure 52: Initial RC values from the STA tool for all affected and neighbouring TSOs for 12:30

Figure 53: Initial RC values from the STA tool for all affected and neighbouring TSOs for 13:30

4.2.2.2 Cross-Regional Adequacy Results

STA calculation (1st run) has been done in time for approximately 30 minutes. This is normal calculation time usual in the everyday STA process.

SCC was the Main RSC for the STA process, so SCC's operator on duty was information about the STA results by email. The whole STA process went well without any detected failures of the system and reported issues on the ticketing system for the STA tool.

Both deterministic and probabilistic results for the period 21.06.2024 – 27.06.2024 did not show any adequacy issues in affected and neighbouring TSOs after the STA calculation.

Final Exchanges and Remaining Capacities

Final Exchanges and RCs per bidding zone for timestamps 11:30, 12:30 and 13:30, after STA calculation, are presented in the figures below. These figures present the final adequacy situation in the region. The framed value of RC for each bidding zone represents the amount of remaining capacity after calculation. If some bidding zone has zero RC after the calculation, the entire production of that bidding zone is exhausted, and this situation is not invalid. In this case, ME bidding zone load is fulfilled with full production in ME bidding zone combined with import from adjacent bidding zones. This is due to STA algorithm rules and priorities. The map also represents exchanges of power between bidding zones.

Based on the results, all TSOs and bidding zones which are important for the analysed incident on 21.06.2024 are adequate. The conclusion is that, based on these results, no problem could be detected. Even if some TSO was inadequate after assessment, no valid conclusion about the potential incident could be derived from that. The Pan-EU STA process is a process which deals with input data about production, load and exchanges, and power grid model is not considered. A regional STA process which will consider the power grid model is under development. The current regional STA process, which was not triggered on calculation day, also cannot predict issues related to power system security as the grid model is not considered.

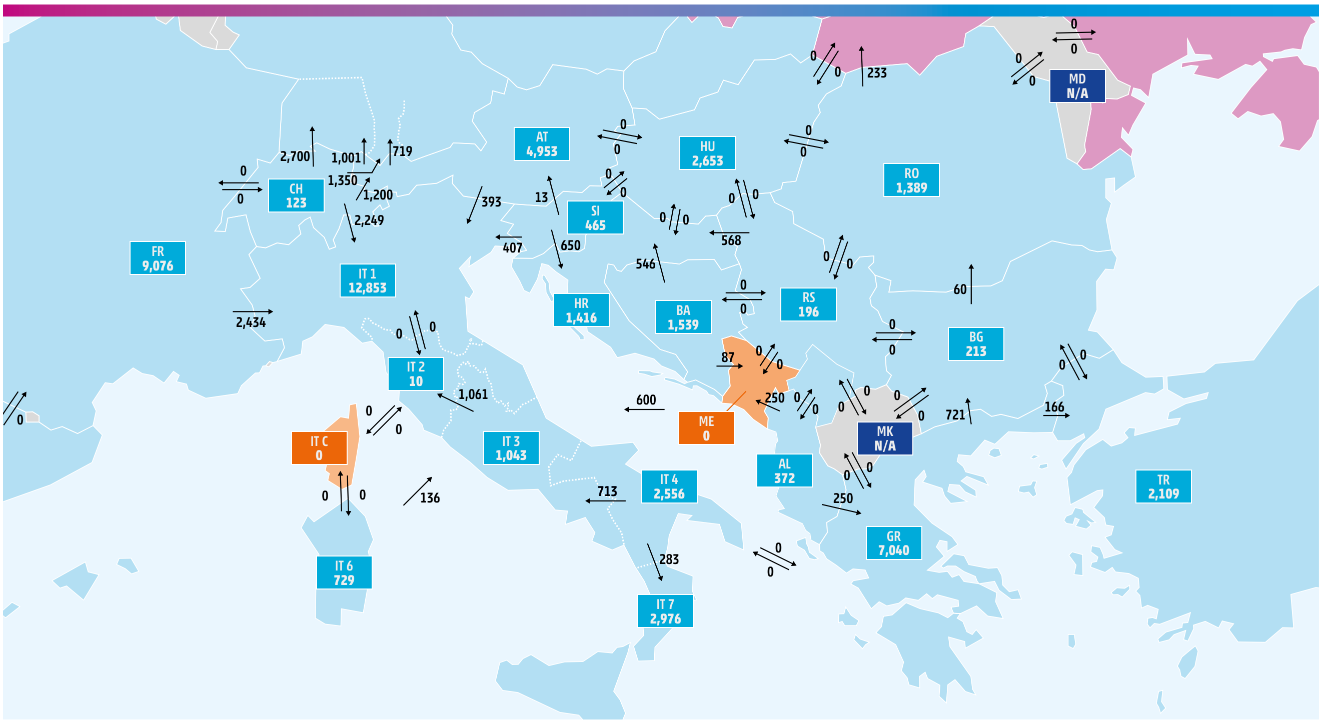

Figure 54: Final Exchanges and RCs from the STA tool for all affected and neighbouring TSOs for 11:30

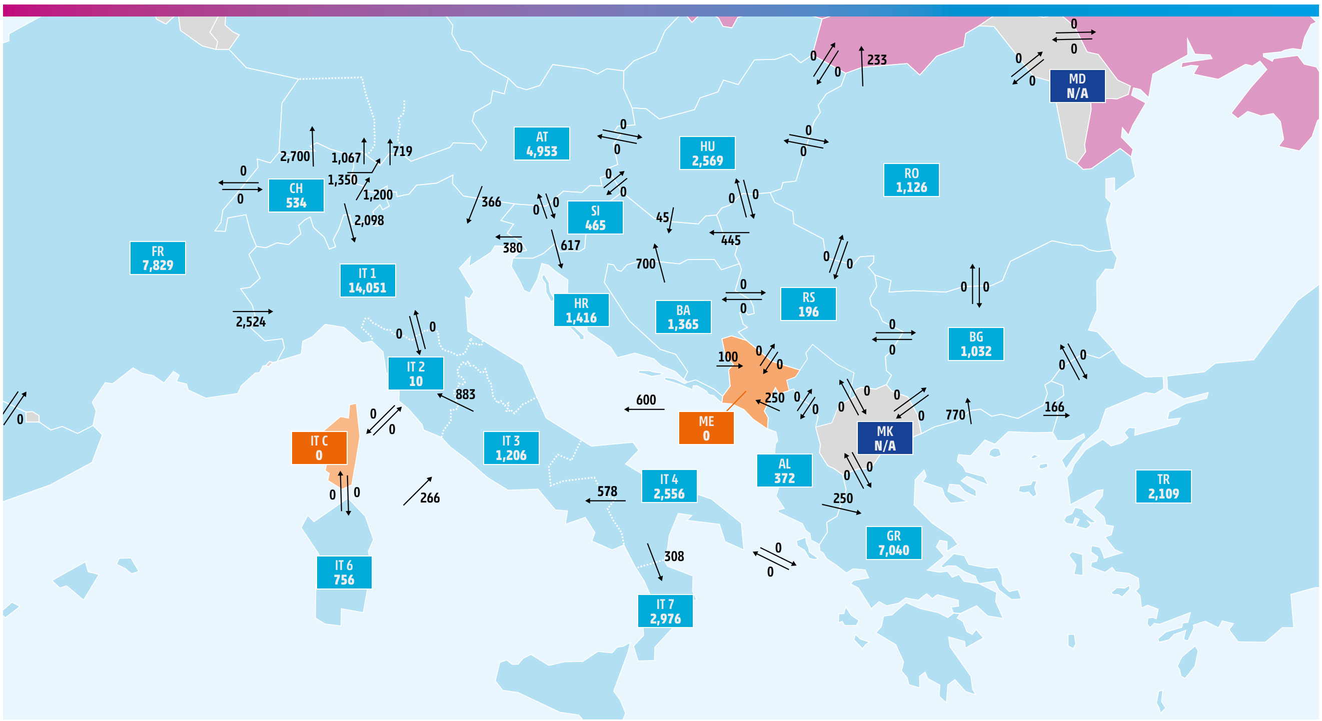

Figure 55: Final Exchanges and RCs from the STA tool for all affected and neighbouring TSOs for 12:30

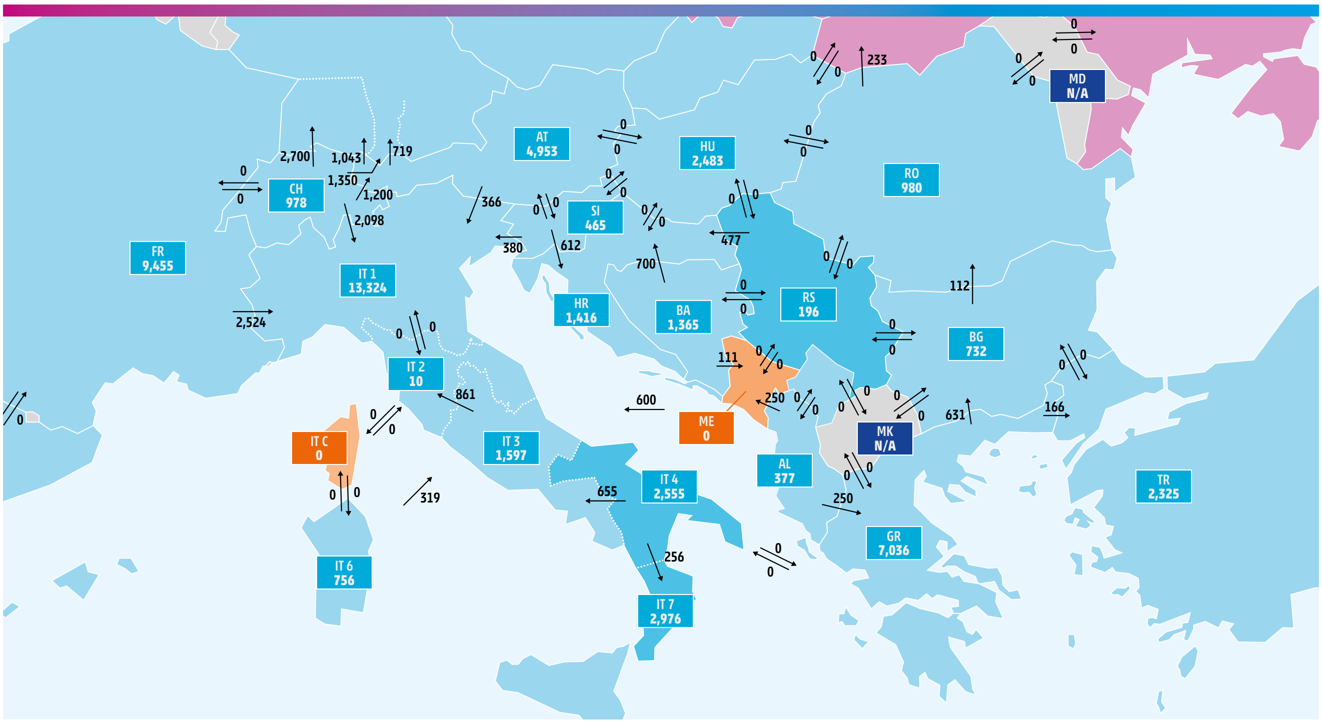

Figure 56: Final Exchanges and RCs from the STA tool for all affected and neighbouring TSOs for 13:30

4.2.3 Coordinated Security Analysis (CSA) and Common Grid Model (CGM)

4.2.3.1 Summary

SCC, SEleNe CC, TSCNET and Coreso have not yet fully implemented the CSA with all requirements according to Article 37(1)(b) of EU Regulation 2019/943. Instead, they perform a legacy Security Analysis for parts of the affected area. This relies on IGMs from the TSOs in the standard UCTE-DEF data exchange format. The CGMES based processes are not yet live. The Security Analysis consists of a DACF and additional Intraday Congestion Forecasts (IDCF) in some areas. For every day, 24 timestamps are considered, CGMs are generated, and N-X Security Analysis is performed. For the incident, the timestamp 12:30 is the best representation of the expected grid situation for the hour 12:00–13:00.

In the DACF and IDCF processes during the N-X calculation, the following lists are used:

» Contingency list – containing the contingencies selected by the TSOs based on CSAm Art. 7; and
» Monitoring list – containing all the elements that certain TSOs consider relevant to be monitored during security assessment in the DACF and IDCF processes, taking into account CSAm Art. 15(1).

These lists are not limited to elements and scenarios within the TSO's grid but may include neighbouring elements. Each TSO is responsible for maintaining its Contingency and Monitoring lists and for announcing in advance if some major changes are expected. The lists are then merged.

All elements from incident area were included in the SCC's regular security assessment process as Contingency and Monitoring elements. For TSCNET and SEleNe CC, they partially fall outside of their observability area.

The N-X Security Analysis assesses ordinary and exceptional contingencies but does not include the combination of multiple unrelated contingencies (N-2, N-3 etc.). These are considered "out-of-range" according to Art. 7 CSAm. Hence, none of the three RCCs assessed the tripping of 400 kV OHL Ribarevine – Podgorica 2 and 400 kV OHL-TIE Zemblak – Kardia together. No relevant congestions were foreseen for the N situation and for the cases of one of these lines tripping. Overall, the grid was considered N-1 secure in the DACF and IDCF processes.

400 kV OHL-TIE Zemblak – Kardia is a tie-line between Albania and Greece and, therefore, both TSOs provide information about it in their IGMs. For 21.06.2024, the TSOs provided different current limits. IPTO provided a limit of 1,599 A and OST a limit of 1,900 A. In such cases, the RCCs consider the lower limit for the whole line. Therefore, in this case 1,599 A were used by all RCCs.

While some differences can be observed between the load flow results from different RCCs and between DACF and IDCF, the results can still be considered consistent. Minor differences are always to be expected as different load flow engines are being used which may have minor differences in their implementation. In addition, the RCCs used individually created UCTE-DEF CGMs. Updated IGMs, updated market schedules and model corrections can create further differences. These did not significantly affect the results for the relevant grid elements and can be considered negligible.

4.2.3.2 SCC DACF & IDCF

According to Agreements on the provision of operational services, which are concluded among SCC and its service users, CGMs and security analysis results for IDCF process were delivered by SCC to NOSBiH, CGES and OST on 21.06.2024. at 8:25 AM.

The IDCF process in SCC is performed 3 times per day for the upcoming 8 hours. The most recent N-X results relevant to this incident were calculated during the second IDCF process (performed for the period from 8:30 AM to 3:30 PM).

According to SCC's regular procedures, all the elements from the monitoring area that are (over)loaded above 90 % of the defined limits either in the base case or after any contingency from the contingency area are listed.

Prior to the event, SCC did not have in its Contingency list the simultaneous outages of 400 kV OHL Ribarevine – Podgorica 2 and 400 kV OHL-TIE Zemblak – Kardia which happened in real time. Because of the physical distance of these two lines, SCC's TSOs did not include them in N-2 contingency.

The results shown below were extracted from SCC's regular reports for timestamp 12:30. As can be seen, nothing indicated a possible critical situation in the affected area. Only the overloading of 150 kV TIE Mourtos – Bistrica between IPTO and OST is noted for the outages of 400 kV TIE Zemblak – Kardia and for the outage of 400 kV OHL Zemblak – Elbasan 2. This overload in case of 400 kV failure is considered as manageable by OST in the operational hour as there is no effect on security of supply for this region of Albania. SEleNe CC DACF analysis based on IPTO's input lists simultaneously outage of Kardia-Zemblak and Bistrica-Mourtos is considered at the contingency analysis), as well as the overloading of 150/110 kV TR Bistrica for the outage of 400 kV TIE Zemblak – Kardia. In the CGES and NOSBiH results of IDCF security analysis for 12:30 no overloads were detected in the 220 kV and 400 kV grid in the case of any outage.

Time stamp	Contingency Name	Monitored Element Name	Loading_BC (%)	Loading after outage (%)
12:30	400 kV TIE Kardia - Zemblak	150 kV TIE Mourtos - Bistrica (AL)	64.08	**130.41**
12:30	400 kV TIE Kardia - Zemblak	150/110 kV TR Bistrica	61.25	**121.79**
12:30	220/110 kV TR Tirana 2 (1)	220/110 kV TR Tirana 2 (2)	74.30	**111.84**
12:30	220/110 kV TR Tirana 2 (2)	220/110 kV TR Tirana 2 (1)	74.30	**111.84**
12:30	400 kV TIE Kardia - Zemblak	150 kV TIE Mourtos - Bistrica (GR)	51.49	**104.38**
12:30	400 kV OHL Zemblak - Elbasan 2	150 kV TIE Mourtos - Bistrica (AL)	64.08	95.35

Table 14: SCC results for OSTof IDCF security analysis for 12:30[10]

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[10] Differences between Table 14 and 15 and similar tables in chapter 2 are due to different filtering of the results.

These results were consistent with the DACF results from the day before which were made available to the TSOs at 20:27 on the 20.06.2024.

Time stamp	Contingency Name	Monitored Element Name	Loading_BC (%)	Loading after outage (%)
12:30	400 kV TIE Kardia - Zemblak	150 kV TIE Mourtos - Bistrica (AL)	64.60	**133.55**
12:30	400 kV TIE Kardia - Zemblak	150/110 kV TR Bistrica	61.73	**124.88**
12:30	220/110 kV TR Tirana 2 (1)	220/110 kV TR Tirana 2 (2)	74.15	**111.62**
12:30	220/110 kV TR Tirana 2 (2)	220/110 kV TR Tirana 2 (1)	74.15	**111.62**
12:30	400 kV TIE Kardia - Zemblak	150 kV TIE Mourtos - Bistrica (GR)	51.91	**106.89**
12:30	400 kV OHL Zemblak - Elbasan 2	150 kV TIE Mourtos - Bistrica (AL)	64.60	97.42

Table 15: SCC results for OSTof DACF security analysis for 12:30

Element	Current (A)	Limit (A)	Loading (%)
Ribarevine - Podgorica 2	471.5	1920	24.6
Zemblak - Kardia	942.7	1599	59.0
Fierze - Prizren 2	127.3	720	17.7
Podgorica 1 - Mojkovac	161.8	720	22.5

Table 16: Load flow results from SCC DACF CGM for 12:30

4.2.3.3 SEleNe CC DACF

SEleNe CC provides a daily DACF process for SEleNe CC area. From the area of the incident in question, only the GR–AL TIE lines are relevant.

The DACF process for SEleNe CC has been performed on 20.06.2024 at 20:15. The results did not suggest any violations for the GR–AL TIE lines, which were relevant to this event. A slight overvoltage only appears in a few nodes at the Greek and Romanian system, irrelevant for this incident.

Element	Current (A)	Limit (A)	Loading (%)
Ribarevine - Podgorica 2	473	1,920	24.0
Zemblak - Kardia	928	1,599	58.0
Fierze - Prizren 2	130	720	18.1
Podgorica 1 - Mojkovac	164	720	23.0

Table 17: Load flow results from SEleNe CC DACF CGM

4.2.3.4 TSCNET DACF & IDCF

TSCNET provides a daily DACF and an hourly IDCF for the TSCNET area. From the area of the incident, this only includes Croatia, including its tie-lines.

The DACF process finished on 20.06.2024 at 23:22. Regarding the critical timestamp 12:30, almost all monitored elements were foreseen to be below the defined limits in the foreseen grid situation (N situation). Only for some 220 kV lines in France and for some transformers in Ukraine were overloads calculated which were considered unrealistic. For the incident, they were irrelevant.

For the contingency analysis, TSCNET simulates all contingency cases from the contingency lists provided by the TSOs. Also, for these scenarios (N-1 situations), there were no congestions foreseen in the area. Very slight N-1 congestions (<106 %) were foreseen for a French–Italian tie-line and an internal line in Austria. Both were fully within the expected limits and no consequent actions were taken by TSCNET.

The first elements that tripped during the incident were neither monitored nor part of the considered contingency cases. The provided CGM indicated the following flows:

Element	Current (A)	Limit (A)	Loading (%)
Ribarevine - Podgorica 2	481.4	1,920	25.1
Zemblak - Kardia	947.0	1,599	59.2
Fierze - Prizren 2	129.2	720	17.9
Podgorica 1 - Mojkovac	160.1	720	22.2

Table 18: Load flow results from the final TSCNET DACF CGM

The latest iteration of the hourly IDCF process before the incident finished at 11:25. Regarding the critical timestamp 12:30, almost all monitored elements were foreseen to be below the defined limits in the foreseen grid situation (N situation). Only for some lines in France and Italy and for some transformers in Ukraine were overloads calculated which were considered unrealistic or manageable. For France and Italy, primarily the results from Coreso would be considered. For the incident they were irrelevant. In addition, there were minor overloads detected on the Croatian transformers in Tumbri 380–110 kV (116 %) and in Ernestinovo 380–110 kV (104 %).

Also, for all configured contingency cases there were no violations of N-1 criterion foreseen in the area. Very slight N-1 violations (<109 %) were foreseen for internal lines in Austria and Italy. For the contingency analysis, TSCNET simulates all contingency cases from the contingency lists provided by the TSOs. Also, for these scenarios (N-1 situations), there were no congestions foreseen in the area.

The first elements that tripped during the incident were neither monitored nor part of the considered contingency cases. The provided CGM indicated the following flows:

Element	Current (A)	Limit (A)	Loading (%)
Ribarevine - Podgorica 2	494.2	1,920	25.7
Zemblak - Kardia	966.1	1,599	60.4
Fierze - Prizren 2	145.7	720	20.2
Podgorica 1 - Mojkovac	166.0	720	23.1

Table 19: Load flow results from the TSCNET IDCF CGM from 11:25

4.2.3.5 Coreso DACF & IDCF

The DACF and IDCF processes at Coreso did not foresee any constraints on the Italian–Montenegro border. For information, the 380 kV Divača PST in Slovenia, at the border with Italy, was in outage.

Constraints in the operational security limits were detected on the FR–IT and IT–CH borders, but there was no impact on the Monita cable.

4.2.4 Coordinated Capacity Calculation (CCC) Processes

Currently, non-EU TSOs in the Balkans area do not belong to any EU CCR, despite the flows within them and within neighbouring EU TSOs having an influence on the CCC in both the Core and SEE CCRs. The capacity calculation is done with bilateral coordination among EU- and non-EU TSOs.

A disadvantage of the current approach is that the capacity calculation is not coordinated and performed sufficiently in advance. Day-ahead CCC in line with Regulation (UE) 2015/1222 went live in June 2022 in Core CCR and in July 2021 in SEE CCR. Unfortunately, CCC in SEE CCR will cover only two borders from the south-east area of CE, RO-BG and BG-GR. Capacity Allocation & Congestion Management (CACM) is not mandatory for non-EU TSOs and basic capacity calculations in SEE (which are still used for commercial purposes) are bilateral NTC calculations performed by neighbouring TSOs, using M-2 regional CGM harmonised among SEE TSOs. Therefore, a stronger and more detailed coordination at the level of RCCs (TSCNET, SCC and SELENE-CC) should be developed in the region as soon as possible. Preconditions for stronger and more detailed RCCs coordination are harmonised methodologies and business processes in SEE for CCC. The concept of CCC is based on "CCR regional modules" as well as coordination and cooperation on these matters with neighbouring CCRs (and RCCs). Currently, non-EU SEE TSOs do not belong to any CCR, and this issue must be solved (possible options are the creation of either so-called Shadow CCR 10 or WB6 CCR) to implement the "CCR regional modules" concept for the entirety of the Continental Europe Synchronous Area. Furthermore, a final solution for CCC in the south-east part of CE is the implementation of the flow-based approach after the application of market coupling within the whole area according to CACM regulation.

The possibility of developing a more sustainable solution for CCC and CSA for non-EU TSOs in the Balkans area and between these TSOs and neighbouring EU TSOs should be assessed to increase the system security and ensure a proper level of TSOs cooperation.

TSCNET and Coreso provide flow-based CCC for the Core Region, which includes the borders from Croatia to Slovenia and Hungary. For the day of the incident, the CCC process was successfully completed. According to the CCC results for the 21.06.2024, the load flow in the region was from north to south. The load flow was expected to be from Austria towards Slovenia and Hungary throughout the day. Similarly, the load flow was expected to be from Slovenia towards Croatia. At the time of the incident, Hungary was exporting energy to Croatia.

The most limiting element from the Core DACC point of view in the Croatia grid was 220 kV Pehlin – Divača with "N-1 Melina – Divača" contingency. Individual reductions have been applied in this element, including the hour when the incident started. In addition, it must be indicated that the minimum Remaining Available Margin (RAM) factor was 45.2 % instead of 70 % for this element.

There were no shadow prices in HR region for the whole day, but there were in neighbouring countries (Obersielach – Podlog with contingency "N-1 Maribor – Kainachtal 1" for almost all day).

Considering the elements that were out of service on the day of the event, there were limited options to manage the load flow. Measures taken, such as individual reductions and a lower minimum RAM factor value, can be cited as examples of steps taken to protect the system from overloads and congestion. Accordingly, no conclusion has been reached that the actions taken during the CCC process contributed to the development of the incident.

4.2.5 Consistency assessment of defence and restoration plans

The first check of the consistency assessment of defence and restoration plans was done in 2019. The final report was approved by SOC on 12.02 2020. There were no inconsistencies detected in 2019.

The consistency check shall be done every 5 years, and an iteration was triggered for 2024.

The consistency assessment by the RCCs was ongoing at the time of the incident and the assessment from 2019 is still relevant for 21 June, 2024.

4.3 Ex Post Analysis

Regional Incident Analysis and Reporting (RIAR) is a legally mandated RCC task, per Article 37 of EU Regulation 2019/943, to conduct post-operation and post-disturbance analysis and reporting activities. The RCC Post-Operation and Post-Disturbance Analysis and Reporting Methodology was approved by ACER (ACER decision 04-2022) on 1 April 2022.

The RCCs' RIAR task interacts with the process run by the ICS Expert Panel. An RCC Investigation Subgroup is created within the ICS Expert Panel when the RCC Investigation Threshold is met.

As the threshold was confirmed (Chapter 7 of the factual report), an RCC investigation subgroup was created under the ICS Expert Panel. The RCC Investigation Subgroup of the ICS Expert Panel shall further investigate the incident as per RCCs' tasks under Article 37 and Annex I of Regulation (EU) 2019/943. The conclusions of the RCC investigation are added in this chapter of the ICS Final Report.

As such, the RCC Investigation Threshold has been met for the incident in question. The following sections detail the investigation and analysis jointly carried out by the RCCs, as well as RCC recommendations based on the conclusions reached.

4.3.1 Security Analysis

On 21 June 2024, multiple grid elements tripped, causing a voltage drop across the grids of all four affected TSOs. The security analysis performed by SCC, TSCNET, and Selene CC aims to prevent such incidents and any cascading faults. Chapter 5.2.3 describes the results and demonstrates that this incident was not detected in advance. As part of the investigation, RCCs have investigated the first faults as described in Chapter 3.1.

The first fault (12:09:16 CEST) happened on the 400 kV OHL Ribarevine (CGES) – Podgorica 2 (CGES). For this line, the RCCs have expected a loading of 24–26 %. This is close to the loading of 26–28 % measured before the fault. As also confirmed by the TSOs, the cause of the fault was not related to any overcurrent and, therefore, is not expected to be found in the security analysis. However, the RCCs performed an N-1 security analysis and simulated the consequences of the fault. SCC and Selene CC had this contingency included in their contingency list. The security analysis, which was performed by SCC as part of their DACF and IDCF processes, showed that no overloads were expected for this contingency. In the SCC's security analysis, elements with loads higher than or equal to 90 % in the N-1 state are displayed. Loading was calculated considering the values of current limits and apparent power limits. For the time stamp 12:30 CEST, as for every other, an outage of the 400 kV OHL Ribarevine (CGES) – Podgorica 2 (CGES) was simulated. However, no element in the CGES observability area – defined by the monitoring list provided by CGES, see Chapter 5.1.3: Coordinated Security Analysis (CSA) and Common Grid Model (CGM) – had a load higher than 90 %, indicating that the system was stable for the outage of 400 kV OHL Ribarevine (CGES)–Podgorica 2 (CGES). Ex post analysis of the CGMs used by TSCNET and Selene CC reached the same conclusion. TSCNET had not included this line in its contingency list and had not simulated it in advance.

The second fault (12:21:33 CEST) happened on the 400 kV OHL Zemblak (OST) – Kardia (IPTO). The line was expected to be loaded at 58–61 %, and in the N-1 case, at 66–69 %. This is close to the measured loading of 53–56 % before and 62–64 % after the first fault mentioned above. Similar to 400 kV OHL Ribarevine (CGES) – Podgorica 2 (CGES), this line did not trip due to an overcurrent; therefore, the second fault is not expected to be found in the security analysis.

As mentioned in Chapter 5.2.1, for the 400 kV OHL Zemblak (OST)–Kardia (IPTO), different current limits were provided by the TSOs. Since RCCs always consider the lower limit in such cases, this did not influence the RCC processes. The TSOs confirmed ex post that they are either using the lower limit (IPTO used the lower limit) or both limits for their processes and this is a modelling artefact. For the incident, the inconsistency was irrelevant. However, as a best practice, RCCs generally urge TSOs to resolve such inconsistencies because they can indicate misalignments in the configurations of their local analysis and alarms. CSAm Article 7 specifies the classification of contingencies. The loss of both the 400 kV OHL Ribarevine (CGES) – Podgorica 2 (CGES) and the 400 kV OHL Zemblak (OST) – Kardia (IPTO) is an out-of-range contingency because the lines are independent of each other and, considering the grid topology, are located in two different geographic areas. Hence, the loss of both elements was not analysed by the RCCs in advance.

One method that can be used to anticipate faults based on historical data received from the relevant TSOs is the probabilistic risk assessment. A dedicated ENTSO-E working group is developing an update or amendment of the CSA methodology, as required by CSAm Art. 44. To understand whether the N-2 case of both the 400 kV OHL Zemblak (OST) – Kardia (IPTO) and 400 kV OHL Ribarevine (CGES) – Podgorica 2 (CGES) could have been anticipated with the use of probabilistic risk assessment, RCCs have also investigated previous faults. The 400 kV OHL Zemblak (OST) – Kardia (IPTO) and the 400 kV OHL Ribarevine (CGES) – Podgorica 2 (CGES) each had one fault in the two months before the incident. The faults were not at the same time, and it has not been possible to determine what caused them. Therefore, it can be concluded that the occurrence of the two faults in such close succession was a very unlikely event. As a part of the ex post analysis, RCCs also simulated the tripping of the two lines. In this case, an overload of about 115–120 % can be seen on the 220 kV OHL Fierze (OST) – Prizren 2 (KOSTT).[11] This was the third outage during a cascading disturbance.

Time Stamp	CO Name	CB Name	Loading_BC (%)	Loading After Outage (%)
	Basecase when 400 kV OHL Ribarevine (CGES) - Podgorica 2 (CGES) is out	400 kV TIE Kardia - Zemblak	66.84	
12:30	400 kV TIE Kardia - Zemblak	220 kV TIE Prizren 2 - Fierze (KS)	33.34	**117.3**
12:30	400 kV TIE Kardia - Zemblak	220 kV TIE Prizren 2 - Fierze (AL)	32.62	**116.81**
12:30	400 kV OHL Zemblak - Elbasan 2	220 kV TIE Prizren 2 - Fierze (KS)	33.34	**105.83**
12:30	400 kV OHL Zemblak - Elbasan 2	220 kV TIE Prizren 2 - Fierze (AL)	32.62	**105.33**

Table 20: Additional SCC analysis for OST after the applied outage of 400 kV OHL Ribarevine (CGES)-Podgorica 2 (CGES) in CGM.

When also simulating the tripping of 220 kV OHL Fierze (OST) – Prizren 2 (KOSTT), an overload of 112 – 116 % on 220 kV OHL Podgorica 1 (CGES) – Mojkovac (CGES) can be seen (the fourth outage during a cascading disturbance).

Time Stamp	CO Name	CB Name	Loading_BC (%)	Loading After Outage (%)
	Basecase when 400 kV OHL Ribarevine (CGES) - Podgorica 2 (CGES) and 400 kV TIE Zemblak (OST) - Kardia (IPTO) are out	220 kV TIE Prizren 2 - Fierze	117.3	
12:30	220 kV TIE Prizren 2 - Fierze	220 kV OHL Podgorica 1 - Mojkovac	78.56	**113.12**
12:30	400 kV TIE Trebinje - Lastva	220 kV OHL Podgorica 1 - Mojkovac	78.56	**102.93**
12:30	220 kV TIE Sarajevo 20 - HE Piva	220 kV OHL Podgorica 1 - Mojkovac	78.56	93.21
12:30	400/220 kV TR Sarajevo 20 (1)	220 kV OHL Podgorica 1 - Mojkovac	78.56	93.21
12:30	220 kV OHL Drenasi 1 - Drenasi 2	220 kV OHL Podgorica 1 - Mojkovac	78.56	92.67
12:30	400 kV OHL Sarajevo 10 - Mostar 4	220 kV OHL Podgorica 1 - Mojkovac	78.56	92.05
12:30	220 kV OHL Drenasi 2 - Prizren 2	220 kV OHL Podgorica 1 - Mojkovac	78.56	91.87
12:30	400 kV OHL TE Gacko - Trebinje	220 kV OHL Podgorica 1 - Mojkovac	78.56	91.84

Table 21: Additional SCC analysis for CGES after applied outages of 400 kV OHL Ribarevine (CGES) - Podgorica 2 (CGES) and 400 kV TIE Zemblak (OST) - Kardia (IPTO) in CGM

The order of outages in the cascading disturbance can be seen in Figure 19 in Chapter 3.1 in the Factual Report. The chronological order for the third and fourth outages during the disturbance fully corresponds to the order obtained in the RCC's ex post analyses.

Therefore, it can be concluded that from 12:09:16 CEST, the grid was no longer N-1 secure, and from 12:21:33 CEST, the grid was no longer secure. Detecting this would have been possible. However, the 12-minute interval made it practically impossible to perform this analysis manually and take appropriate actions. At the time of the incident, it

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[11] There are differences regarding the currents calculated for the KS and the AL side of the tie-line. These differences are explained by the physical parameters of the line and the losses. Marginal differences of below 1 %p are common in such cases. The limits for both sides of the line were consistent with 720A.

was common to have IDCF calculations every eight hours in the SCC region which is aligned with the frequency of IGM updates by most TSOs in the region. For the Coordinated Security Analysis, hourly calculations are planned in the future but are not yet a fixed plan; as far as Selene CC is concerned, hourly calculations are envisaged after the transition to CGMES processes is completed. This will allow more updates closer to real time, but in such short time intervals like this incident, it would not have made a difference.

While the models used for the security analysis were generally able to detect the overloads of the third and fourth tripping element, they were highly inaccurate concerning the voltage results. The voltage drop cannot be simulated using these models. The RCCs face challenges, especially when calculating non-stable grid situations. The commonly used load flow methods, such as Newton–Raphson, can in such cases result in non-convergence. The handling of such non-convergent scenarios differs significantly between TSOs and regions and is a limitation of current security analysis. In the models used for 21 June 2024, there have been no such issues in the region. However, the calculated voltage results are significantly higher than they were in real time. Voltage and reactive power results are often considered unrealistic. However, there has been no quantitative analysis of this on a larger scale. RCCs currently have no data to perform such an analysis without additional support from the TSOs.

The suspected low accuracy of voltage and reactive power results have two direct consequences in incidents like this one. First, the decision to take measures to stabilise the voltage is usually made in real time and not as part of the RCC tasks. This affects the whole load flow results. Secondly, this means that issues like excessively low voltage are not detected. Currently, only current limits and apparent power limits are considered, while voltage limits are not utilised as security limits in RCC processes.[12]

4.3.2 Assessment of the Relevance of Different RCC Tasks in the Context of the Incident

As part of the incident investigation, the RCCs have also assessed the other RCC tasks; an overview is provided in Chapters 5.1 and 5.2. However, based on the nature of the incident and the sequence of events, it can be concluded that the RCC tasks OPC, STA, and the consistency check of the Defence and Restorations plans were not relevant for further analysis of this specific incident.

The STA has foreseen no adequacy issues in the region and there have been no real-time adequacy issues. The process was generally successful and no points for improvement could be identified.

Regarding the OPC process, there were no planned disconnections relevant to the incident on the day it occurred.

The consistency check of the Defence and Restoration plans also did not identify any relevant issues, and the TSOs did not identify any inconsistencies in the execution of these plans in the ex post analysis. Therefore, no issues or points for improvement were identified concerning this task.

4.3.3 Capacity Calculation and Outage Planning

Since the security and ex post analyses showed that the grid was fully N-1 secure until the tripping of 400 kV OHL Ribarevine (CGES) – Podgorica 2 (CGES), the outage plans and allocated capacities were fully within operational limits. The scheduled flows were not too high, and outages have not been excessive. However, one potential weakness similar to the one raised in Chapter 5.3.1 is the consideration of voltage limits, which is currently not included in these processes.

While the voltage and reactive power results are calculated, these calculations are suspected to be of insufficient accuracy to limit market capacities or detect outage planning incompatibilities. Considering the security analysis results, it can be concluded that the capacity calculations and outage plans were fully functional.

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[12] It is unclear whether this could be improved in the current processes based on the UCTE DEF format due to the limitations of the format. However, the analysis should be a first step towards enabling mid- and long-term improvements.

4.3.4 Security Analysis on Improved CGM

After the incident, SCC also performed analyses on the improved CGM. Since it was reported that the real-time grid situation differed from the initial analyses, the IDCF CGM (for the time stamp 12:30 CEST) was corrected to align with the real-time grid situation during the incident.

Four inconsistencies between the forecasts and the real-time situation were observed. The differences are shown in the table below.

Element	IDCF	Real Time
TPP Gacko	170 MW	0 MW
400 kV Višegrad (NOSBiH) – Tuzla 4 (NOSBiH)	ON	OFF
400 kV Tuzla 4 (NOSBiH) – Ugljevik (NOSBiH)	OFF	ON
HVDC Monita cable	391 MW	410 MW

Table 22: Differences between CGM for 12:30 from regular IDCF process and real-time situation

SCC post-event analysis on the improved CGM with real-time values included N-1, N-2, and N-3. Even if the SCC took those changes into account in the calculation, the results would not have had a significant impact on the result. This would have been covered if the IGMs had been updated more frequently than every eight hours.

Reasons for the differences:

- TPP Gacko was out of operation in real time, instead of generating 170 MW as it was in CGM. This is because SCC uses a unit file that is delivered before 7 AM for the creation of NOSBiH IDCF models. In the latest delivered unit file for the period of the event, TPP Gacko generation was 170 MW, but in the meantime, TPP Gacko had tripped.
- 400 kV OHL Višegrad – Tuzla 4 was out of operation in real time, while in the CGM for 12:30 from the regular IDCF process, this line was in operation based on information received from NOSBiH dispatchers on duty.
- 400 kV OHL Tuzla 4 – Ugljevik was in operation in real time, while in the CGM for 12:30 from the regular IDCF process, this line was out of operation based on information received from NOSBiH dispatchers on duty.
- Flow on HVDC Monita cable was 410 MW in real time according to the Vulcanus platform, while in the CGM for 12:30 from the regular IDCF process, this value was 391 MW.

Taking into account the previously mentioned differences by improving CGM from the regular IDCF process, the SCC performed N-1 analysis once again, obtaining very similar results, as shown in Table 22.

Time Stamp	CO Name	CB Name	Loading_BC (%)	Loading After Outage (%)
	Basecase	400 kV OHL Podgorica 2 – Ribarevine	25.1	
	Basecase	400 kV TIE Kardia – Zemblak	58.65	
	Basecase	220 kV TIE Prizren 2 – Fierze	18.12	
12:30	400 kV TIE Kardia – Zemblak	150 kV TIE Mourtos – Bistrica (AL)	64.22	**130.47**
12:30	400 kV TIE Kardia – Zemblak	150/110 kV TR Bistrica	61.37	**122.29**
12:30	220/110 kV TR Tirana 2 (1)	220/110 kV TR Tirana 2 (2)	73.75	**110.9**
12:30	220/110 kV TR Tirana 2 (2)	220/110 kV TR Tirana 2 (1)	73.75	**110.9**
12:30	400 kV TIE Kardia – Zemblak	150 kV TIE Mourtos – Bistrica (GR)	51.61	**104.44**
12:30	400 kV OHL Zemblak – Elbasan 2	150 kV TIE Mourtos – Bistrica (AL)	64.22	95.1

Table 23: Additional SCC analysis for OST performed on improved CGM

The SCC also conducted post-event analysis on the improved CGM for 12:30 by disconnecting 400 kV OHL Podgorica 2 (CGES)–Ribarevine (CGES) in a model and performing N-2 security analysis. The results of this analysis are shown in Table 23.

It shows that in addition to the previously detected overloading, overloading of the 220 kV TIE Prizren 2(KOSTT)–Fierze (OST) was detected for the 400 kV TIE Zemblak (OST)–Kardia (IPTO) outage (which reflected the real-time situation), as well as for the outage of 400 kV OHL Zemblak (OST)–Elbasan 2 (OST).

Time Stamp	CO Name	CB Name	Loading_BC (%)	Loading After Outage (%)
	Basecase when 400 kV OHL Ribarevine (CGES) - Podgorica 2 (CGES) is out.	400 kV TIE Kardia - Zemblak	**67.62**	
12:30	400 kV TIE Kardia - Zemblak	220 kV TIE Prizren 2 - Fierze (KS)	34.09	**117.43**
12:30	400 kV TIE Kardia - Zemblak	220 kV TIE Prizren 2 - Fierze (AL)	33.38	**116.93**
12:30	400 kV OHL Zemblak - Elbasan 2	220 kV TIE Prizren 2 - Fierze (KS)	34.09	**105.96**
12:30	400 kV OHL Zemblak - Elbasan 2	220 kV TIE Prizren 2 - Fierze (AL)	33.38	**105.46**

Table 24: An additional SCC analysis for OST after applying the outage of the 400 kV OHL Ribarevine (CGES)-Podgorica 2 (CGES) in the improved CGM

SCC also performed an N-3 security analysis on the improved CGM for 12:30 with both the 400 kV OHL Podgorica 2 – Ribarevine and 400 kV Zemblak – Kardia disconnected. The results of this analysis, presented in Table 26, indicate that overloadings on 220 kV OHL Podgorica 1 – Mojkovac are now detected for multiple outages, including 220 kV TIE Prizren 2 – Fierze (which happened in real time).

Time Stamp	CO Name	CB Name	Loading_BC (%)	Loading After Outage (%)
	Basecase when 400 kV OHL Ribarevine (CGES) - Podgorica 2 (CGES) and 400 kV TIE Zemblak (OST) - Kardia (IPTO) are out	220 kV TIE Prizren 2 - Fierze	**117.43**	
12:30	220 kV TIE Prizren 2 - Fierze	220 kV OHL Podgorica 1 - Mojkovac	79.46	**114.15**
12:30	400 kV OHL Sarajevo 10 - Mostar 4	220 kV OHL Podgorica 1 - Mojkovac	79.46	**100.31**
12:30	220 kV OHL Drenasi 1 - Drenasi 2	220 kV OHL Podgorica 1 - Mojkovac	79.46	93.51
12:30	220 kV OHL Drenasi 2 - Prizren 2	220 kV OHL Podgorica 1 - Mojkovac	79.46	92.71
12:30	400 kV OHL Ugljevik - Tuzla 4	220 kV OHL Podgorica 1 - Mojkovac	79.46	92.55
12:30	400 kV OHL TE Gacko - Mostar 4	220 kV OHL Podgorica 1 - Mojkovac	79.46	92.2
12:30	400 kV OHL TE Gacko - Trebinje	220 kV OHL Podgorica 1 - Mojkovac	79.46	92.18
12:30	220 kV TIE Sarajevo 20 - HE Piva	220 kV OHL Podgorica 1 - Mojkovac	79.46	91.21
12:30	400/220 kV TR Sarajevo 20 (1)	220 kV OHL Podgorica 1 - Mojkovac	79.46	91.21
12:30	110 kV OHL Bijelo Polje - Berane	220 kV OHL Podgorica 1 - Mojkovac	79.46	90.08

Table 25: Additional SCC analysis for CGES after applying the outages of 400 kV OHL Ribarevine (CGES)-Podgorica 2 (CGES) and 400 kV TIE Zemblak (OST)-Kardia (IPTO) in the improved CGM

It can be concluded that there are no significant differences in the additional N-X results performed on the CGM from the regular IDCF process and the improved CGM. For an improved representation of the real-time grid situation and more relevant N-X results from the security analysis, West Balkan TSOs should provide their updated IGMs more frequently than three times a day.

In the context of this significant milestone and the South-East Europe Energy Community TSO's joint declaration on regional coordination, all TSOs from the SEE Region, with the support of neighbouring TSOs and ENTSO-E, will ensure that future system security analyses and capacity coordination and calculation methods include the latest available data on all relevant system elements located within the region as well as between the regions.

4.3.5 Communication

Whilst there was prompt and effective communication amongst the involved TSOs while the incident unfolded, the RCCs have determined that communication between the TSOs and the relevant RCCs was not optimal. Namely, during the incident, the SCC operators on duty received a total of three calls from other RCCs (operators from Coreso and TSCNET trying to obtain more details about the incident) but no official calls were received from SCC TSOs to notify them of the incident and share grid details. As such, all gathered information by SCC operators on duty was unofficial (e.g. media, other calls). Similarly, Selene CC received no formal communication regarding the incident until after system stability was restored. Based on operational processes performed for the incident time stamp, there was no indication of a possibly critical situation that would lead to the incident/blackout in the affected region, which was shared during phone calls between SCC operators and other RCCs.

Based on their experience from this incident, the RCCs jointly recommend that in future events, TSOs should communicate any unplanned outages or changes to the system state to their respective RCCs as soon as possible. The EAS[13] shall also reflect each TSO system state as soon as is practically possible.

4.3.6 Quality Management and Usage of Post-Operational Data

In the context of the incident investigation, the RCCs also looked into the quality management processes in place for the affected region. This quality management is mandatory for all RCCs under Article 46 of EU Regulation 2019/943 and the requirements outlined in methodologies such as Article 42 CSAm. While there are some processes in place for the Balkan region, they differ from those in place for Central Europe. The main difference is the usage of post-operational data like RTSN (Real Time Snapshots) models.

RTSN is a process in which TSOs from the Central European System Operation Region (SOR) provide an IGM in UCTE DEF (data exchange format) reflecting the actual grid situation every five to 60 minutes. These are currently being merged by TSCNET and Coreso and used to assess the quality of the forecast processes. They enable both RCCs and TSOs to conduct post-operational assessments of data quality and grid security. No such process exists in the Balkan region. Therefore, neither SCC nor Selene CC have access to the actual grid situation and are unable to assess how closely their processes reflect reality. Quality management is therefore highly limited and mostly addresses questions like how often results were delivered in the foreseen time frame. The accuracy of these results cannot be assessed.

For the investigation of this incident, all involved TSOs provided RTSN models, which were partially used in the incident investigation. However, the lack of a regular process and experience with these models increased the effort and partially delayed the investigation. For the Central European TSOs, the assessment of the situation during the incident was significantly easier. Therefore, in addition to its use for quality assessments, implementing a regular RTSN process also supports the investigation of specific grid incidents.

The current format being used for grid modelling by most RCC tasks is the UCTE DEF. In the future, they should all use the CGMES format. This means that the TSO's RTSN will also be transferred to CGMES format at some point in the future and used to prepare IGMs based on snapshots. This will allow RCCs and TSOs to take full advantage of this data. As of 2024, there is no concrete plan for this transition, nor is there a mandate for all TSOs to deliver such data. However, this could represent an important opportunity to enhance the quality management of all regional or pan-European processes. It is highly likely that improved quality management of regional or pan-European processes, supported by the regular provision of post-operational data, could not have prevented the events of 21 June 2024. As outlined in the previous analysis, from a regional perspective, this was a highly improbable trigger event with significant consequences. However, the RCCs concluded in their investigation that the lack of respective quality management processes not only limits their ability to fully comply with regulatory requirements but also restricts more complex ex post analysis. This will be increasingly important in the future, when processes like Coordinated Capacity Calculation could increase the utilisation of the grid beyond the current level.

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[13] The EAS (European Awareness System) is used by all TSOs and will be used by all RCCs (with read-only access) in the future. In the EAS, TSOs share operational data, including the actual system state for each control area.

5 COMMUNICATION OF COORDINATION CENTRES/ SAM AND BETWEEN TSOs

As communication between the Coordination Centres and the TSOs is of utmost important in any term for a reliable and stable system operation, this chapter presents the different contacts at the time of the incident between the Coordination Centres on the one hand and the affected TSOs among each other on the other hand. The purpose of this chapter is thus to present the available data in this regard, while the data is further examined in the other chapters.

5.1 Communication of Coordination Centres SAM and between TSOs

» **21 Jun, 11:26 CET:**
CGES contacted TERNA to request a reduction in the setpoint on the HVDC Monita for voltage/reactive-power flows adjustment purposes. TERNA declined the request due to internal congestions on the North borders and proposed as a countermeasure the disconnection of the 70 MVAr – reactor in KS Kotor (TERNA). Due to the fact that voltages in SS Lastva and Podgorica 2 were above 400 kV at that moment, the measure was assessed as not appropriate. No further communication regarding this matter.

The incident triggered a series of communication exchanges among the affected TSOs, with the aim of coordinating restoration efforts and ensuring the safe and efficient operation of the grid. **The following timeline outlines the key communication events:**

» **21 Jun, 12:24 CET:**
TERNA informed CGES that HVDC cable Monita is out of operation.

» **21 Jun, 12:27 CET – 12:34 CET:**
During this period, CGES, NOSBiH, HOPS and OST engaged in an exchange of information regarding the incident and the system state in each country. The affected TSOs communicated relevant details of the incident to their neighbouring TSOs, including TERNA, IPTO, EMS, MAVIR and ELES. In addition, EMS and HOPS offered their support through the utilisation of 220 kV and 400 kV power lines.

» **21 Jun, 12:29 CET:**
OST informed IPTO that 400 kV TIE Zemblak (OST) – Kardia (IPTO) was disconnected and requested its reconnection.

» **21 Jun, 12:34 CET:**
OST called KOSTT – call related to switching on 220 kV TIE Fierze (OST) – Prizren (KOSTT).

» **21 Jun, 12:36 CET:**
OST contacted IPTO to communicate their readiness to switch on the 400 kV TIE Zemblak (OST) – Kardia (IPTO) and to request reconnection.

» **21 Jun, 12:48 CET:**
CGES updated NOSBiH concerning the operational status of the 220 kV TIE Piva (CGES) – Sarajevo 20 (NOSBiH), informing them not to exceed the power exchange limit of 100 MW.

» **21 Jun, 12:50 CET – 12:55 CET:**
A series of coordinated calls took place between HOPS and NOSBiH regarding the energisation of the 220 kV TIE Međurić (HOPS) – Prijedor (NOSBiH). These discussions were crucial for implementing a top-down restoration strategy aimed at gradually re-establishing power supply to the affected regions.

» 21 Jun, 12:56 CET – 13:08 CET:
Several calls occurred between CGES and OST regarding the energisation of the 400 kV TIE Podgorica 2 (CGES) – Tirana (OST). These calls were focused on the critical step of switching on the power line as part of a top-down restoration approach to restore voltage in certain areas of Montenegro. During the discussions, OST established a power exchange limit of 100 MW for the line to ensure safe operations and prevent potential system overloads.

» 21 Jun, 13:06 CET:
HOPS informed NOSBiH that maintenance operations on the 220 kV TIE Sisak (HOPS) – Prijedor (NOSBiH) had been completed. NOSBiH responded by indicating that the relevant work permits on their side remained open.

» 21 Jun, 13:16 CET:
HOPS communicated to NOSBiH that they were prepared to switch on the 400 kV TIE Konjsko (HOPS) – Mostar 4 (NOSBiH). Discussions ensued regarding whether closing the 400 kV ring would be more advantageous if NOSBiH switched off the 400 kV OHL Sarajevo 10 – Mostar 4.

» 21 Jun, 13:24 CET – 13:28 CET:
Several calls between HOPS and NOSBiH related to switching on 400 kV TIE Konjsko (HOPS) – Mostar 4 (NOSBiH).

» 21 Jun, 13:36 CET:
Call between HOPS and NOSBiH related to switching on 220 kV TIE Mostar 4 (NOSBiH) – Zakučac (HOPS).

» 21 Jun, 13:46 CET:
Conversations between HOPS and MAVIR took place concerning the energisation of the 400 kV TIE Ernestinovo (HOPS) – Pecs ckt2 (MAVIR).

» 21 Jun, 13:54 CET:
Call between CGES and NOSBiH related to switching on 220 kV TIE Trebinje (NOSBiH) – Perućica (CGES).

» 21 Jun, 13:56 CET:
Call between HOPS and NOSBiH related to switching on 220 kV TIE Trebinje (NOSBiH) – Plat (HOPS).

» 21 Jun, 13:56 CET – 14:19 CET:
Several calls between EMS and NOSBiH related to switching on 110 kV TIE Janja – Lesnica.

» 21 Jun, 14:13 CET:
Call between HOPS and NOSBiH related to switching on 110 kV TIE Opuzen – Neum.

» 21 Jun, 14:28 CET – 14:35 CET:
Several calls between HOPS and NOSBiH related to switching on 110 kV TIE Županja – Orašje.

- **21 Jun, 14:37 CET – 15:03 CET:**
  Several calls between HOPS and NOSBiH related to switching on 110 kV TIE Neum – Ston.
- **21 Jun, 14:44 CET – 14:50 CET:**
  Several calls between HOPS and NOSBiH related to switching on 110 kV TIE Grahovo – Knin.
- **21 Jun, 14:49 CET:**
  Call between CGES and NOSBiH regarding switching on 220 kV TIE Podgorica 1 (CGES) – Koplik (OST).
- **21 Jun, 14:56 CET – 15:01 CET:**
  Several calls between HOPS and NOSBiH related to switching on 220 kV TIE Đakovo (HOPS) – Gradacac (NOSBiH) and 220 kV TIE Đakovo (HOPS) – Tuzla (NOSBiH).
- **21 Jun, 14:59 CET – 15:05 CET:**
  Several calls between CGES and NOSBiH regarding switching on 400 kV TIE Lastva (CGES) – Trebinje (NOSBiH).
- **21 Jun, 15:03 CET – 15:05 CET:**
  Several calls between HOPS and NOSBiH related to switching on 110 kV TIE Mazin (HOPS) – K. Vakuf (NOSBiH) and transformer 150 MVA in Đakovo (HOPS).
- **21 Jun, 15:07 CET – 15:16 CET:**
  Several calls between HOPS and NOSBiH related to switching on 110 kV TIE Livno – B. Blato.
- **21 Jun, 15:29 CET:**
  Call between HOPS and NOSBiH related to switching on 110 kV TIE Imotski – Grude.
- **21 Jun, 15:31 CET – 15:34 CET:**
  Several calls between HOPS and NOSBiH related to switching on 110 kV TIE Capljina – Opuzen.
- **21 Jun, 15:36 CET:**
  Call between HOPS and NOSBiH related to switching on 110 kV TIE Vrgorac – Ljubuski.
- **21 Jun, 15:41 CET – 15:59 CET:**
  Several calls between HOPS and NOSBiH related to switching on 220 kV TIE Prijedor (NOSBiH) – Sisak (HOPS).
- **21 Jun, 15:42 CET – 15:45 CET:**
  Several calls between HOPS and NOSBiH related to switching on 220 kV TIE Zakucac (HOPS) in SS Mostar 4 (NOSBiH).
- **21 Jun, 15:56 CET:**
  Call between CGES and NOSBiH related to switching on 110 kV TIE Nikšić – Bileća.
- **21 Jun, 16:00 CET:**
  Call between HOPS and NOSBiH related to switching on 110 kV TIE Komolac – Trebinje.

5.2 Communication between RCCs

During the incident situation, SCC operators on duty received total of three (3) calls from other RCCs but no official calls were received from SCC TSOs about the incident root cause and further situation.

In these calls, operators from Coreso and TSCNET tried to figure out more details about incident situation. Since there was no information from TSOs, all gathered information by SCC operators on duty were unofficial (media, other calls…). Based on operational processes that were performed for the incident timestamp, there was no indication about possible critical situation that would lead to the incident/blackout in affected region, which was shared during the phone calls that SCC operators had with other RCCs.

- **21 Jun, 13:23 CET:**
  Call between SCC and Coreso.
- **21 Jun, 13:35 CET:**
  Call between SCC and TSCNET.
- **21 Jun, 16:28 CET:**
  Call between SCC and Coreso.

5.3 Communication between affected TSO and Synchronous Area Monitor (SAM)

As defined for even month, Swissgrid was due as Synchronous Area Monitor (SAM) and thus took over the coordination following the blackout. This section presents a timeline of key interactions between Swissgrid and various TSOs.

» **21 Jun, 12:27 CET:**
Swissgrid received a phone call from Amprion and was informed about the frequency jump. Swissgrid also confirmed that it had noticed this jump. Amprion and Swissgrid further discussed the incident and the further coordination briefly as the frequency measurements of HOPS were marked as invalid on the EAS at this time. Regardless, the SAM was unable to clearly identify HOPS as the cause.

» **21 Jun, 12:29 CET:**
Swissgrid contacted ELES, the leader of SHB block, who reported a substantial load loss in HOPS, stating, "[...] many people without electricity. [...]". CC South & North extended an offer of assistance, which ELES declined at that time, indicating that they would provide further updates as new information became available.

» **21 Jun, 12:38 CET:**
Swissgrid informed Amprion about the assistance offer from CC South & North and ELES's subsequent refusal.

» **21 Jun, 12:50 CET:**
The frequency remained at the upper 50 mHz limit. Swissgrid contacted ELES to ask again whether they needed help. ELES accepted. Swissgrid said that they could get in touch as soon as they needed negative power. ELES also provided information about the blackout situation in Bosnia-Herzegovina, Albania, Montenegro and Croatia. However, they did not yet have an overview of their ACE about all affected lines in the control block.

» **21 Jun, 13:01 CET:**
ELES contacted Swissgrid and provided another update on the blackout situation. They did not need any help for the time being. However, they wanted to know what the help would look like.

» **21 Jun, 13:18 CET:**
Amprion was informed again by Swissgrid. They discussed whether a possible LLFD procedure should be carried out as normal or whether adjustments should be made. Swissgrid suggested that all procedures should be carried out as planned, provided that no further input was received from the affected TSOs – including a possible LLFD.

» **21 Jun, 13:26 CET:**
Swissgrid contacted OST. OST declined the offer of assistance, asserting that it was unnecessary. They elaborated on the measures they had undertaken, including the activation of power plants and management of affected transmission lines. OST indicated their intent to restore a 400 kV and 220 kV line between Montenegro and Albania, clarifying that these lines were energised but had not yet been switched on operationally by Montenegro.

5.4 ENTSO-E Awareness System (EAS)

The EAS was activated in response to critical incidents, enabling a coordinated response among various TSOs within the ENTSO-E framework. Below are the detailed changes in system states for each affected TSO during the series of events.

HOPS:

- 12:28:06 – Alert State – "07 Critical Event"
- 12:39:47 – Emergency State
- 12:57:56 – Restoration State
- 14:50:03 – Alert State
- 15:03:10 – Normal state

NOSBiH:

- 12:36:15 – Black Out State – "07 Critical Event"
- 12:53:07 – Restoration State
- 14:29:38 – Alert State – "01 N-1 Violation"
- 15:09:49 – Normal state

OST:

- 12:38:07 – Black Out State – "07 Critical Event"
- 12:48:05 – Restoration State
- 13:08:48 – Alert State – Frequency Degradation
- 13:11:48 – Alert State – "01 N-1 Violation"
- 15:03:29 – Normal state

CGES:

- 13:08:51 – Restoration state – "07 Critical Event"
- 15:37:53 – Normal state

5.5 Conclusion

The effective communication during the critical event and subsequent restoration process was paramount. The TSOs were informed of the disturbance, allowing for a swift response to the voltage collapse and blackouts across the affected regions. This timely communication facilitated coordinated efforts and ensured that the necessary preconditions and preparatory actions for the restoration process were efficiently implemented.

6 TECHNICAL ANALYSIS

6.1 System Conditions

6.1.1 Load Behaviour

The analysis of consumption data reveals that air conditioning systems have a significant impact during peak cooling hours (11:00–14:00). By comparing spring and summer data, CGES estimated that prior to the event, 30–35 % of the total consumption originated from air conditioning systems. This estimation is supported by the number of air conditioning units and their individual consumption profiles. In CGES, this corresponds to increased demand of approximately 150 MW active power and 40 MVAr reactive power. This load increase affected all Transmission System Operators (TSOs) involved in the incident, contributing to the initial conditions that will be detailed in the voltage collapse analysis. As air conditioning systems are mainly connected to the distribution grid, there is no measurement data available that would allow a comprehensive analysis of their impact on reactive power demand or their contribution to voltage stability during the incident.

Regarding the anticipation of increased load, HOPS reported that the consumption during the period before the collapse was 100–150 MW higher than forecasted the previous day, although not at record levels. OST noted that consumption was 110 MW higher than the scheduled amount, though still below peak levels. NOSBiH indicated that consumption was approximately in line with the planned amount from the previous day. In terms of load forecast in the DACF process, HOPS mentioned that the additional load matched expectations, OST stated that the load was close to expected values in Initial Grid Models (IGMs), and NOSBiH confirmed that the load was anticipated. It can be concluded that even though the load was high due to the high usage of air conditioning systems, no major deviations from expectations were reported by HOPS, OST, or NOSBiH.

6.1.2 Import Conditions and Generation Pattern

The high level of imports into the region has led to an increase in currents on the 400 kV grid, which in turn has increased MVAr consumption and caused lower than usual operational voltages in the area.[14] To evaluate the deviations between expected and actual power flows, HOPS and NOSBiH reported that scheduled and real flows are usually different due to loop flows, although flows forecasted in the CGMs (DACF and IDCF) are very similar to actual flows. OST noted significant differences between predicted and real flows due to uncoordinated NTC calculations; however, IGMs and CGMs were close to real flows. The high deviations were attributed to the uncoordinated NTC calculation (only bilateral) and lack of market coupling, which, in a highly meshed region with small control areas, is not surprising.

Regarding the dispatch of conventional generation, NOSBiH confirmed that the dispatches were according to schedules. OST reported that the dispatch of generation units matched the schedules, with 460 MW from hydropower, 110 MW from photovoltaics, and 550 MW from imports recorded in the hour before the event. HOPS confirmed that the conditions were typical for June. Imports covered nearly 50 % of the load, although higher imports have been experienced in the past. High imports are common in the summer due to low hydropower production, with instances of even 20 % higher imports compared to the hour of the incident.

In summary, high (but not unusual nor unexpected due to the heat) imports, increased the use of air conditioning systems and low hydro production led to lower voltages due to significant reactive power demand.

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[14] It should be noted that the voltages were still above their nominal values

6.1.3 Available Reactive Power Support

From operational experience, the affected TSOs typically experience high voltage profiles in the 220 kV and 400 kV grids rather than the low voltage conditions observed during the event. Even during previous very high import situations, low voltage issues have not previously been observed. This is due to the low loading of interconnectors, which in turn produce reactive power. Thus, high voltages are counteracted by temporarily disconnecting overhead lines and/or switching on shunt reactors. As stated in Chapter 2.1.1., the 400 kV Tuzla 4 – Višegrad line in the NOHBiH grid was still out of service as a countermeasure of high voltages from the night before. This will be further analysed in Chapter 6.7.

During the high load and high import conditions experienced during the incident, the number of operating power plants in the affected HOPS grid (Dalmatia) was limited to a single hydro power plant and several wind power plants, which were operating under low wind conditions, resulting in reduced reactive power capabilities in the region. Similarly, OST faced limited reactive power support due to low generation from hydroelectric plants. NOSBiH reported that approximately 60 % of the installed generation capacity was in service at the time. Lastly, only one power plant is located within the affected area of CGES, HPP Perucica, with three out of its seven generators in service on the day of the incident.

Table 26 provides a list of available reactive compensation devices located within the HOPS, OST, CGES, and NOSBiH grids.

TSO	Substation	Voltage Level (kV)	Type	Mode	Reactive Power (MVAr)	Status
HOPS	Ernestinovo	110	VSR	Q(U)	–100	In service
HOPS	Mraclin	220	VSR	Q(U)	–100	In service
HOPS	Melina	220	VSR	Q(U)	–200	In service
HOPS	Konjsko	220	SVC	Q(U)	+70/–250	In service
OST	Tirana2	400	MSR	n/a	–120	Disconnected
OST	Tirana2	220	MSR	n/a	–120	Disconnected
OST	Zemblak	400	MSR	n/a	–120	Disconnected
OST	Fier	110	MSC	n/a	+2×25	In service
OST	Lushnje	110	MSC	n/a	+25	In service
Terna[15]	Kotor	400	MSC	n/a	+75	In service
Terna	Kotor	400	MSC	n/a	+75	Not in service as a standalone shunt reactor

Table 26: Reactive power compensation devices located within the area of the affected TSOs

6.2 Short Circuit of 400 kV OHL Podgorica 2 – Ribarevine

At 12:09:16, the differential protection of the 400 kV OHL Podgorica 2 – Ribarevine trips due to a ground fault at span 174–175 caused by a reduction in the distance between the conductors and vegetation.

6.2.1 Weather Conditions During the Months Before the Short Circuit

Weather measurements are not available for the specific location of 400 kV OHL Podgorica 2 – Ribarevine; however, general observations for the months of May and June 2024 in Montenegro indicate that these months were warmer and more rainy than usual. The average temperature in Podgorica was 0.7 °C above the 1981–2020 norm in May, and 2.3 °C above the average in June.

At the same time, the precipitation level in Podgorica was 20 % above average and 176 % above average in May and June 2024, respectively. The conditions during the spring were favourable for faster than usual vegetation growth.

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[15] The Kotor substation is the converting substation for the Monita HVDC link and is owned and operated by Terna; however, the substation is geographically located within the CGES grid. The shunt reactor can be used as a stand-alone shunt reactor when the HVDC link is not in active power transmission.

6.2.2 Vegetation Control

CGES does not have a formal written vegetation control policy or set of guidelines. The existing procedures primarily focus on the frequency of corridor inspections, which are conducted twice a year (in spring and fall), and on reporting the outcomes of these inspections. The reports categorise the results as "no action needed", "action needed", or "action needed with urgency". However, the process between inspections is managed informally, following industry best practices rather than a structured protocol.

While CGES employees conduct optical corridor inspections, vegetation cutting is outsourced to external contractors and requires prior approval from local and/or national forestry authorities. The approval process is often subject to external factors and prioritisation by the relevant forestry authorities. Unlike in some neighbouring countries, Montenegro's forestry regulations do not grant special status to forests within or near overhead line (OHL) corridors. As a result, any intervention in these areas requires the same full authorisation process as any other logging activity.

The last regular inspection of the line was performed in April 2024. According to the inspection results, this span, along with several others, was included in the vegetation control plan for cutting. However, the inspection did not indicate the possibility of an outage due to the reduced distance between the conductor and the detected vegetation, which would have led to either a quick trim of the area or the temporary disconnection of the line. The work of clearing the vegetation under the 400 kV OHL Podgorica 2 – Ribarevine had already begun several days before the incident; however, this span had not yet been cleared. It was scheduled to be completed less than two weeks later.

In general, cutting activities are performed in May and June, so there was no significant deviation from the usual cutting schedule. However, the process faces increasingly complex authorisation procedures that require additional time between the inspection and vegetation-cutting activities.

6.2.3 Loading of the 400 kV OHL Podgorica 2 – Ribarevine

As stated in Chapter 3, the 400 kV OHL Podgorica 2 – Ribarevine was only loaded at 30 % of its rated value. That level of loading has no significant influence on line sag, which confirms that the proximity of vegetation was the primary cause of the line trip.

6.2.4 Design Parameters of the OHL

The 400 kV OHL Podgorica 2 – Ribarevine was designed in 1975 and commissioned in 1982 with the following design condition:

- Maximum environmental temperature of 40°C
- Wind pressure of 75 daN/mm^2

At the time of design, in line with standard procedures, the average solar radiation was not considered as a parameter for the design condition.

6.2.5 Weather Conditions at the Time and Location of the Short Circuit

As stated in Chapter 2.2, the maximum temperature in Podgorica increased to 40°C, with a daily average temperature of 30°C. Due to the specific terrain of the particular span, it is not possible to provide detailed weather data for the location.

The design conditions are used to calculate the maximum permissible current under the worst environmental conditions, which yields the maximum conductor temperature. The maximum line sag is calculated when a line is operated under the maximum conductor temperature. Although the ambient temperature had reached the maximum designated by the design conditions, the loading of the line is the primary factor influencing conductor heating. Thus, it can be concluded that although the temperature was high, the line was still operating under normal conditions.

6.2.6 Definitive Trip of 400 kV OHL Podgorica 2 – Ribarevine

At 12:09:16.213, the 400 kV Podgorica 2 – Ribarevine line tripped due to vegetation proximity. The fault was instantaneously and properly cleared by the line differential protection as a single-phase ground fault in phase 3, which CGES confirms is the nearest to the vegetation due to the asymmetry of the ground profile under the faulted span. The subsequent automatic re-closure failed due to the permanence of the fault.

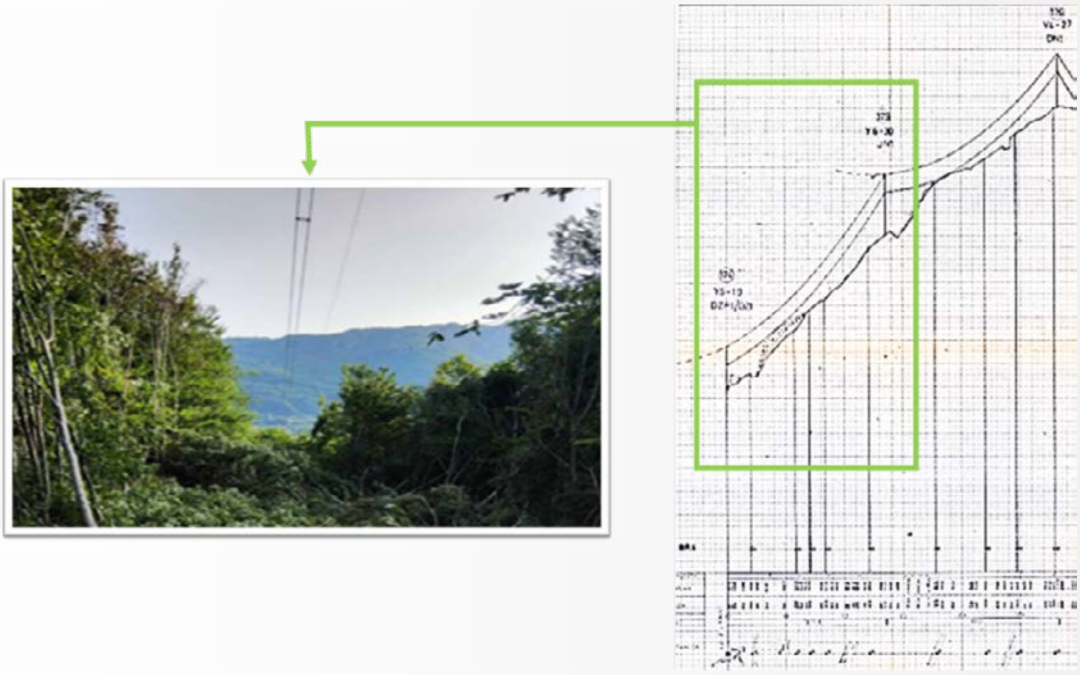

Figure 57: Picture of the area of the short circuit

An inspection of vegetation after the incident showed that several trees were taller than expected; however, only one of them – a tree on the side of the corridor on very steep terrain – caused the outage.

The factual report data confirms that the lack of clearance of the vegetation near the conductors resulted from a combination of these potential factors:

- the underestimation of the distance between the line and the vegetation
- the underestimation of the growth of the vegetation
- the duration of the authorisation procedure to trim the area

6.2.7 Voltage Decrease in the 400 kV Podgorica 2 Substation

The trip of the line causes a voltage dip of 10 kV in Podgorica 2, with a smaller effect on the low sub-transmission level (3 kV).

6.2.8 Reduced Interconnection Between Montenegro South and North

The first trip caused an initial redistribution of the power flows, increasing the import from Greece to Albania/Montenegro and the import to Montenegro from other southern borders.

6.2.9 Root Cause Tree of the Short Circuit of 400 kV OHL Podgorica – Ribarevine

The root cause tree shown in Figure 58 illustrates the causes and effects of the trip of the 400 kV OHL Podgorica – Ribarevine.

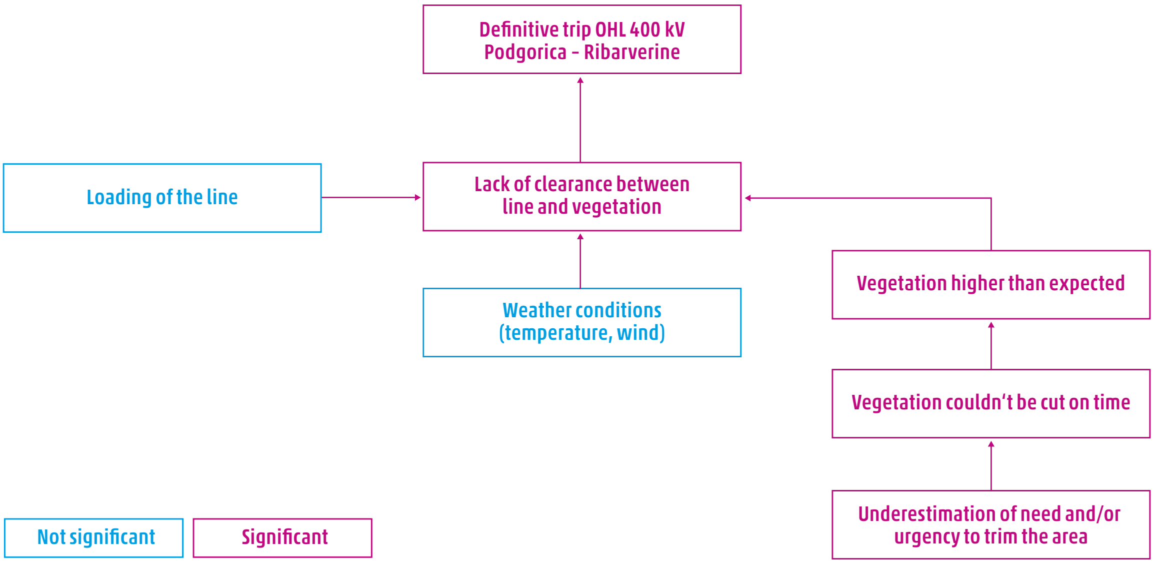

Figure 58: Root cause tree of the short circuit of 400 kV OHL Podgorica - Ribarevine

6.3 Short Circuit of 400 kV TIE Zemblak – Kardia

At 12:21:33:200, 400 kV TIE Zemblak – Kardia tripped with the distance protection due to a ground fault at the line span between pylons 257 and 258 (Albanian Territory) caused by the reduction of the distance between the conductors and vegetation.

6.3.1 Weather Conditions During the Months Before the Short Circuit

Weather measurements available for the nearby Korce region show an average for May 2024 of 15°C and a maximum of 26.6°C, with the maximum value higher than the historical min/max of 9°C/19°C. Precipitation level in this region during May was 5mm per day on average, which is higher compared to the previous three years. The conditions during the spring were favourable for faster than normal vegetation growth.

6.3.2 Vegetation Control

Vegetation control is undertaken in accordance with national legislation with prior notification to the local municipality. The maintenance concept is written in an internal regulation of OST, stipulating that visual checks must be performed at least every 30 days on all OHLs. The clearance distance for 400 kV is 9 m above ground surface for each conductor. If there is vegetation under the overhead line, this vegetation must be at least 5m away from the conductors, considering the potential displacement of the conductor. For 400 kV TIE Zemblak – Kardia, the conditions did not show a low line span; rather, it is assumed that the vegetation locally exceeded the allowed safety distance.

The last inspection, performed during the period of 27 to 31 May 2024, identified the need for vegetation cutting in the near future; however, it was not yet deemed critical. Thus, the cutting of the vegetation was planned between 15 September 2024 and 5 October 2024, when the next maintenance of the OHL was planned. Had the vegetation been deemed critical, the standard procedure would have been to perform an unscheduled clearance as soon as possible.

6.3.3 Design Parameters of the OHL

400 kV TIE Zemblak – Kardia was built in 1985, with the following design parameters:

- Maxmium environmental temperature of 40°C.

During the design, which was according to normal procedure at the time, the average solar radiation was not used as a parameter for the design condition.

6.3.4 Loading of the 400 kV TIE Zemblak – Kardia

This line faced a gradual increase of the maximum load over the first weeks of June, as shown in Figure 1, confirming that the line reached the maximum flow recorded in that period at time of the trip equal to 734 MW (i. e. 0.54 p. u. in the figure). The main reason for the sudden higher loading of the line was the loss of the 400 kV Podgorica 2 – Ribarevine line. This caused additional heating of the line, which explains the slight increase in sagging over the next 10 to 15 minutes.

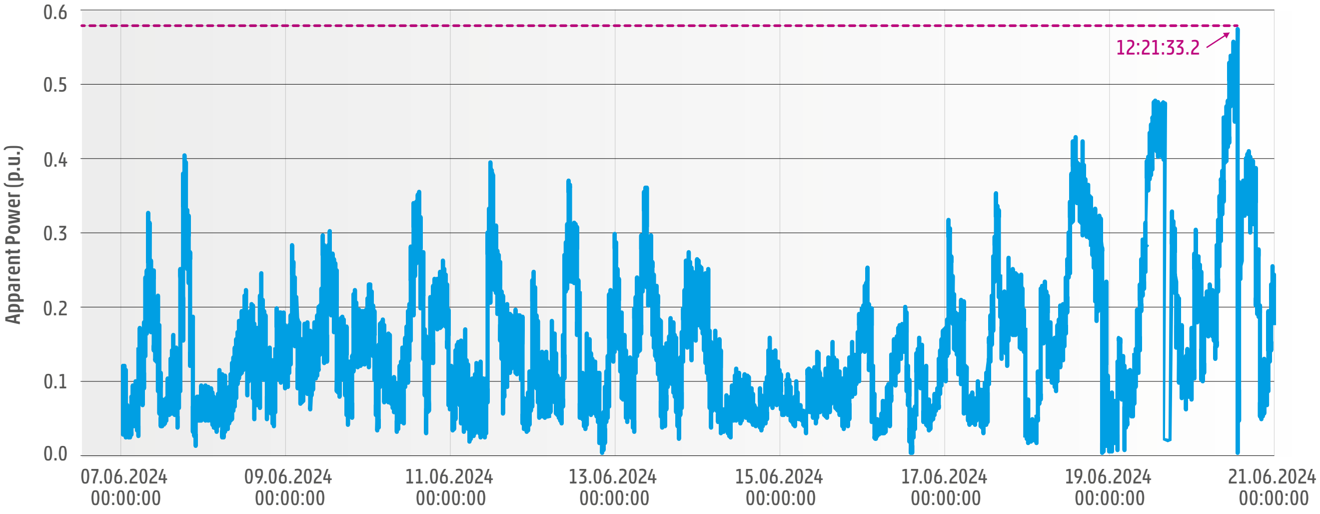

Figure 59: TIE Zemblak - Kardia loading for June 2024

6.3.5 Definitive Trip of 400 kV TIE Zemblak – Kardia

At 12:21:33, 400 kV TIE Zemblak – Kardia tripped due to vegetation proximity. The fault was instantaneously cleared by the distance protection. The subsequent automatic reclosure was not successful. The protection log shows that the short circuit happened in phase B, which is consistent with the finding of the inspection. During the restoration process, the line was successfully put into service at 12:38. Inspection by the maintenance team concluded that vegetation was in close proximity to the line span between pylons 257 and 258. The line was subsequently taken out of service after midnight for vegetation cutting.

Figure 60: Picture of the area of the short circuit

6.3.6 Loss of Interconnection Between Albania and Greece

The trip of 400 kV TIE Zemblak – Kardia caused a complete electrical separation between the Albanian and Greek transmission grids, except for a load that remained connected to Greece via the 150 kV TIE Bistrice – Mourtos.

6.3.7 Root Cause Tree of the Short Circuit of 400 kV OHL Zemblak – Kardia

The root cause tree shown in Figure 61 illustrates the causes and effects of 400 kV TIE Zemblak – Kardia trip.

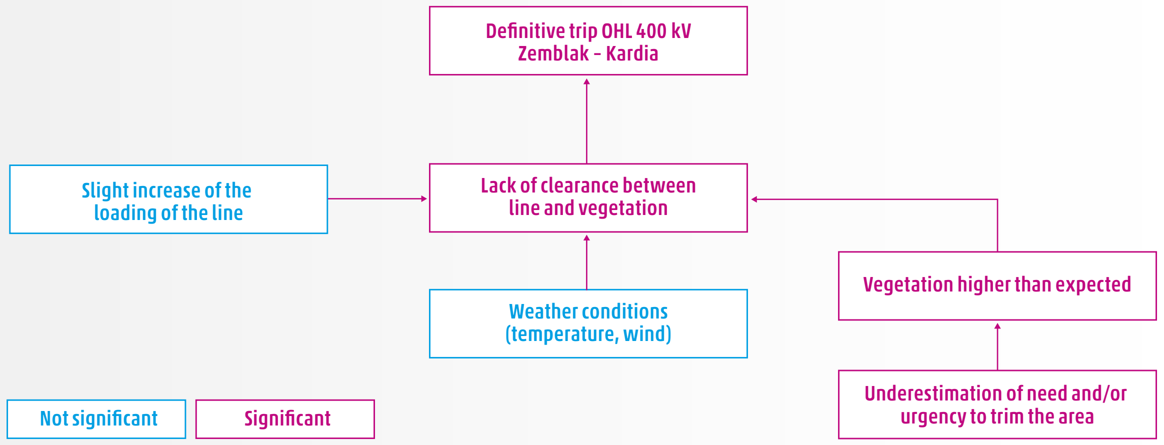

Figure 61: Root cause tree of the short circuit of 400 kV TIE of Zemblak - Kardia

6.4 Disconnection of 220 kV Fierze – Prizren 2, 220 kV Podgorica 1 – Mojkovac and 220 kV Sarajevo 20 – Piva

On 21 June 2024 at 12:21:33, the disconnection of the 400 kV Zemblak – Kardia line triggered a series of cascading events which led to a voltage collapse and blackout in the affected area. The analysis of the sequence of events and the corresponding protection actions are detailed below.

6.4.1 Trip of 220 kV TIE Fierze – Prizren 2

The operational limit used is 720 A, in accordance with the protection's settings and the DACF and IDCF models.

The trip of the 400 kV OHL Zemblak – Kardia activated the overloading protection in the 220 kV Fierze substation (bay Prizren) with a threshold of 720 A (100 % of the operational limit) and a delay of 10 seconds. The flow from Kosovo* to Albania exceeded 720 A, reaching approximately 833 A (116 % of the operational limit), causing the 220 kV TIE Fierze – Prizren 2 to disconnect at 12:21:44.

As detailed in Chapter 5 RCC, disconnecting the 400 kV OHL Podgorica 2 – Ribarevina shows that a trip on 400 k zV TIE Kardia – Zemblak will cause overloads of around 116 % on 220 kV TIE Prizren – Fierza. These outages, along with differences between the merged model and real-time situations, are thoroughly discussed in Chapter 5 of the final report. The results were obtained after applying real-time line statuses to the merged model.

Fierze: Overcurrent protection set at 720 A (100 % of the operational limit) after 10 seconds (bi-directional) to protect the current transformer and at 720 A (100 % of the operational limit) from Albania to Kosovo* after one second.

Prizren 2: Overcurrent protection set at 900 A (125 % of the operational limit) after 3.5 seconds and at 1200 A (167 % of the operational limit) after 1.5 seconds to protect the overhead line.

6.4.2 Trip of 220 kV OHL Podgorica 1 – Mojkovac

The operational limit used is 660 A, in accordance with the protection settings; however, this limit is at 720 A in the DACF and IDCF models. For the following paragraphs, we take 720 A as the operational limit, since it is the value communicated to the RCC.

The trip of the 220 kV TIE Fierze – Prizren 2 activated the overcurrent protection in the 220 kV Podgorica 1 substation (bay Mojkovac) with a threshold of 840 A (117 % of the operational limit) and a delay of 1.7 seconds. The flow exceeded this threshold, leading to the disconnection of the 220 kV Podgorica line at 12:21:45:744.

Podgorica 1: Overloading protection was set at 660 A (92 % of the operational limit) after 20 minutes and at 720 A (100 % of the operational limit) after 20 seconds to protect the overhead line. Overcurrent protection was set at 840 A (117 % of the operational limit) after 1.7 seconds[16] and at 2118 A (294 % of the operational limit) after 0.35 seconds.

Mojkovac: Overcurrent protection was set at 900 A (125 % of the operational limit) after 20 seconds and at 3600 A (500 % of the operational limit) after 0.8 seconds to protect the overhead line.

6.4.3 Trip of Monita HVDC

Analysis shows that the Monita cable acted according to protection settings.

As shown in the subchapter on voltage stability, the system was still stable before and after the disconnection of Monita and the cable had no adverse effect on the voltage level.

6.4.4 Trip of 220 kV TIE Sarajevo 20 – Piva

The operational limit used is 720 A, in accordance with the protection settings; however this limit is at 800 A in the DACF and IDCF models for the Bosnia and Herzegovina side and 790 A for the Montenegro side (the lowest value is always used). For the following paragraphs, we take 790 A as the operational limit, since it is the value communicated to the RCC.

The trip of the 220 kV OHL Podgorica 1 – Mojkovac activated the overcurrent protection in the 220 kV Sarajevo 20 substation (bay Piva) with a threshold of 808 A (102 % of the operational limit) and a delay of 20 seconds. The flow, calculated to be approximately 905 A (115 % of the operational limit), caused the disconnection of the 220 kV TIE Sarajevo 20 – Piva line at 12:22:06. It is important to state that the trip of the DCC 500 kV Monita, which occurred at 12:21:51:446, did not worsen or improve the situation.

Sarajevo 20: Overloading protection was set at 720 A (91 % of the operational limit) after 20 minutes. Overcurrent protection was set at 808 A (102 % of the operational limit) after 20 seconds to protect the overhead line.

Piva: Overloading protection was set at 792 A (99 % of the operational limit) after 20 minutes and at 1032 A (130 % of the operational limit) after 20 seconds to protect the overhead line.

6.4.5 Root Cause Tree of the Tripping of the 220 kV Fierze – Prizren 2, 220 kV Podgorica 1 – Mojkovac, and 220 kV Sarajevo 20 – Piva Lines

The root cause tree shown in Figure 62 illustrates the causes and effects of the disconnection of the 220 kV TIE Fierze – Prizren 2, 220 kV OHL Podgorica 1 – Mojkovac, and 220 kV TIE Sarajevo 20 – Piva lines.

In Montenegro, Albania, and Bosnia and Herzegovina, overloading and overcurrent protection serve as a secondary defence (tripping after 20 minutes) to distance protection or in specific situations like current transformer limits or sensitive areas near the line. The factual report confirmed that all three lines' protections functioned correctly.

However, due to the several reasons mentioned (protection of material or unharmonised values), the three lines had protections settings with a threshold at around 100 % (some of them even lower) of the operational limit after 10–20 seconds. This led to an avoidable cascading trip of the three lines and prevented the dispatchers from taking remedial actions.

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[16] The overcurrent relay on the Podgorica side of the 220 kV OHL Podgorica 1 – Mojkovac activates at precisely 1.7 seconds. The main overcurrent relay is set to 1.5 seconds, while the backup overcurrent relay, which operates when distance protection is active, is set to 1.7 seconds.

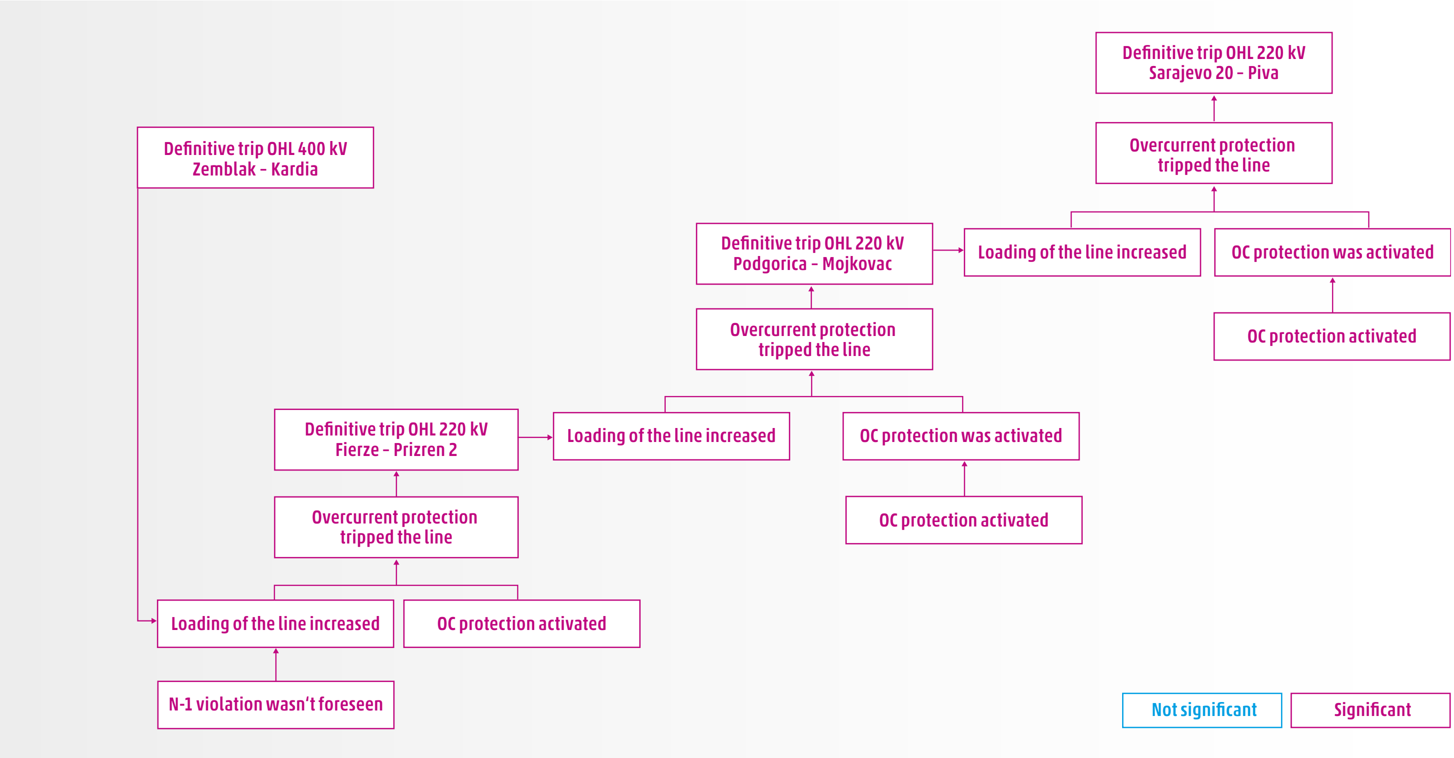

Figure 62: Root cause tree of the tripping of 220 kV Fierze – Prizren 2, 220 kV Podgorica 1 – Mojkovac, and 220 kV TIE Sarajevo 20 – Piva

6.5 Voltage Stability During the Incident

On 21 June 2024, the sequence of the two initial events in combination with the system state led to voltage instability. Main factors contributing to the voltage instability and collapse were:

- Prior system conditions:
  - High level of import into the area contributing to a voltage decrease over the area
  - Lack of sufficient sources of voltage support, also due to a limited amount of synchronous generation connected to the grid in the area
- Disconnection of all 400 kV lines between the area going into blackout and the rest of Europe except for a few lines in Croatia, meaning that the grid was weakly connected from the North-West

A few minutes later, due to the subsequent sequence of events, the system experienced a voltage collapse.

6.5.1 Theoretical Background

Voltage stability is defined as the ability of a power system to withstand disturbances while still ensuring acceptable voltage level at all buses in the system. The main reason for voltage instability is the inability of the power system to fulfil reactive power demands.

Voltage stability is best explained by the so-called nose curve, where the relation between voltage is plotted over transferred power across a line.

Let us consider a two-bus system, where a load is supplied by a constant voltage source E_s through a transmission line. Under a constant power factor, the voltage at the load terminals, V_r, is a function of the active power delivered to the electrical load, P_r. Figure 63 shows the power–voltage curve, normalised for the maximum transmittable power, P_{rmax} ,and the voltage source,E_s.

When we start following the voltage–power curve when the voltage is high ($V_r / E_s \approx 1$) and power is low ($P_r / P_{rmax} \approx 0$), it is possible to increase the power transmitted by reducing the load impedance. When the power transferred hits the maximum (here in Figure 63: $P_r / P_{rmax} = 1$, $V_r / E_s = 0.6$), it is referred to as the critical operating condition, or bifurcation point, and the corresponding voltage is the critical voltage. Any attempt to increase the power transmitted by reducing the load impedance after the critical operating point will be met with a lower voltage and less power transmitted. When the voltage reaches the critical voltage, the system experiences voltage instability.

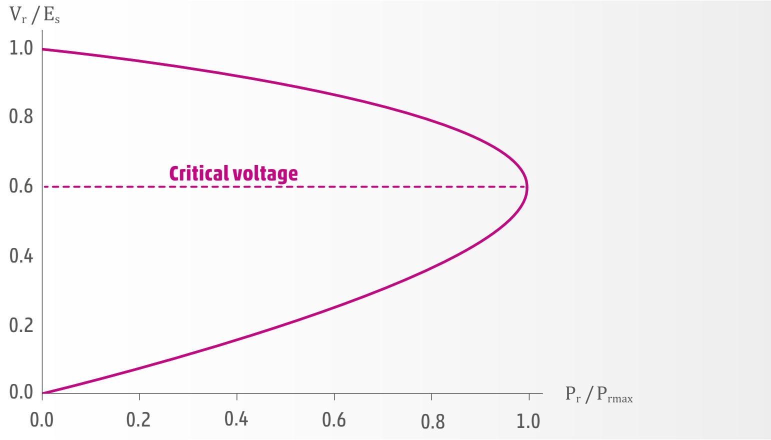

Figure 63: Explanatory figure of the power voltage curve [17]

6.5.2 Behaviour of ULTC During Low Voltages

When a load is supplied by a transformer with an automatic under-load tap changing (ULTC) transformer during low voltages, the transformer will attempt to raise the load voltage. However, this leads to an increase in the load consumption due to the ohmic behaviour. This can ultimately increase the reactive power demand of the transmission grid, causing further voltage decline and creating a vicious cycle until all transformers' tap positions have been used. Several substations in the CGES, HOPS, and NOSBiH grids were equipped with transformers with ULTC capability.

6.5.3 Effect of High Penetration of Air Conditioning Load During Low Voltages

The load during the day was characterised by a dominant presence of air conditioning devices operated by asynchronous machines. These motors reduce electrical torque as the square of voltage, so that during the voltage depression, motor torque decreases and current, trying to compensate the lack of torque, increases until the motor stalls.

6.5.4 Effect of LCC HVDC Cables During Low Voltages

The HVDC link between Montenegro and Italy, often referred to as the Monita link, is equipped with LCC (line-commutated converter) technology that cannot provide voltage support or control. The reactive power consumption of an LCC HVDC is dependent on voltage and active power flow. In contrast to a VSC HVDC, no dynamic voltage support can be expected from LCC technology.

6.5.5 Effect of OHL During Voltage Collapse

OHLs, which have low active power flowing through them, generate reactive power, which in turn increases voltages. When a line tripping occurs, the power flow on other lines increases, which in turn reduces the reactive power produced by the lines. When the active power reaches the surge impedance loading (SIL) of an OHL, the OHL starts consuming reactive power instead of producing it, resulting in even lower voltages. This was the case for many OHLs during the incident.

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[17] [1] Kundur, P. S., & Malik, O. (2022). Power system stability and control, second edition (2nd ed.). McGraw Hill Education.

6.5.6 Evolution of the Voltage Collapse

In Figure 64, Events 1 to 7 from Table 1 in Chapter 3 are marked with a dashed line. The Phasor Measurement Unit (PMU) recordings illustrate how the voltage collapse occurred. All bays shown are 400 kV, with the exception of 220 kV Sarajevo 20.

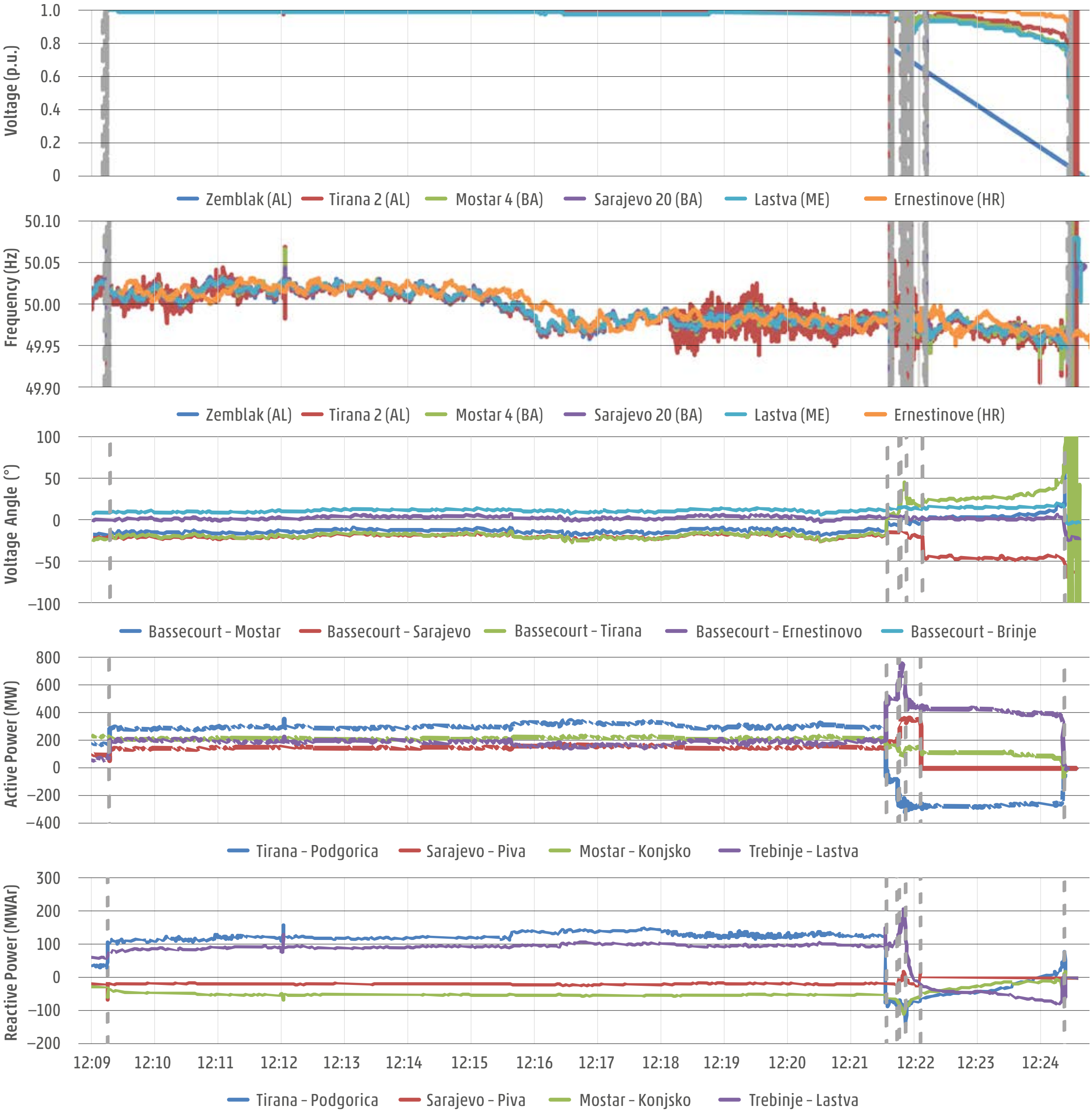


Figure 64: Frequencies, voltages, voltage phase angle differences (reference angle is Bassecourt [CH]), active power, and reactive power

The events from 12:09:16:33 to 12:24:28 can be categorised into four stages, which are further analysed below:

a. Slow voltage decrease between Events 1 and 2 (12:09:16 to 12:21:32)

b. Voltage instability from 12:21:33 to 12:22:06 (Events 2 – 6)

c. Automatic tapping of ULTC transformers from 12:22:06 to 12:24:10

d. Voltage collapse from 12:24:10

6.5.6.1 Automatic Tapping of ULTC from 12:09:16 to 12:21:33

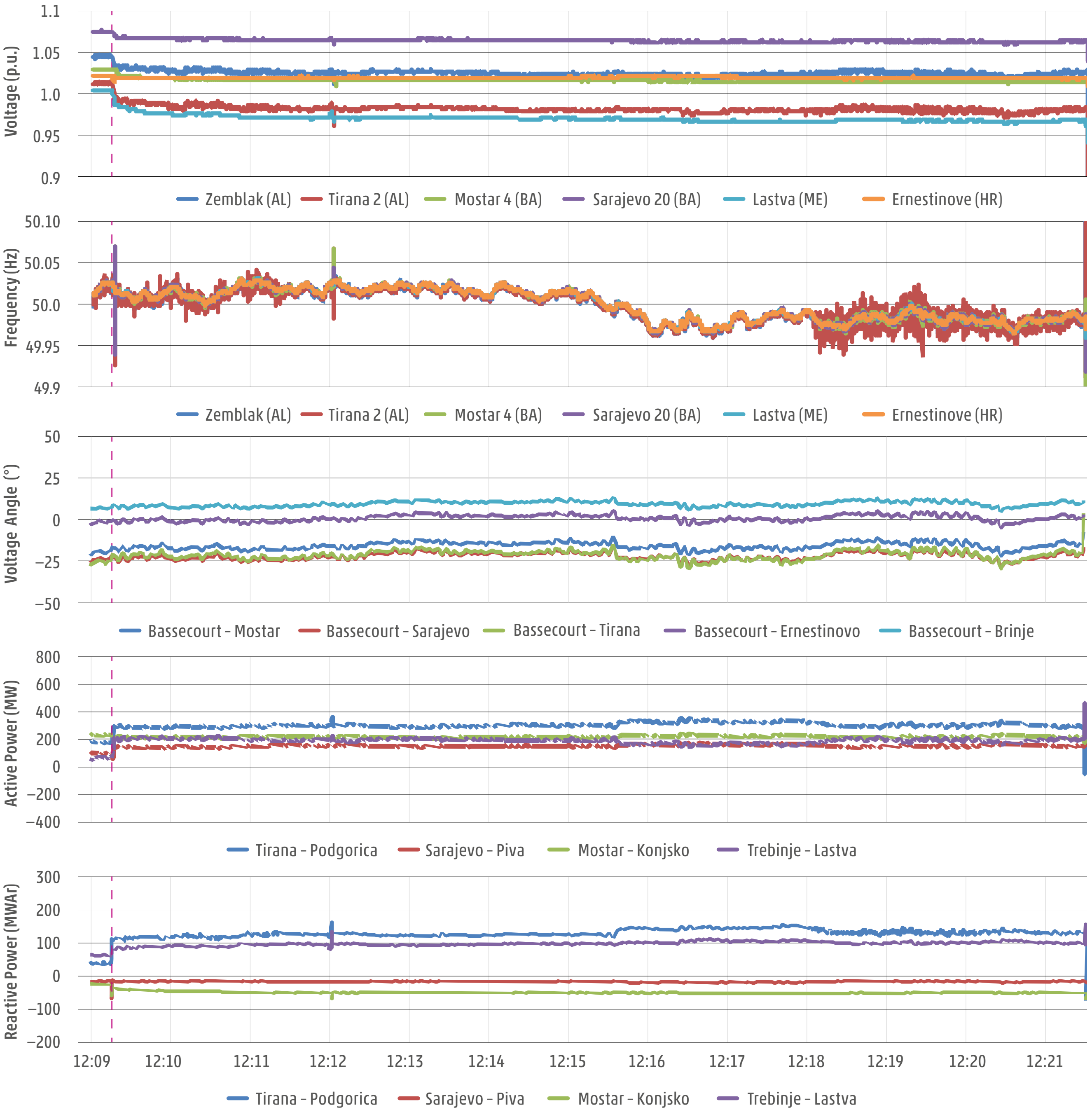


Figure 65: Frequencies, voltages, voltage phase angle differences, active power, and reactive power for 12:09:16 to 12:21:33

In Event 1, the trip of the 400 kV OHL Podgorica 2 – Ribarevine resulted in a voltage drop of up to 5 kV within a second, experienced most predominantly in Montenegro.

- Within a few seconds after the trip of the 400 kV OHL Podgorica 2 – Ribarevine, the transformers' automatic tap changers started to tap, resulting in a further decline in voltage until the voltage stabilised at approximately 14 kV lower than the pre-disturbance level.
- In Tirana at 12:18:06, a local frequency mode of the OST hydropower plant units from the Drin River cascade (Fierze, Koman, Vau Dejes) was excited. The oscillation was still present, although dampened, at the time of the tripping of 400 kV TIE Zemblak – Kardia.

6.5.6.2 Voltage Instability from 12:21:33 to 12:22:06

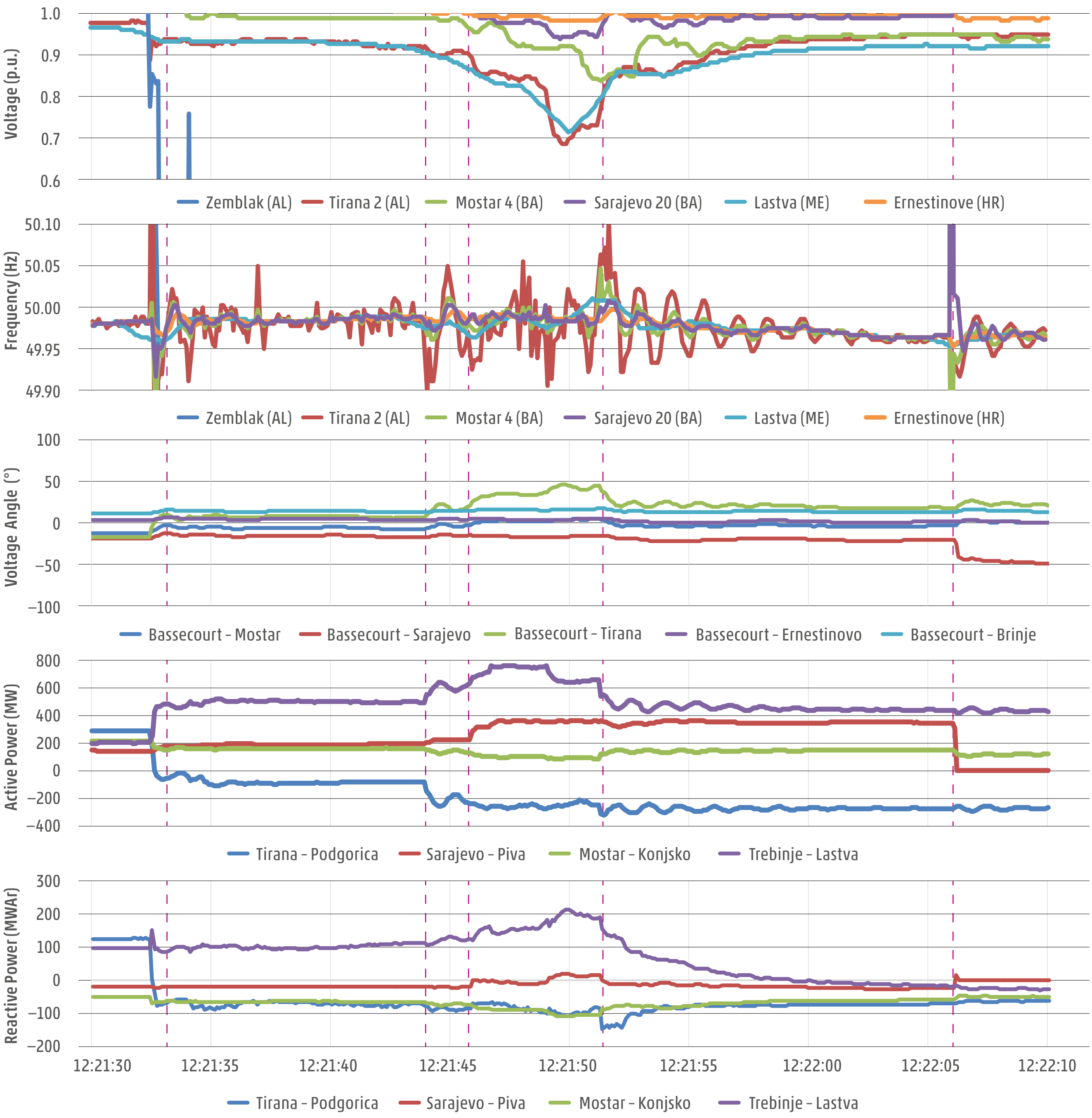


Figure 66: Frequencies, voltages, voltage phase angle differences, active power, and reactive power for 12:21:33 to 12:22:06

As mentioned earlier, Event 2, the tripping of 400 kV Zemblak (OST) – Kardia (IPTO), occurred due to a tripping of distance protection, resulting in the overloading of other grid elements. This subsequently led to Event 3, the third tripping of 220 kV Fierze (OST) – Prizren 2 (KOSTT), and Event 4, the tripping of 220 kV Podgorica 1 (CGES) – Mojkovac (CGES). The combination of these trippings led to a severe voltage drop, with a remaining voltage of 0.68 p.u./272 kV in Tirana 2 (AL).

» From the voltage profile, it can be seen that after Events 2–4, the voltage was unstable. Further explanation of the point of instability can be found in Chapter 6.5.10.

» From the frequency measurements, it can be seen that a local frequency mode of the OST hydropower plant units from the Drin River cascade (Fierza, Komani, Vau Dej) was excited, which was damped within a few cycles.

- Event 5, the tripping of the Monita HVDC line, occurred due to minimum voltage logic – 0.8 pu corresponding to 400 kVdc after a delay of two seconds according to the FRT requirement – reaching limit conditions to control the converter bridge. As explained in Section 1.4.4, the voltage drop after the second outage led to increased reactive power consumption of the LCC technology of the HVDC Monita link. Additionally, the HVDC link was in export of active power and the converter was consuming reactive power; thus, the disconnection of the HVDC link had the same effect as load shedding. The voltage appeared to recover locally; however, some transmission nodes remained below 370 kV, and the trip of the HVDC line did not alter the transient voltage phenomenon.
- Event 6, the tripping of the TIE-line 220 kV Sarajevo 20 (NOSBiH) – Piva (CGES), was a one-sided trip in Sarajevo 20. The PMU measurement device in Sarajevo 20 is situated on the bay after the circuit breaker. After the trip, the Sarajevo 20 measurement did not depict the situation in Sarajevo 20, but rather the situation on the other side of an open line from Piva.
- At 12:21:48 – 12:21:51, hydropower plants in HOPS and NOSBiH regions tripped, causing a loss of approximately 290 MVAr in reactive power capability, further aggravating the already tense situation.
- After each outage, the equivalent impedance between the main grid and the blackout area increases, leading to further voltage degradation.

6.5.6.3 Automatic Tapping of ULTC from 12:22:06 to 12:24:10

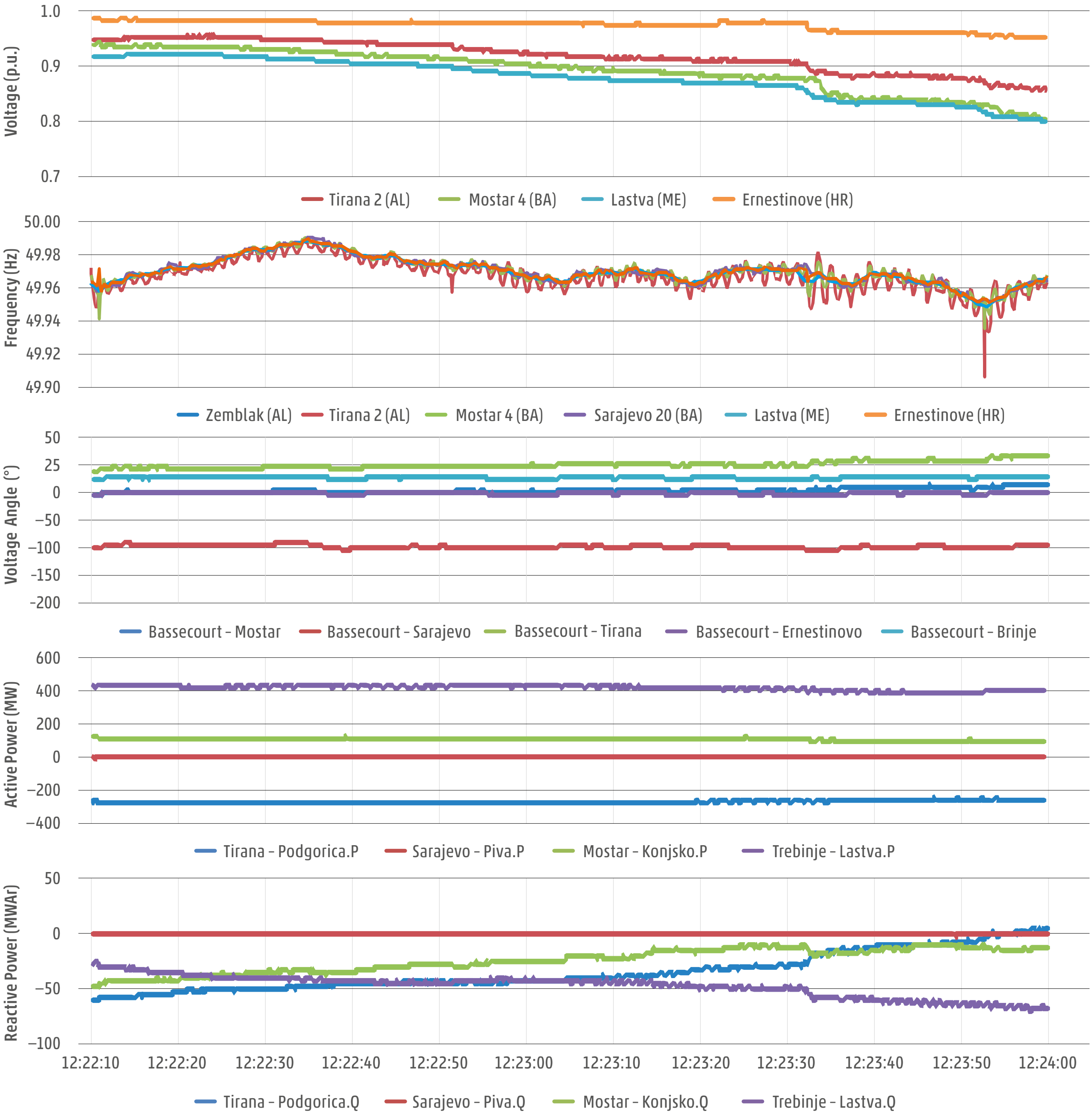


Figure 67: Figure 5: Frequencies, voltages, voltage phase angle differences, active power, and reactive power for 12:22:06 to 12:24:10

- This period can be characterised by slow voltage decay, as the transformers in 110/x kV substations, which are equipped with ULTC, attempted to raise the voltages at the lower voltage level. However, this caused a reduction in the impedance of the system, leading to a further voltage drop on the high voltage side.
- At 12:23:33, low voltages led to the disconnection of an additional generator in the NOSBiH grid, resulting in a loss of 124 MVAr in reactive power capability.
- A local frequency oscillation was excited, which can be seen most predominantly in Tirana and Trebinje based on the nearby hydropower plant units.

6.5.6.4 Voltage Collapse 12:24:10 –

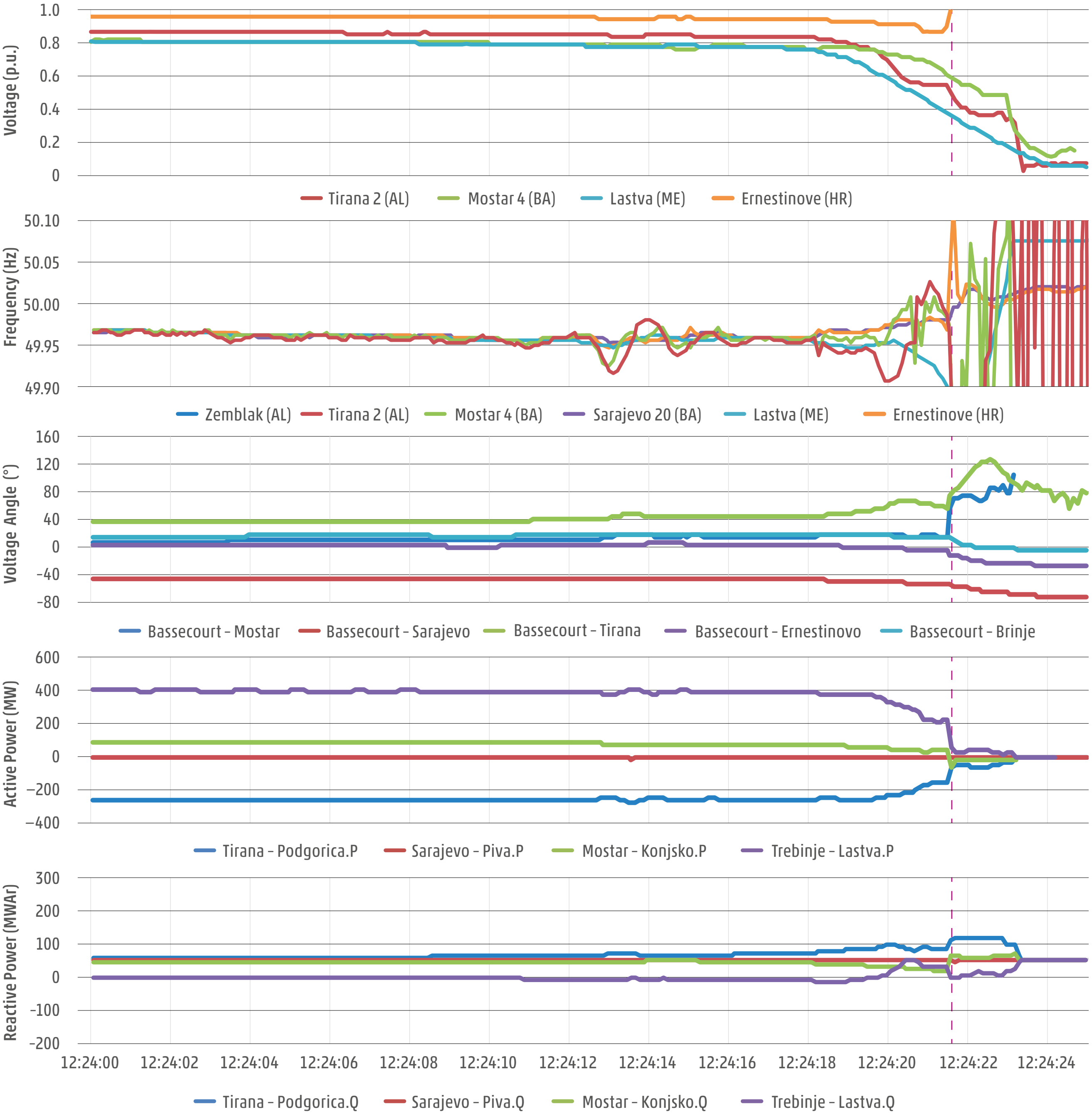


Figure 68: Figure 7: Frequencies, voltages, voltage phase angle differences, active power, and reactive power for 12:24:10 –

- At 12:24:10, the hydropower plant in Jablanica in the NOSBiH grid was disconnected due to under-voltage protection, resulting in the loss of approximately 117 MVAr in reactive power capability. This marks the knee point of the final rapid voltage decay, where the remaining reactive power in the system can no longer maintain balance.
- At 12:24:19, the thermal power plant in Tuzla in the NOSBiH grid was disconnected, resulting in the loss of approximately 124 MVAr in reactive power capability.
- An important element in rapid voltage decay is the effect of the high reactive power demand for all induction-machine-driven loads due to the stalling of those devices.
- Subsequently, each line tripped in succession, leading to a total load of **3.5 GW** being de-energised by the blackout in the affected areas.

6.5.7 Automatic Tapping of the ULTC of Transformers

6.5.7.1 HOPS

The behaviour of automatic tapping in transformers equipped with ULTC functionality in the HOPS grid can be seen in Figure 69 to Figure 71. For readability purposes, transformers that had no reaction were not shown, as it can be concluded that those transformers were far away from the affected area. In the HOPS grid, most transformers did not react to the initial five events by adjusting their tap position. Those that did react changed their tap position by only one or two positions. After Event 6, the trip of 220 kV Sarajevo – Piva, the transformers started to change their tap positions significantly.

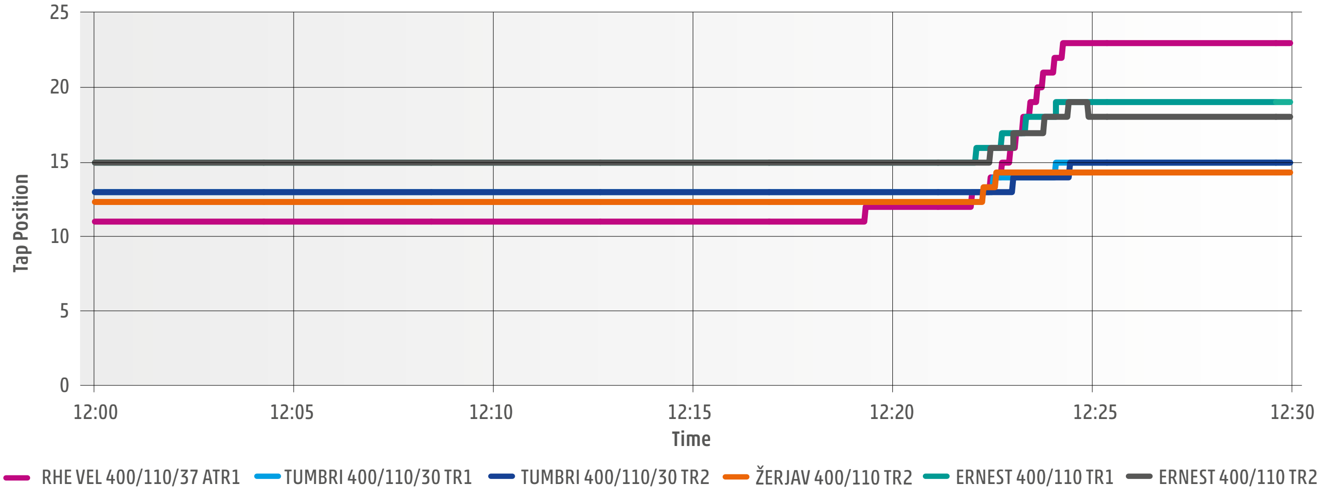


Figure 69: Tap positions of 400/110 kV transformers in the HOPS grid with ULTC

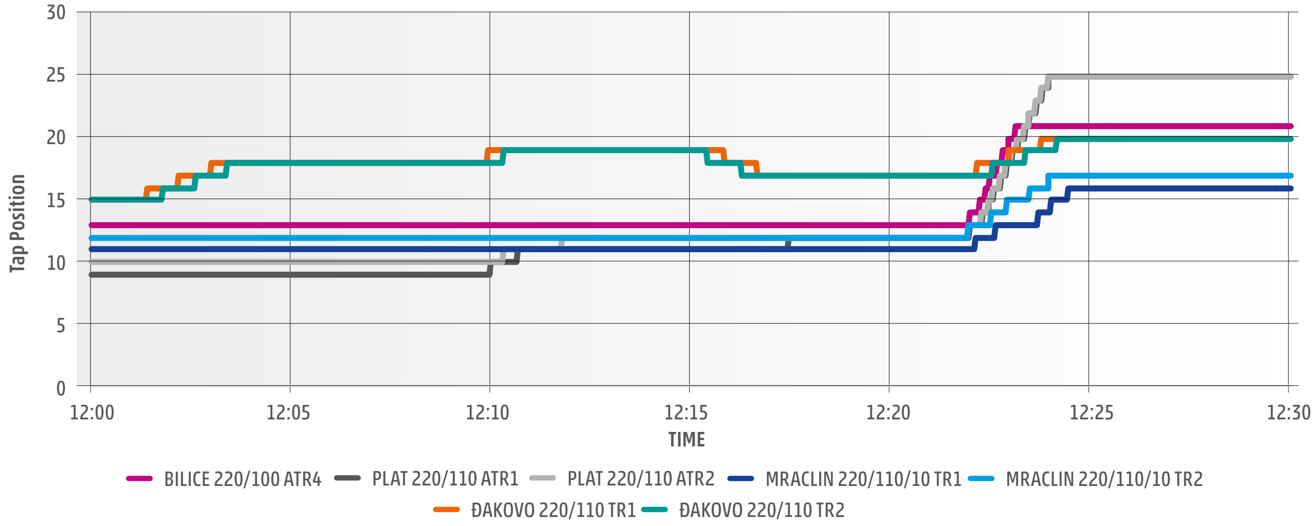


Figure 70: Tap positions of 220/110 kV transformers in the HOPS grid with ULTC

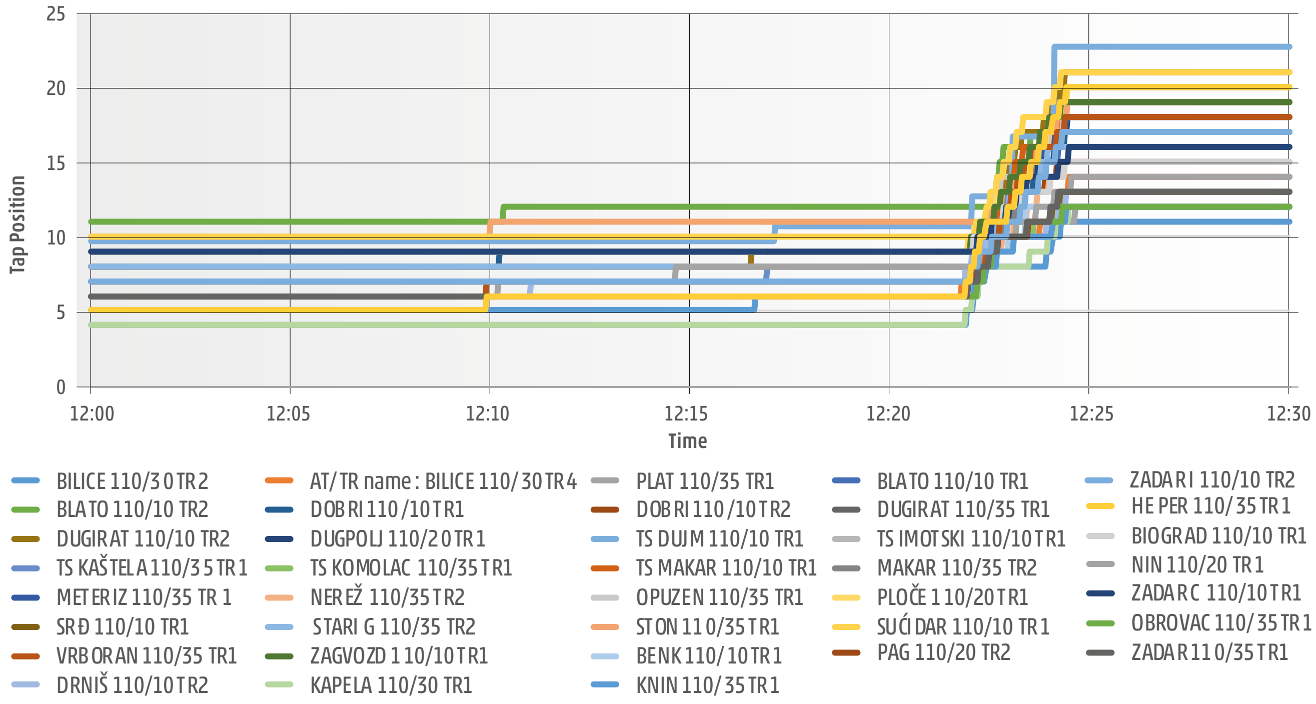


Figure 71: Tap positions of 110/X kV transformers in the HOPS grid with ULTC

6.5.7.2 CGES

The automatic tapping of the ULTCs in the CGES grid can be seen in Figure 72. Due to the numerous transformers equipped with ULTC, not all transformers are shown to improve readability. The figure shows that the two phases of the tap position changes are after the initial fault and then again after the cascade of disconnections (starting after Event 4 and onwards), with the last tap position changes happening immediately before the knee point of rapid voltage decay.

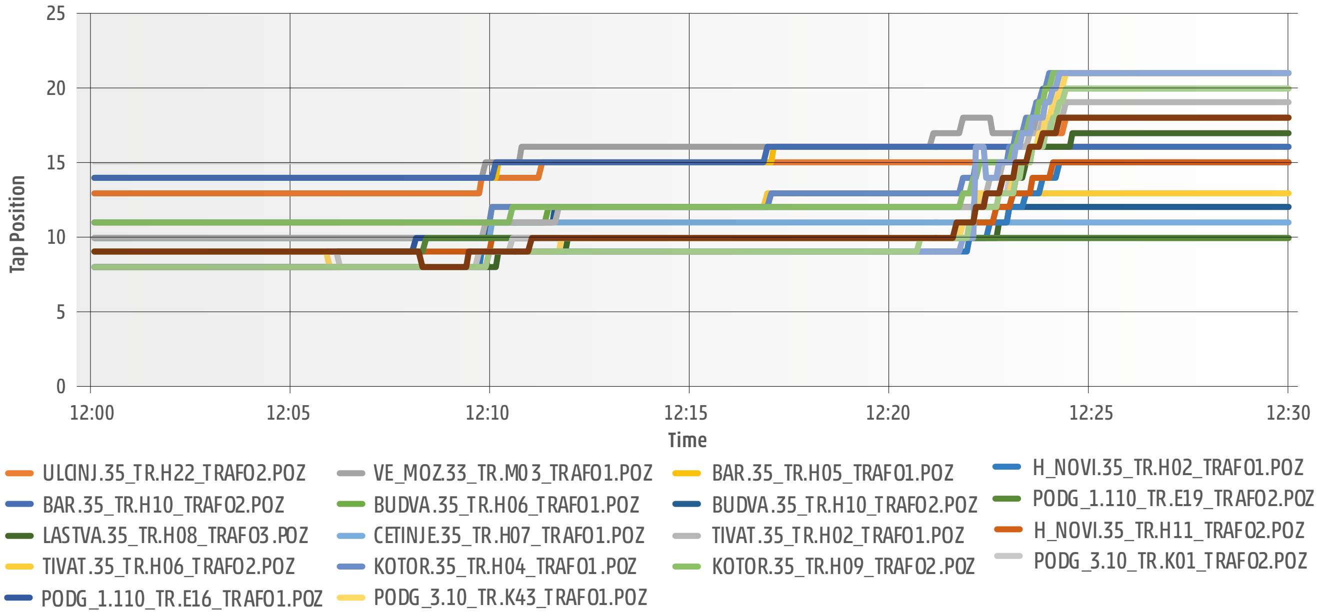


Figure 72: Tap positions of 110/X kV transformers in the CGES grid with ULTC

6.5.7.3 NOSBiH

The automatic tapping of the ULTCs in the NOSBiH grid can be seen in Figure 73 and Figure 74. The transformers reacted to the first event by tapping the transformer by one tap position. After Event 6, the trip of 220 kV Sarajevo – Piva, the transformers started changing their tap positions significantly, with the last tap position changes happening immediately before the knee point of rapid voltage decay.

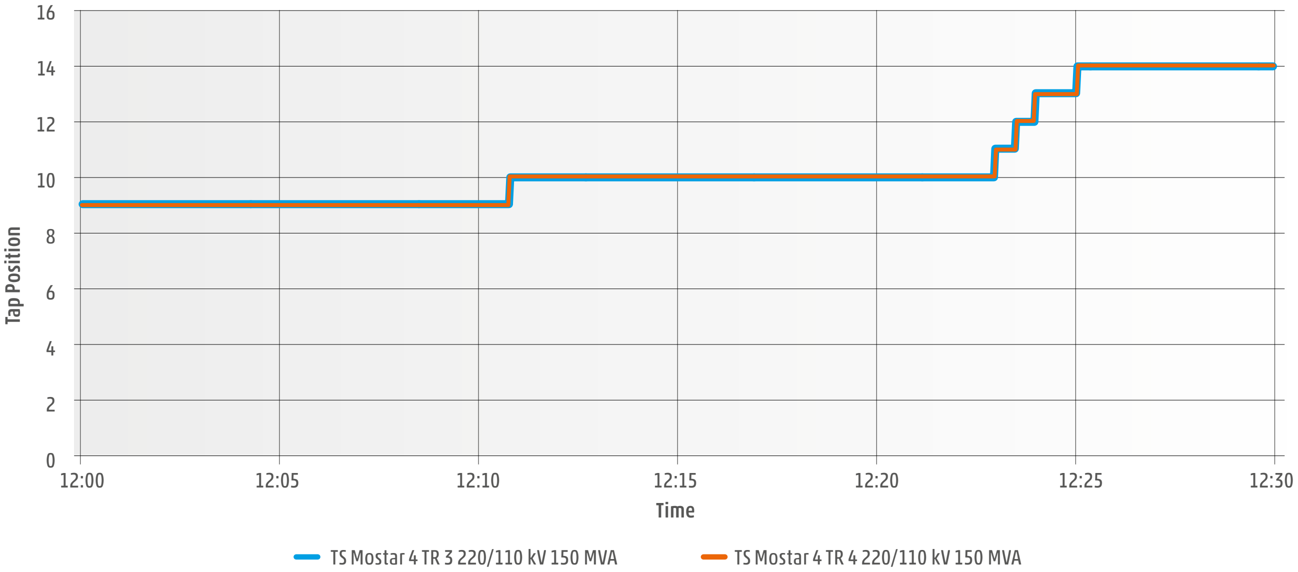


Figure 73: Tap position of 220/110 kV transformers in the NOSBiH grid with ULTC

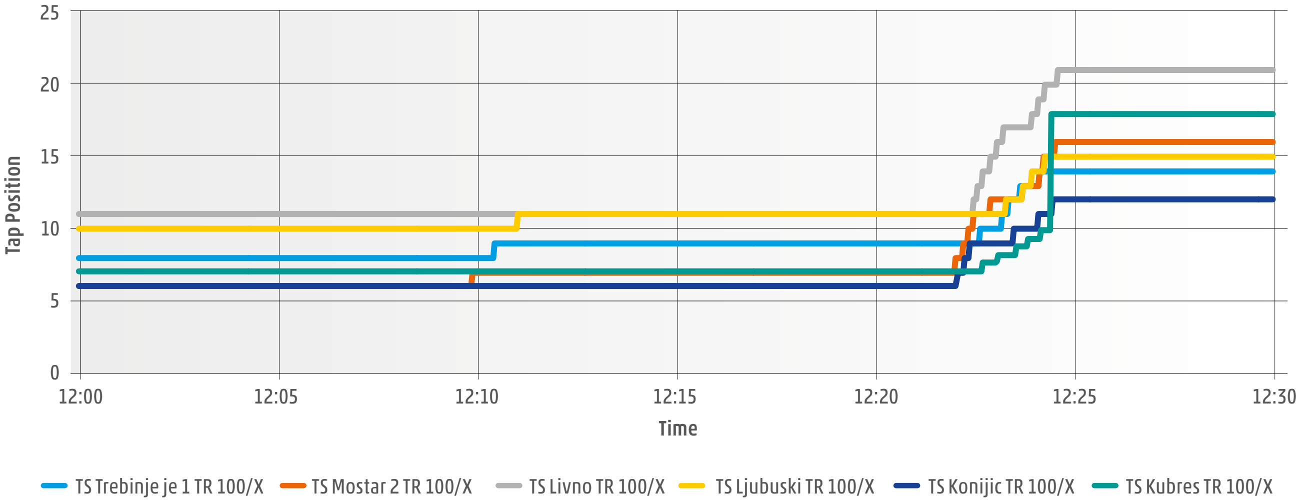


Figure 74: Tap positions of 110/x kV transformers in the NOSBiH grid with ULTC

6.5.8 Reactive Power Support of Generators During the Incident

Figure 75 to Figure 78 show the reactive power output of four generators that disconnected before the knee point of the voltage collapse and their respective reactive power limits. Generator 2 of HPP Dubrovnik (Figure 75), HPP Jablanica (Figure 76), and generator 4 of TPP Tuzla (Figure 78) reached their reactive power limit right before the disconnection due to under-voltage protection. HPP Trebinje (Figure 77) tripped due to under-voltage protection, although the reactive power limits had not yet been fully reached. Here it can be concluded that the control loop of the automatic voltage regulator (AVR) did not have sufficient time to utilise the reactive power limit before the generator's under-voltage protection tripped. Similarly, generator 5 of TPP Tuzla (Figure 78) tripped due to under-voltage protection, although the reactive power limit had not yet been fully reached. However, the reactive power output was still close to its limit when the generator tripped. We can conclude that the lack of additional reactive power reserves needed to balance the affected area led to the subsequent voltage collapse for the corresponding area.

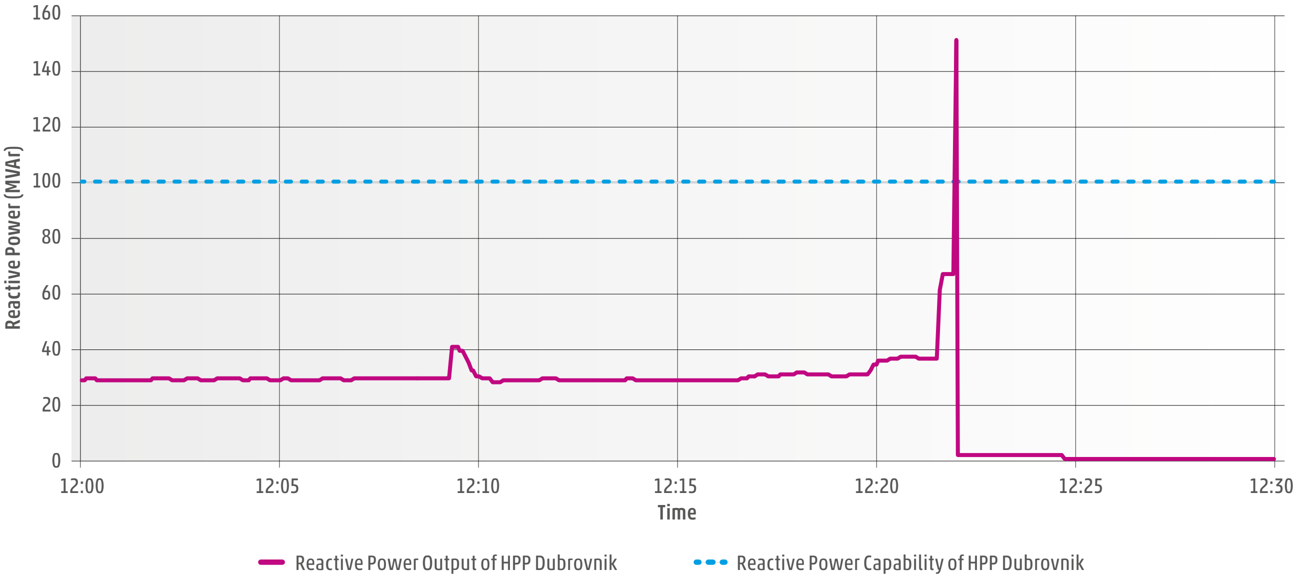


Figure 75: Reactive power output of generator 2 of HPP Dubrovnik

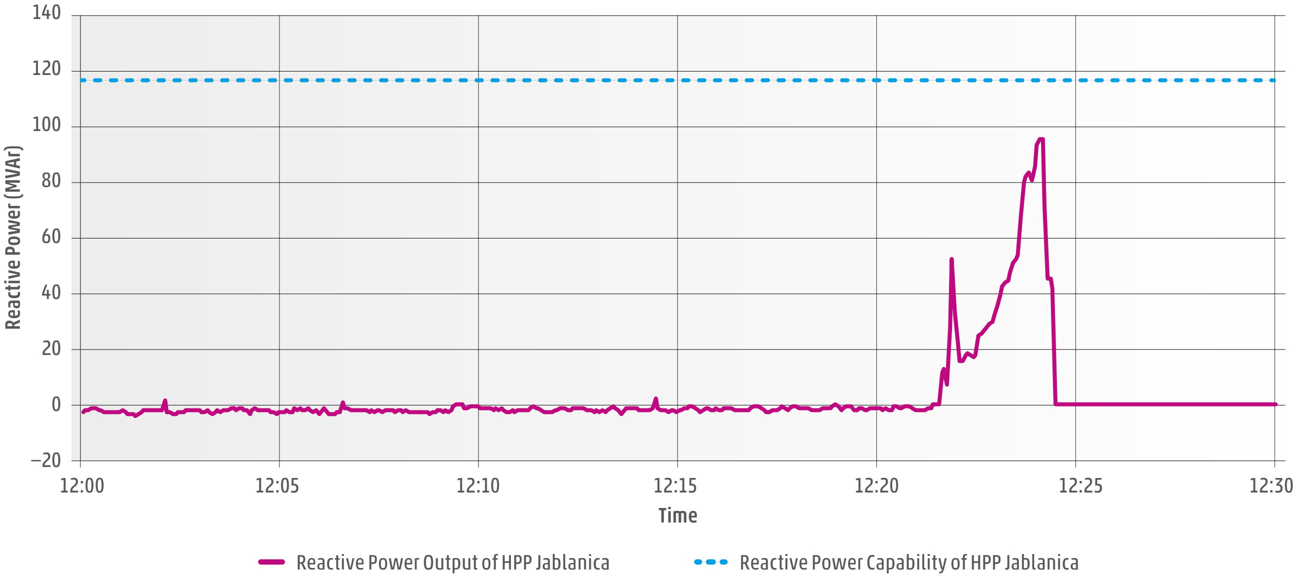


Figure 76: Reactive power output of HPP Jablanica

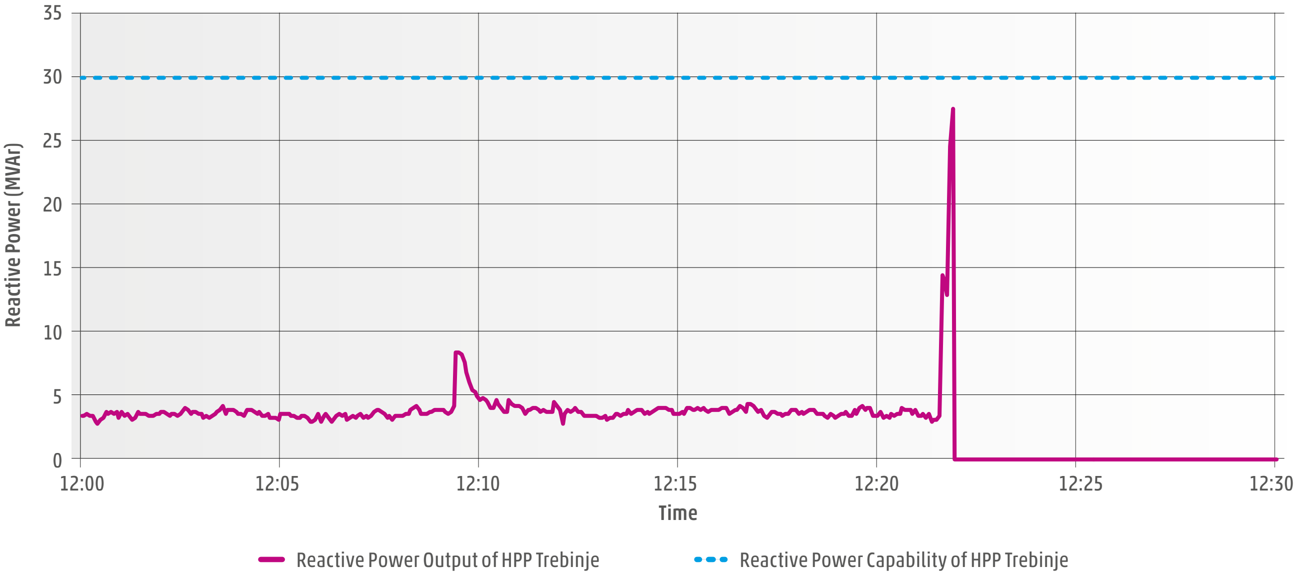


Figure 77: Reactive power output of HPP Trebinje

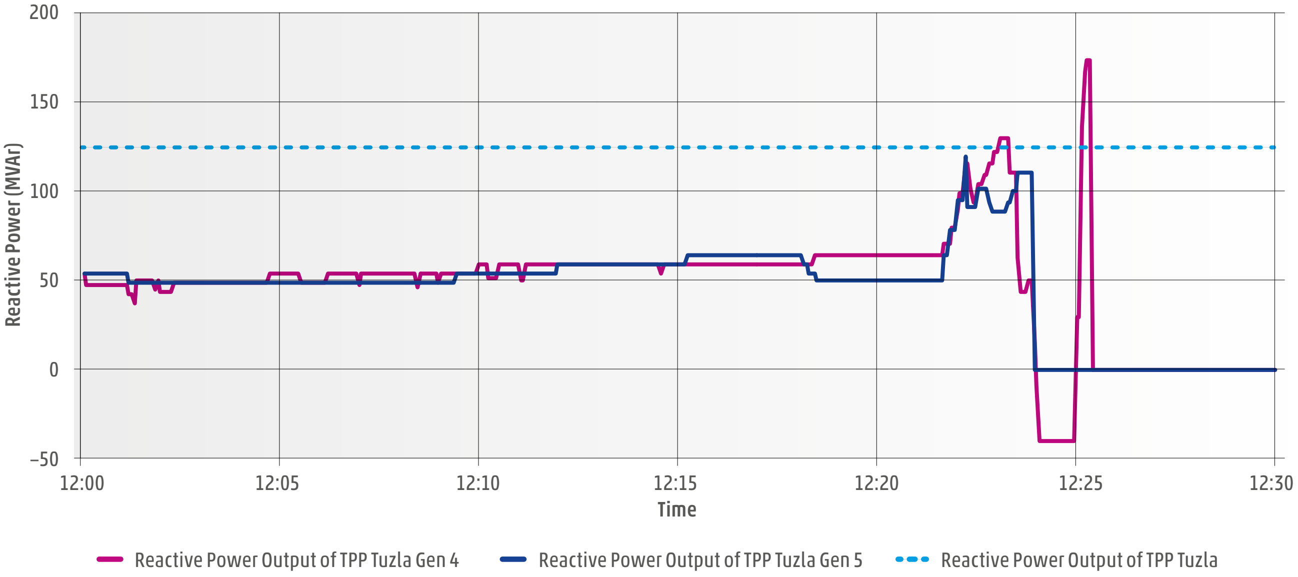


Figure 78: Reactive power output of generators Tuzla 4 and 5 of TPP

6.5.9 Reactive Power Compensation Devices During the Incident

6.5.9.1 HOPS

In the HOPS grid, four reactive power compensation devices were active during the incident. Three were variable shunt reactors (VSR) and one was a static var compensator (SVC). The reactive power output of compensation devices can be seen in Figure 18. Until 12:23:22, when the VSR in Ernestinovo tripped due to under-voltage protection, the net consumption of reactive power from compensation devices was approximately 110 MVAr. When the VSR in Ernestinovo tripped, the voltage was 390 kV. All VSRs in the HOPS grid were outside the affected area

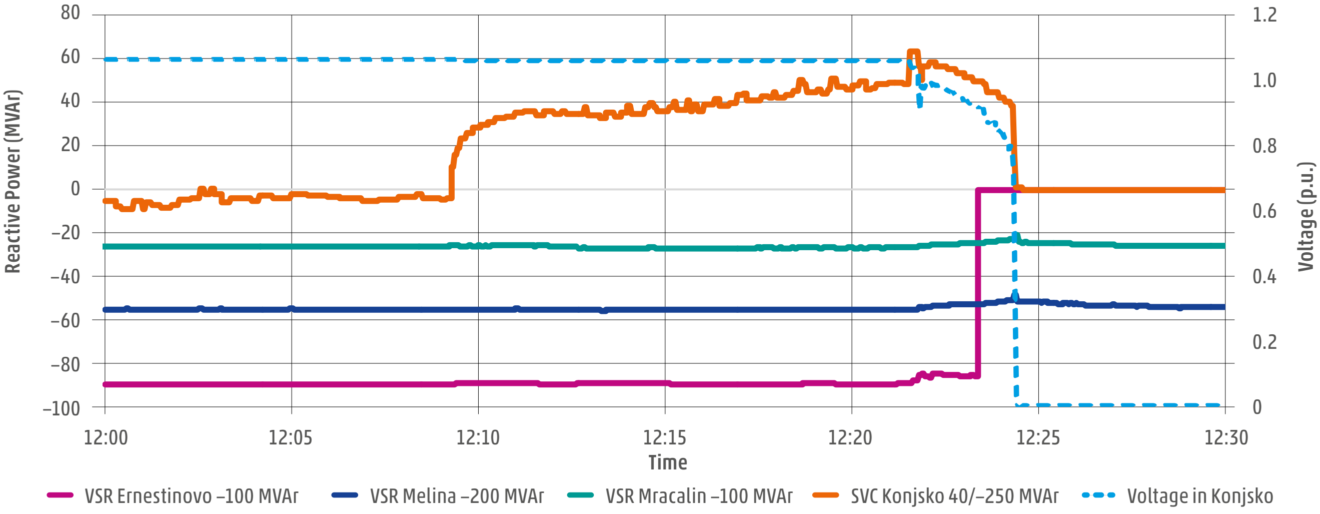


Figure 79: Reactive power output of compensation devices in the HOPS grid

6.5.9.2 CGES

There are no reactive power compensation devices in the CGES grid. However, the converter substation for the Monita cable in Kotor, Montenegro (albeit operated by Terna), is equipped with two shunt reactors, one per pole of the Monita cable, which are dedicated to the converter and managed by the HVDC control system to properly operate the HVDC cable (see the single line diagram in Chapter 3.4.1.3). When the HVDC cable is not in active power transmission, the shunt reactor can be used as a stand-alone shunt reactor. Terna has control of the substation; however, switching actions are undertaken at the request of CGES.

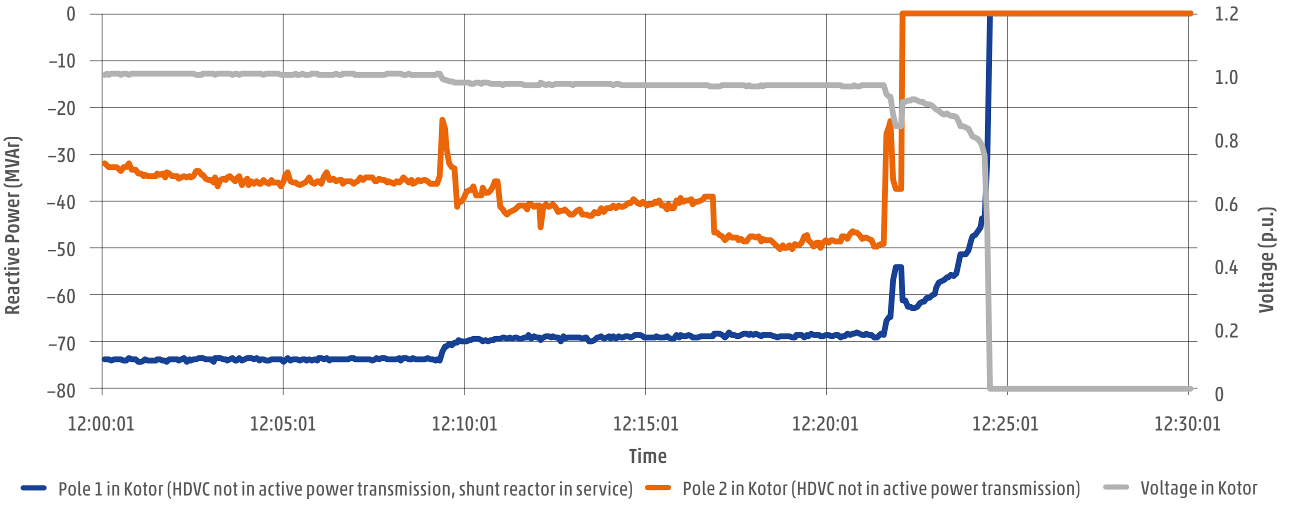


Figure 80: Reactive Power Outputpower output of the AC lines in Kotor (geographically located within the CGES grid of CGES, howeverbut owned and operated by Terna)

6.5.9.3 NOSBiH

There are no reactive power compensation devices in the NOSBiH grid.

6.5.9.4 OST

In the OST grid, three shunt capacitors were active during the Incident: two 25 MVAr in 110 kV Fier and 25 MVAr in 110 kV Lushnje. The reactive power output of the compensation devices can be seen in Figure 81.

At 12:21:48, the shunt capacitors in Fier disconnected due to under-voltage protection, resulting in a loss of 50 MVAr in reactive power capability.

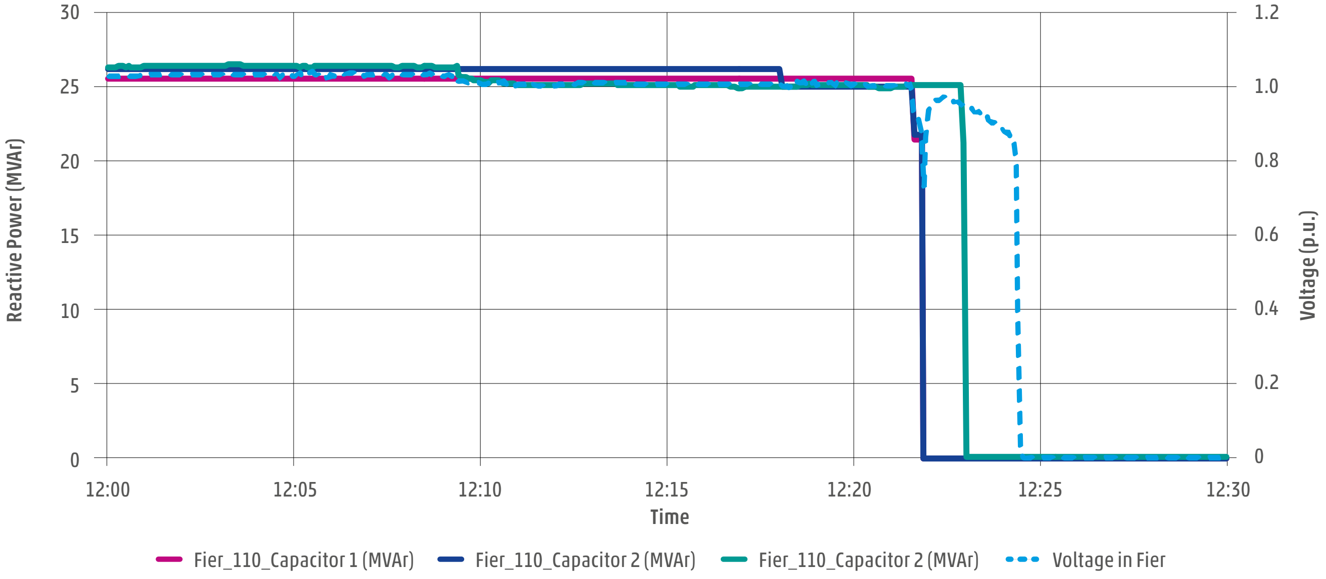


Figure 81: Reactive power output of compensation devices in the OST grid

6.5.10 Voltage Stability Margin

Figure 82 to Figure 84 show the voltage stability margins for the 400 kV Tirana 2 – Podgorica 2, 400 kV Trebinje – Lastva, and 400 kV Mostar 4 – Konjsko lines, where the time is represented by the colour bar. The measurements come from PMU, where the top plot illustrates voltage versus power. Events 2 to 6 are listed the moment before they happen.

Figure 82 shows that the voltage becomes unstable after Event 4 and before Event 5. The system manages to recover slightly after Event 5; however, the system is operating very close to the tip of the nose curve. This operating point is defined as voltage unstable since any increase in the load will ultimately result in a voltage collapse.

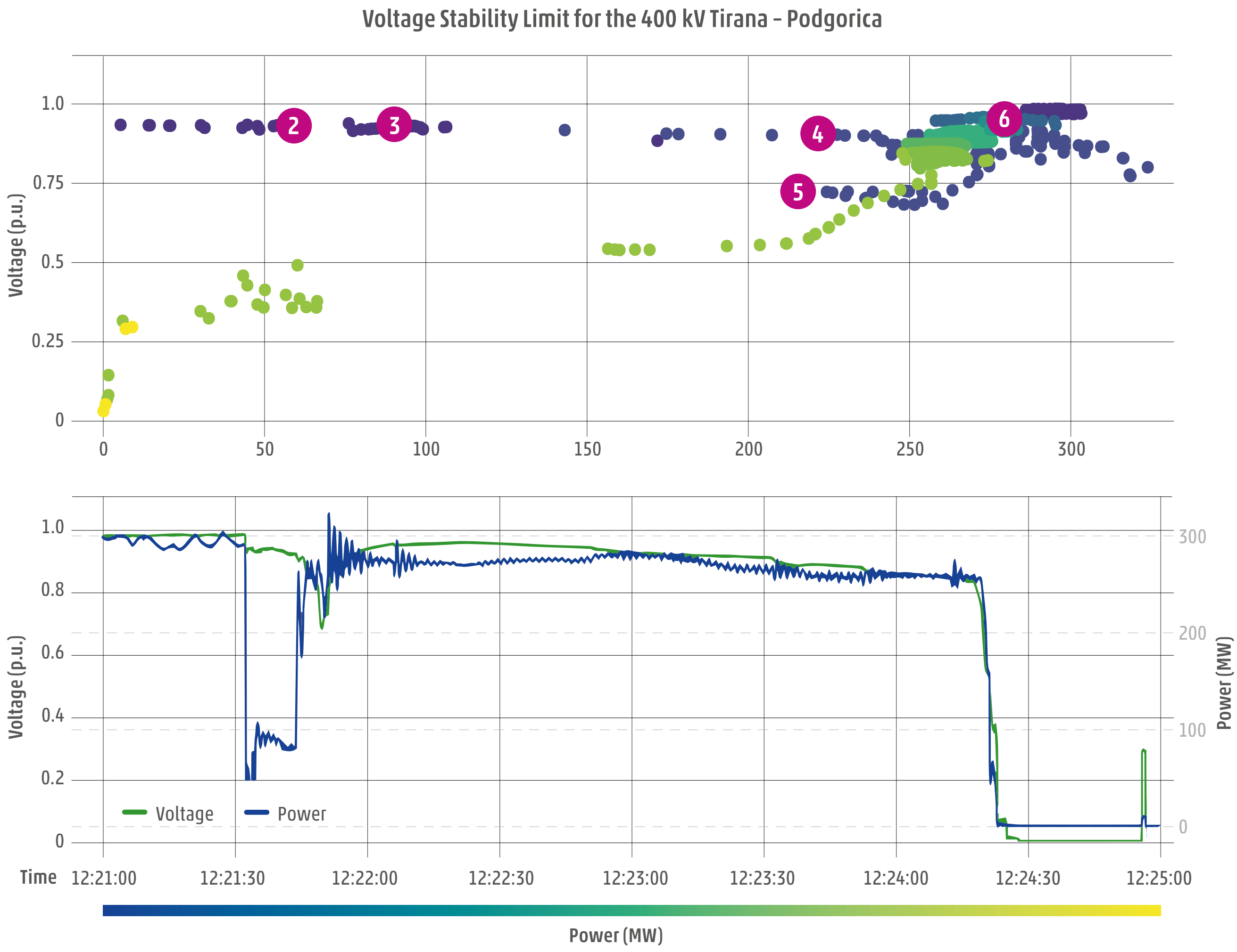


Figure 82: Voltage stability limit for the 400 kV TIE Tirana 2 – Podgorica 2

A sudden change can be seen in the nose curve in Figure 83. This is explained by the fact that the nose curve is heavily influenced by the power factor. When the reactive power demand of a system is unmet and the power factor moves from leading to lagging, the critical operating point (the tip of the nose curve) occurs earlier.

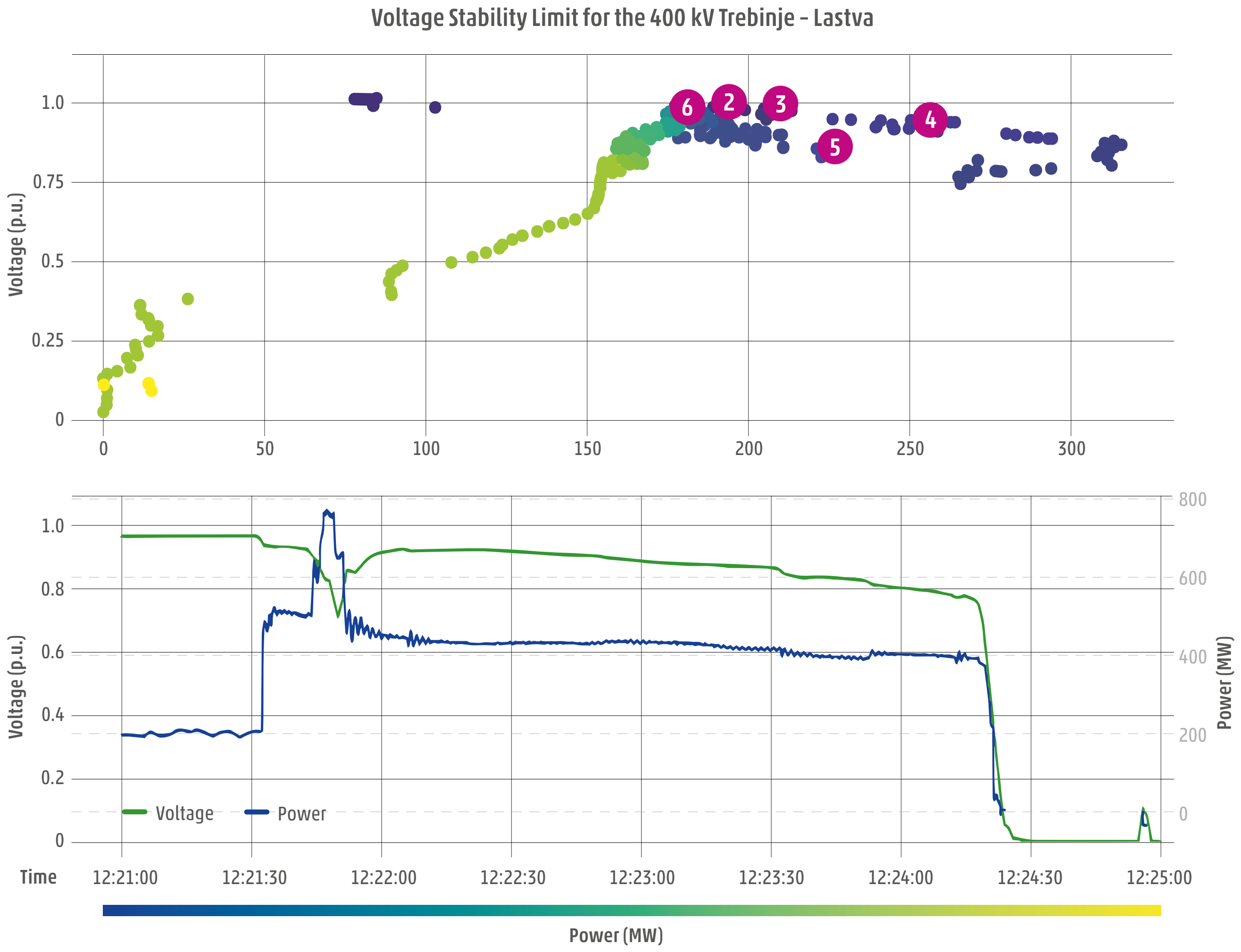


Figure 83: Voltage stability limits for the 400 kV TIE Trebinje – Lastva

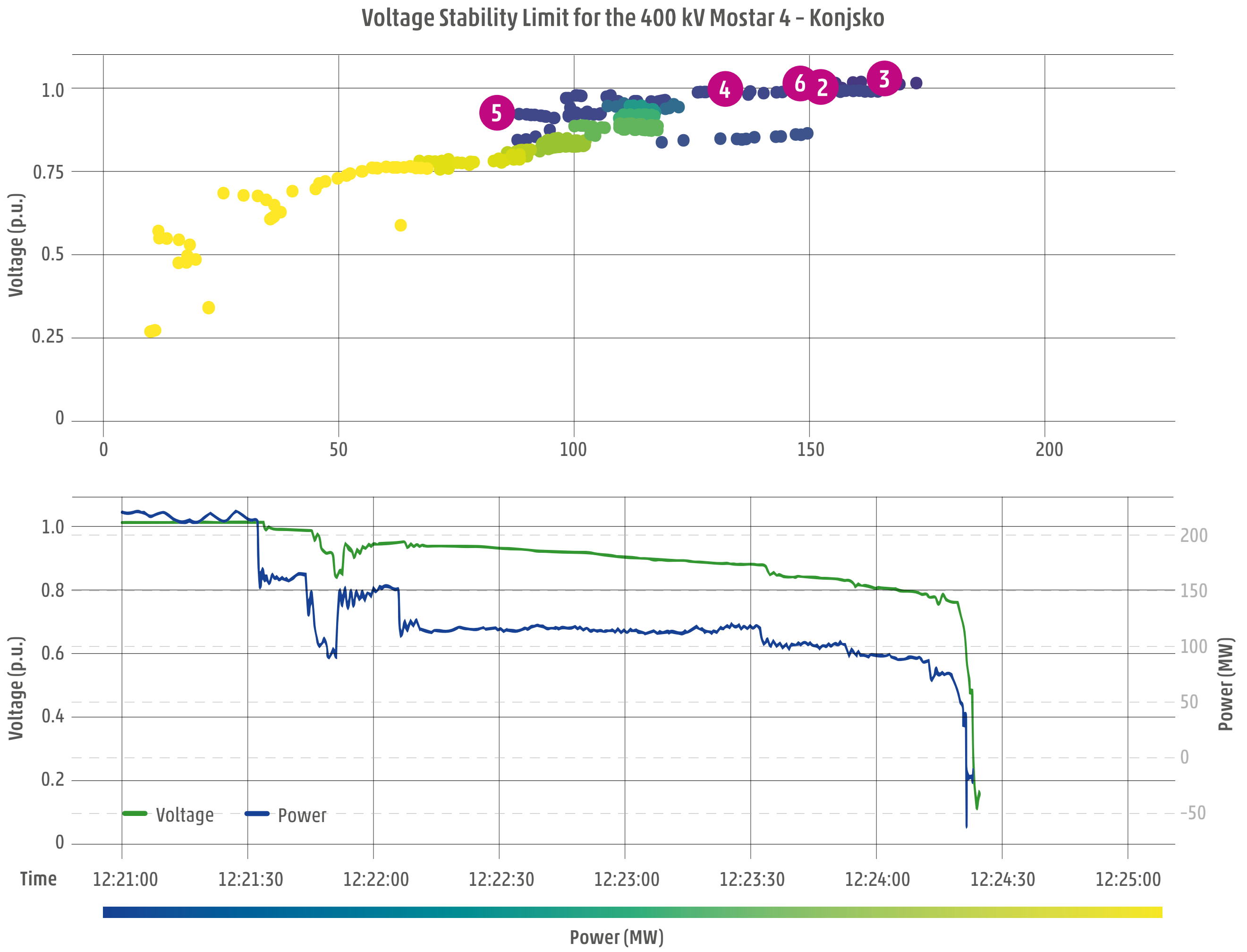


Figure 84: Voltage stability limits for the 400 kV TIE Mostar 4 – Konjsko

6.5.11 Root Cause Tree of Voltage Stability During the Incident

The root cause tree shown in Figure 85 illustrates the causes and effects of the voltage collapse.

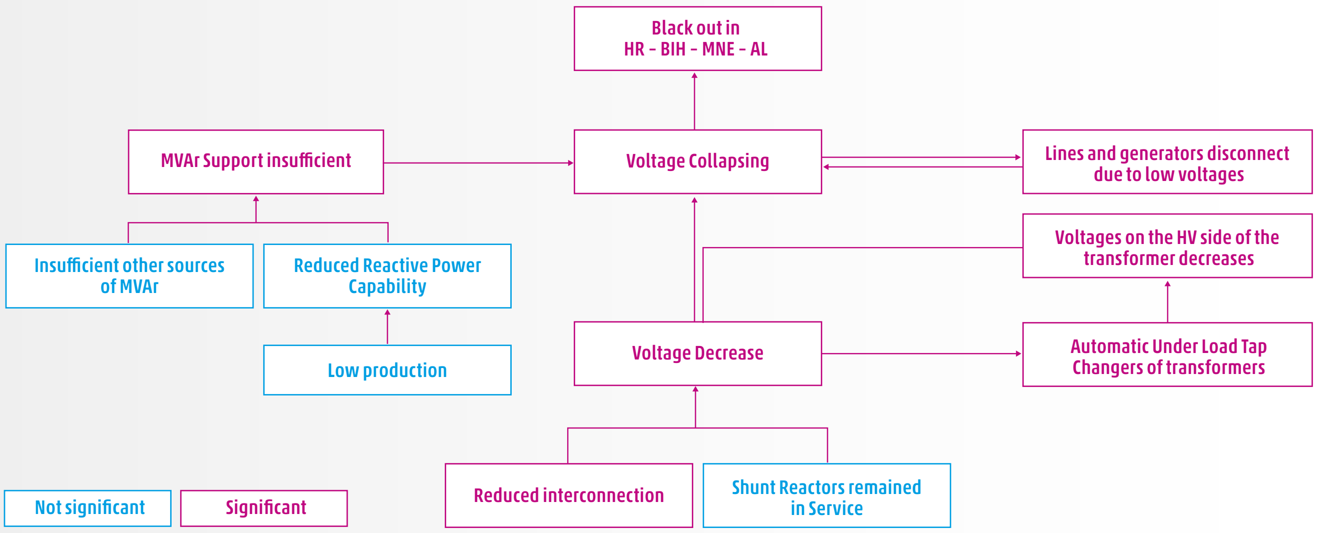


Figure 85: Root cause tree of the voltage collapse

6.6 Situational Awareness

6.6.1 Dynamic Stability Assessment

None of the affected TSOs have a EMS-SCADA system equipped with a dynamic stability assessment toolbox. Therefore, the affected TSOs had no method of detecting potential voltage instability in real time other than with contingency analysis. However, all of the affected TSOs confirm that they conduct annual offline studies in accordance with Article 38 of SOGL.

6.6.2 N-1 Security Assessment

All affected TSOs stated that the most accurate model they use to perform N-1 calculation is the DACF process, since an accurate calculation for the individual TSO requires using a model that also includes a large portion of the neighbouring grids. Another reason is that intraday market sessions in the Balkan region generally experience few changes.

The DACF process is performed the evening before the target day. Additionally, a check is performed during the morning of the target day to verify that everything is correct and identify any modifications to the grid configuration or system conditions that may require updates to the DACF models and further calculations. Additional calculations can be performed at the dispatchers' request. Since these calculations are manually performed by a back-office specialist, they can take up to one hour to complete.

All TSOs stated that voltages in the area are usually very high. N-1 voltage assessment is performed; however, the quality of the voltage results cannot be considered accurate.

6.6.2.1 HOPS

The HOPS observability area includes the extremely detailed model of ELES and NOSBiH as well as parts of Terna, APG, MAVIR, EMS, and CGES. HOPS is currently in the process of extending its observability area to further fulfil the requirement of including all sensitive elements in its new EMS-SCADA system. The old EMS-SCADA system posed a technical barrier to extending the observability area. The more recent calculations of relevant elements show that some elements on the grid periphery were missing, including the 400 kV TIE Zemblak – Kardia.

The EMS-SCADA model used for the N-1 calculations includes the aforementioned observability area. N-1 calculations in the HOPS EMS-SCADA system are performed every minute. Internal contingencies are considered, along with a limited number of external contingencies.

6.6.2.2 NOSBiH

The NOSBiH observability area encompasses all relevant elements from CGES, including all 400 kV, 220 kV, and parts of 110 kV lines, as well as from HOPS, covering all 400 kV, almost all 220 kV, and some 110 kV lines near the border. Additionally, it includes all relevant elements from EMS 400 kV, 220 kV, and 110 kV lines close to the border. Following the events of 21 June, efforts have been made to further expand the observability area.

In the NOSBiH EMS-SCADA system, N-1 calculations are automatically performed every 15 minutes. When necessary, operators can also manually trigger these calculations to ensure system reliability. Only internal contingencies are considered.

6.6.2.3 OST

The OST observability area includes the northern part of the IPTO grid as well as the southern part of the CGES grid. No bilateral agreement is in place between OST and MEPSO for sharing data for observability purposes. Additionally, OST has integrated the KOSTT 400 kV and 220 kV stations into the EMS-SCADA module but lacks some essential data. OST is required to exclude certain substations from EMS-SCADA calculations, instead transmitting the data on behalf of KOSTT to EAS and Swissgrid. The OST observability area does not include all sensitive elements.

N-1 calculations in the OST EMS-SCADA system are performed every 15 minutes. When needed, an additional run can be triggered by the operator. Only internal contingencies are considered.

6.6.2.4 CGES

The CGES observability area encompasses the entire 220 kV and 400 kV grid north of Tirana in Albania, along with a portion of southern Albania. The 400 kV TIE Zemblak – Kardia is modelled as an injection to the reduced network. Additionally, the relevant part of the 400 kV and 220 kV grid of NOSBiH, EMS, and KOSTT is modelled. At the time of the blackout, CGES did not have observability of the HOPS grid; although Croatia and Montenegro share a border, no TIE line connects the two TSOs. Since the blackout, CGES has improved its observability area by also including certain HOPS grid elements.

In the CGES EMS-SCADA system, N-1 calculations are automatically performed every five minutes or upon a relevant topology change.

6.6.2.5 Conclusion

The implementation of the observability area is regulated by the SO GL, which the TSOs of the Member States in the synchronous area of continental Europe are required to follow. The incident highlighted the need to improve the observability area of the affected TSOs. Additionally, each TSO shall simulate all contingencies in the observable area that are considered sensitive.

6.7 Outage of 400 kV OHL Tuzla – Višegrad

6.7.1 Background

The Hydro Power Plant Višegrad (with three generators totalling 315 MW) is connected to the substation (SS) Višegrad via 400 kV OHL HPP Višegrad – SS Višegrad.

At SS Višegrad, there are also 400 kV OHL Tuzla 4, along with a 400/220 kV 400 MVA transformer, which connects to the 220 kV TIE Pozega (EMS) – SS Višegrad. Additionally, there is a 400/110 kV transformer (300 MVA), which has been out of operation since 2019.

When power flows from the NOSBiH grid towards the east (as on 21 June), the 400 kV OHL Tuzla 4 – Višegrad essentially operates as a 220 kV line, as the connection from SS Višegrad to SS Pozega is a 220 kV TIE.

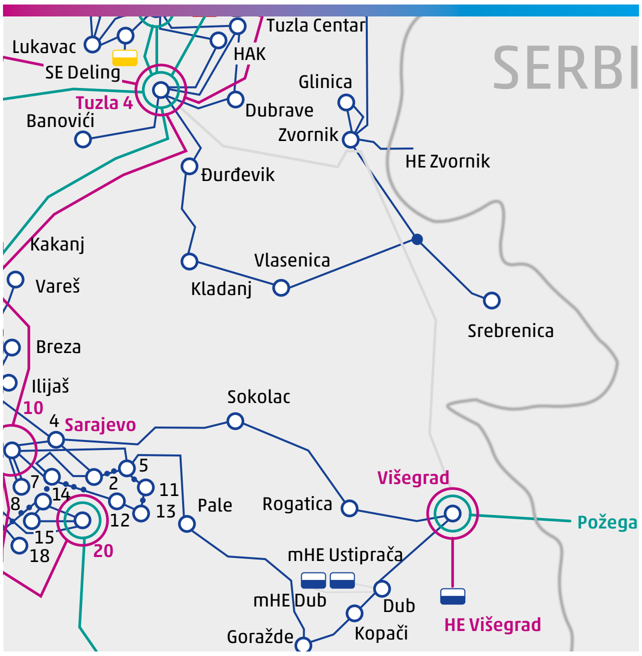


Figure 86: Single line diagram of partial grid of NOSBiH

Figure 87: NOSBiH grid

6.7.2 Why Was the 400 kV OHL Tuzla 4 – Višegrad Still Out of Service During the Voltage Collapse?

The 400 kV OHL Tuzla 4 – Višegrad spans 123 km and, when underloaded, generates reactive power, which can cause high voltage levels at SS Višegrad. Since the voltage in SS Višegrad directly influences the voltage at HPP Višegrad, this can lead to undesirably high voltage at the power plant.

The protection settings at HPP Višegrad are configured to trip if the voltage exceeds 430 kV, which is due to the aging SF6-based substation. When the voltage at HPP Višegrad reaches 430 kV, the protection system automatically disconnects both sides of the 400 kV OHL Višegrad – HPP Višegrad, resulting in a cessation of power generation.

To prevent this, a remedial action is taken by the NOSBiH operator almost every night: the 400 kV Tuzla 4 – Višegrad line is manually disconnected to reduce the voltage in SS Višegrad and enable HPP Višegrad to remain operational. This is critical, as the NOSBiH grid lacks a static VAR compensator, making this the only feasible solution to synchronise HPP Višegrad with the grid.

On 20 June, at 23:36, the 400 kV OHL Tuzla 4 – Višegrad was disconnected to prevent overvoltage at SS Višegrad. This action resulted in a 10–15 kV voltage drop at SS Višegrad, which allowed HPP Višegrad to remain synchronised with the grid into the morning of 21 June.

The morning of 21 June saw a trip of TPP Gacko (300 MW), a significant asset for voltage control in the region. The NOSBiH operator reconnected 400 kV OHL Tuzla 4 – Višegrad at 11:06:30, but the 400 kV OHL Višegrad – HPP Višegrad immediately tripped due to high voltage in SS Višegrad (430 kV protection activation).

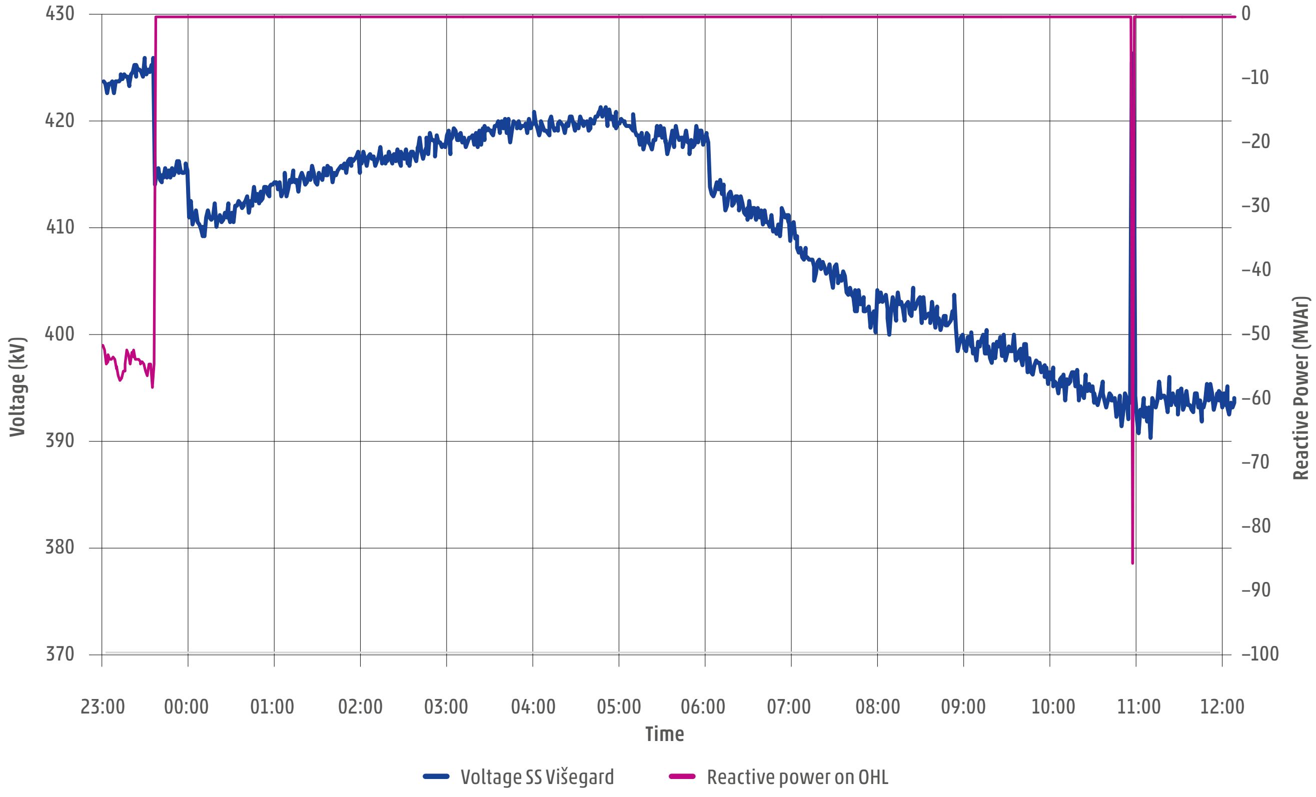


Figure 88: Influence of disconnected 400 kV OHL Tuzla 4 - Višegrad on voltage in SS Višegrad

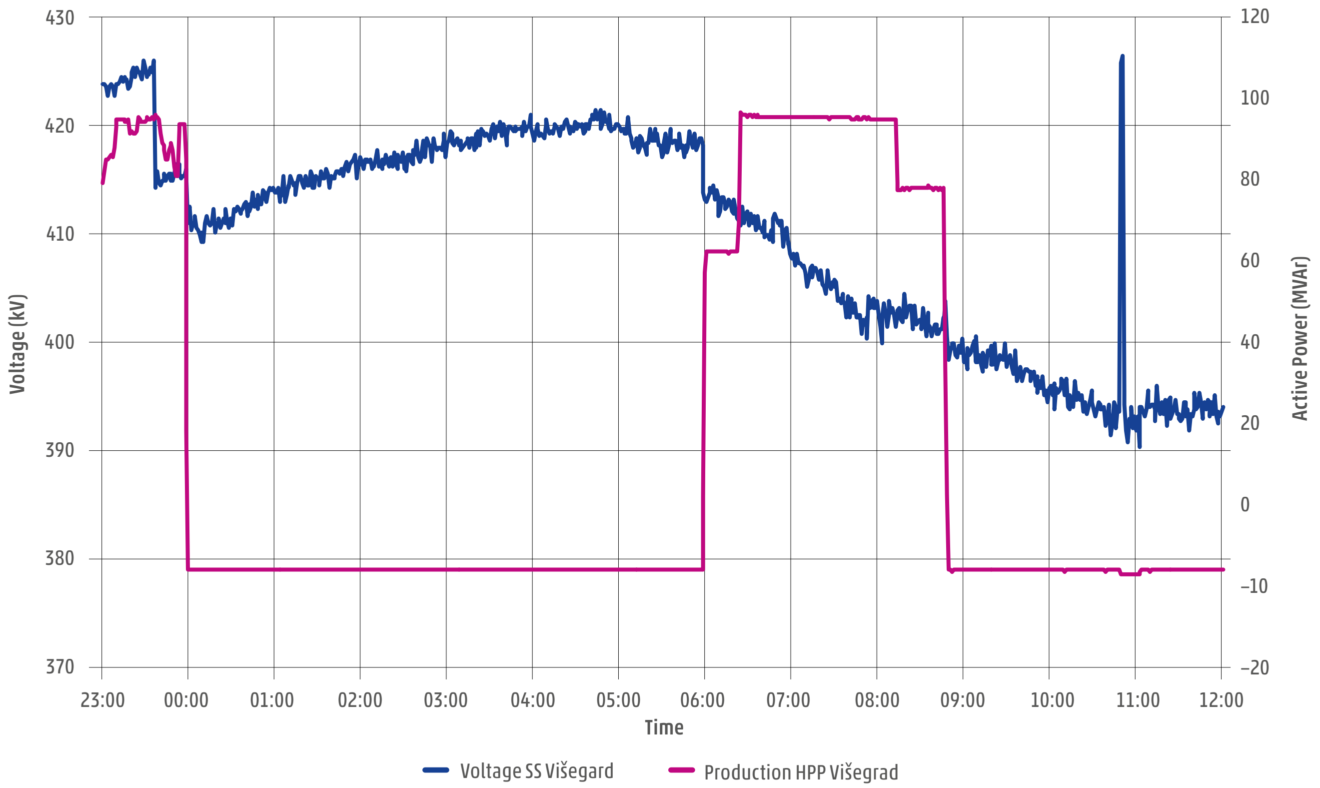


Figure 89: Voltage in SS Višegrad and production in HPP Višegrad

At 11:08:06, the operator manually switched off 400 kV OHL Tuzla 4 – Višegrad again, and by 11:20:19, the 400 kV OHL Višegrad – HPP Višegrad was re-energised, ensuring that HPP Višegrad remained synchronised with the grid.

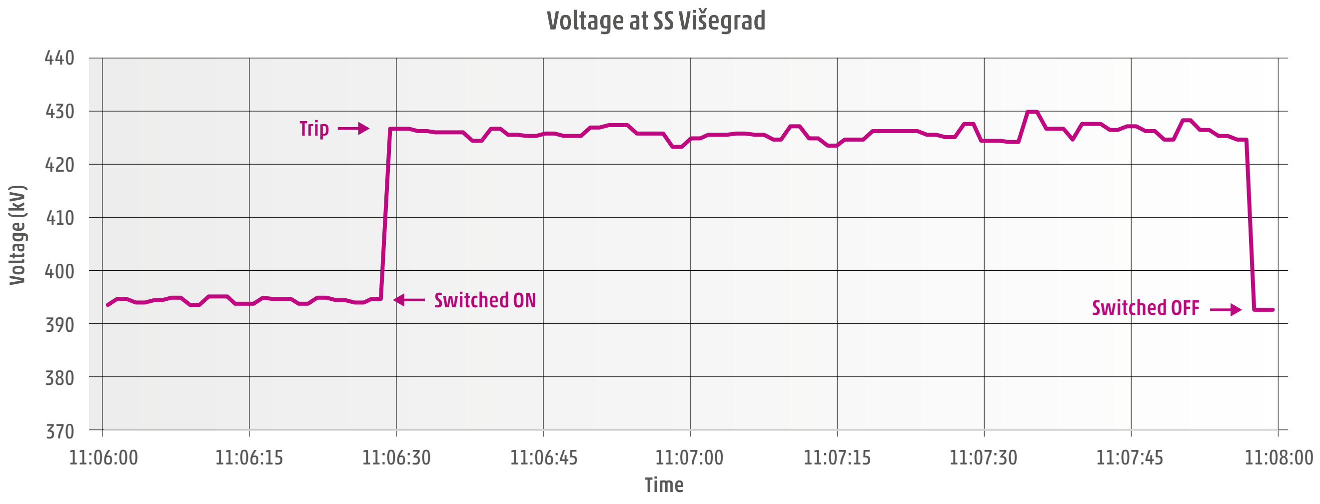


Figure 90: Busbar voltages in SS Višegrad before/after switched on/off 400 kV OHL Tuzla 4 in SS Višegrad

6.7.3 Power Flow and Grid Separation After the First Trip

Following the disconnection of 400 kV OHL Tuzla 4 – Višegrad, the CGES grid was effectively separated into a northern and southern section, with around 70 % of the consumption concentrated in the southern part.

The NOSBiH operator was aware of this grid separation and attempted to re-energize 400 kV OHL Višegrad – Tuzla 4 at 12:20, but the reconnection was interrupted by the second trip in Albania.

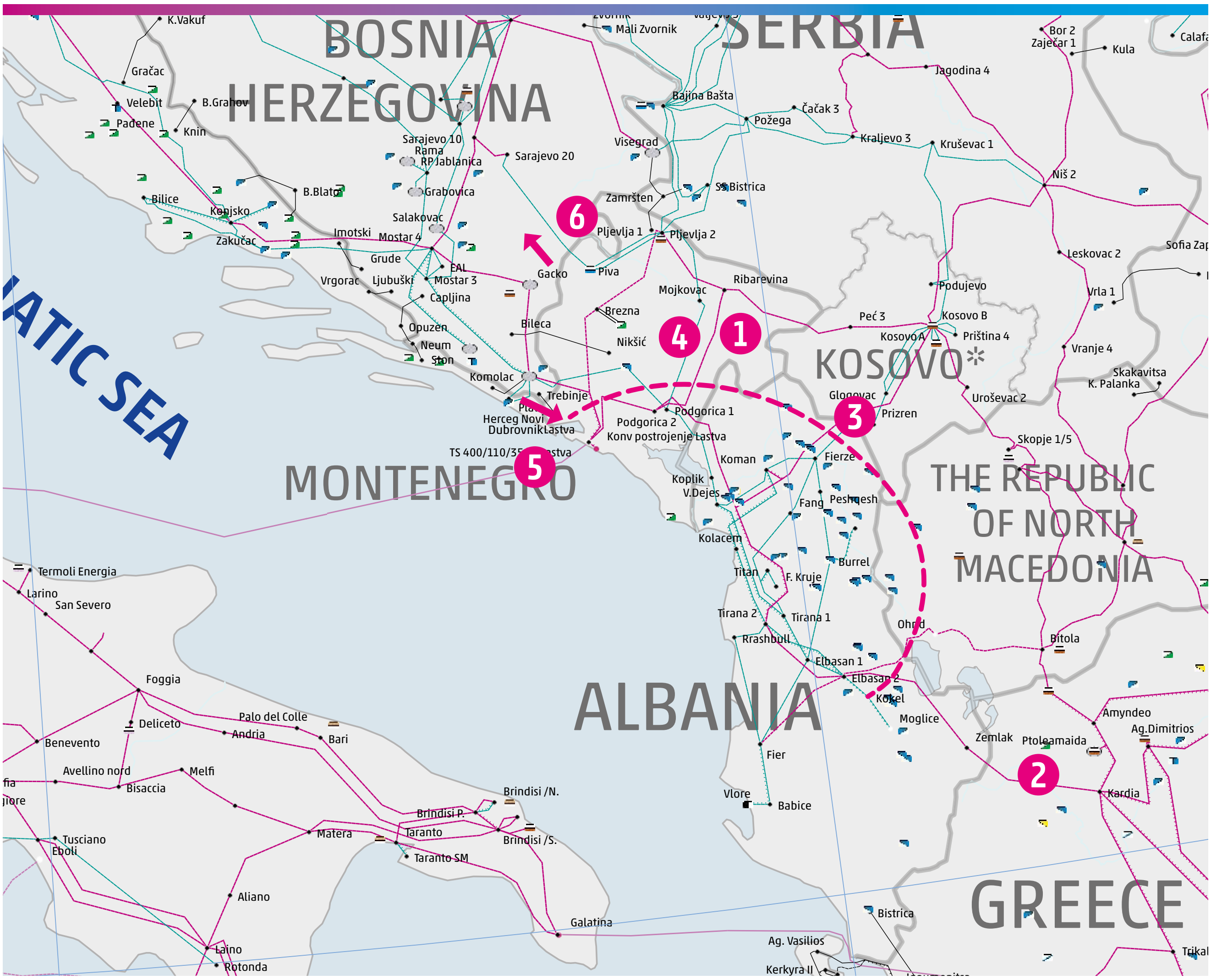


Figure 91: Seperation line and power flow

6.7.4 Impact of Reconnecting 400 kV OHL Tuzla 4 – Višegrad

Simulations conducted with the RCC model (considering the N-4 scenario) showed that reactivating 400 kV OHL Tuzla 4 – Višegrad would have had a minimal effect. The power flow on the 220 kV TIE Sarajevo 20 – Piva line decreased by only 25 MW, which was insufficient to prevent the voltage collapse. Furthermore, this line would have eventually tripped due to overcurrent.

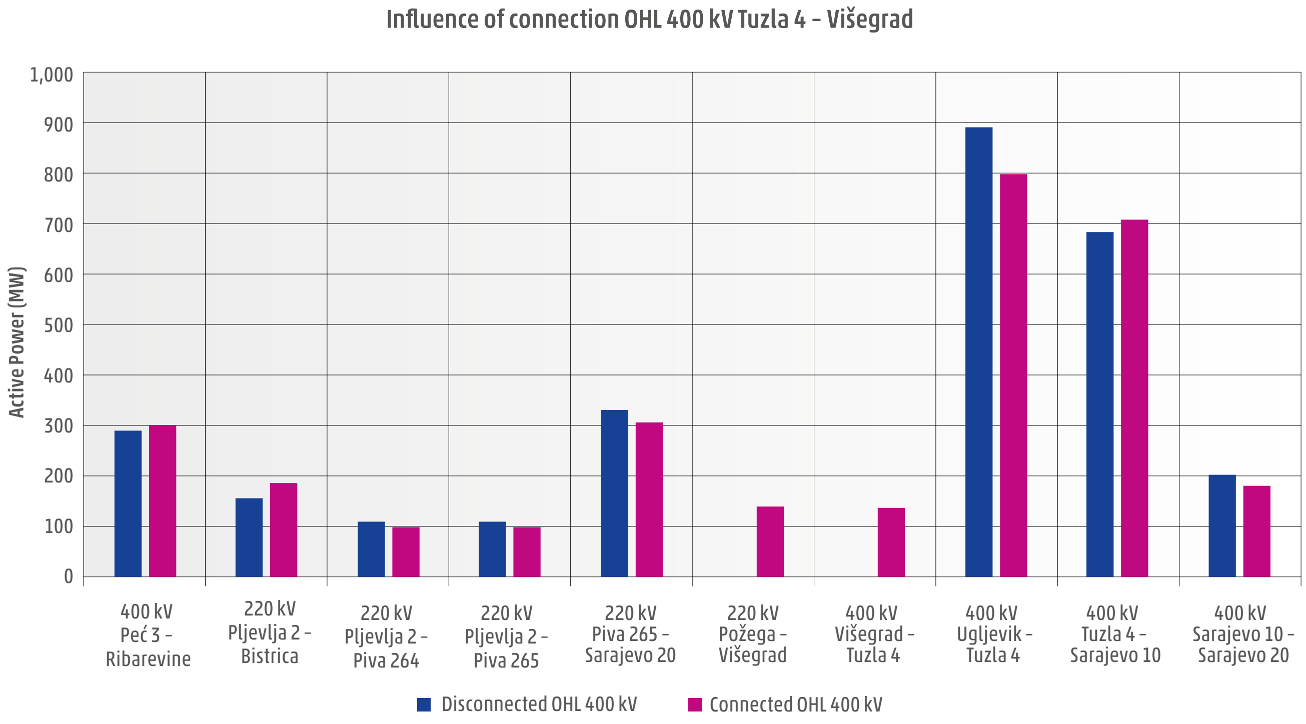


Figure 92: Figure 7: Influence of connection of 400 kV OHL Tuzla - Višegrad

6.7.5 Conclusion

The decision to keep 400 kV OHL Tuzla 4 – Višegrad out of service during the voltage collapse was crucial for maintaining the stability of HPP Višegrad. Despite efforts to restore the line, the overall impact on the grid's voltage behavior was minimal, confirming that the line's operation would not have prevented the voltage collapse.

7 RESTORATION PROCESS

7.1 Preconditions and preparatory actions for restoration process

Thanks to the traffic lights changes in EAS, TSOs received information shortly after the disturbance that the large part of the transmission systems of Albania, Montenegro, Bosnia and Herzegovina as well as Croatia suffered a voltage collapse followed by a totally or partly blackout (as shown in Figure 57).

Figure 93: Blackout incident in the south-eastern part of CE on 21 June

During the blackout incident in the south-eastern part of CE on 21 June, HOPS had blackouts in the small part of area Osijek and almost completely area Dalmatia.

NOSBiH and OST (except small load supplied radially in South of Albania from Greece System) had blackouts in all systems and the fastest restoration process of power system was undertaken using the neighbour's interconnections.

CGES was separated into the north part which was energised and the south part which was not energised, and the restoration plan was to connect these two parts of the CGES system, taking care of internal power flow.

After the exchange of information related to incidents between affected TSOs, restoration plan of TSOs was started immediately.

Interconnections were used for the top-down method of the restoration process, taking care with active power on tie-lines according to the Agreement on transmission system operation between TSOs.

7.2 Restoration sequences

7.2.1 HOPS

Due to the blackout state in Bosnia and Herzegovina and because of maintenance on 400 kV OHL Melina – Velebit, the HOPS dispatcher started the restoration process of the Dalmatia area from 220 kV voltage level (top-down method). The sequence of reconnection of elements in the HOPS network is shown in Figure 58.

At 12:52 the first reconnection was 220 kV OHL Brinje – Pađene ①, at 12:53 switched on 220 kV OHL Pađene – Konjsko ② at 12:54 switched on 220 kV OHL Konjsko – Zakučac and then at 12:55 put in operation transformer 220/110 kV in substation (SS) Zakučac ③. The aim of this manipulation was to energise 220 kV busbar in HPP Zakučac and to energise busbar 220 kV SS Konjsko where is connected static VAR compensator (SVC).

Due to the high voltage in the 220 kV grid, the HOPS dispatcher at 13:02 switched on HPP Zakučac with power of 63 MW and at 13:05 switched on SVC in the busbar 220 kV SS Konjsko. These manipulations helped with the problem of high voltage caused by long underloaded lines (Ferranti effect), as is shown in Figure 59.

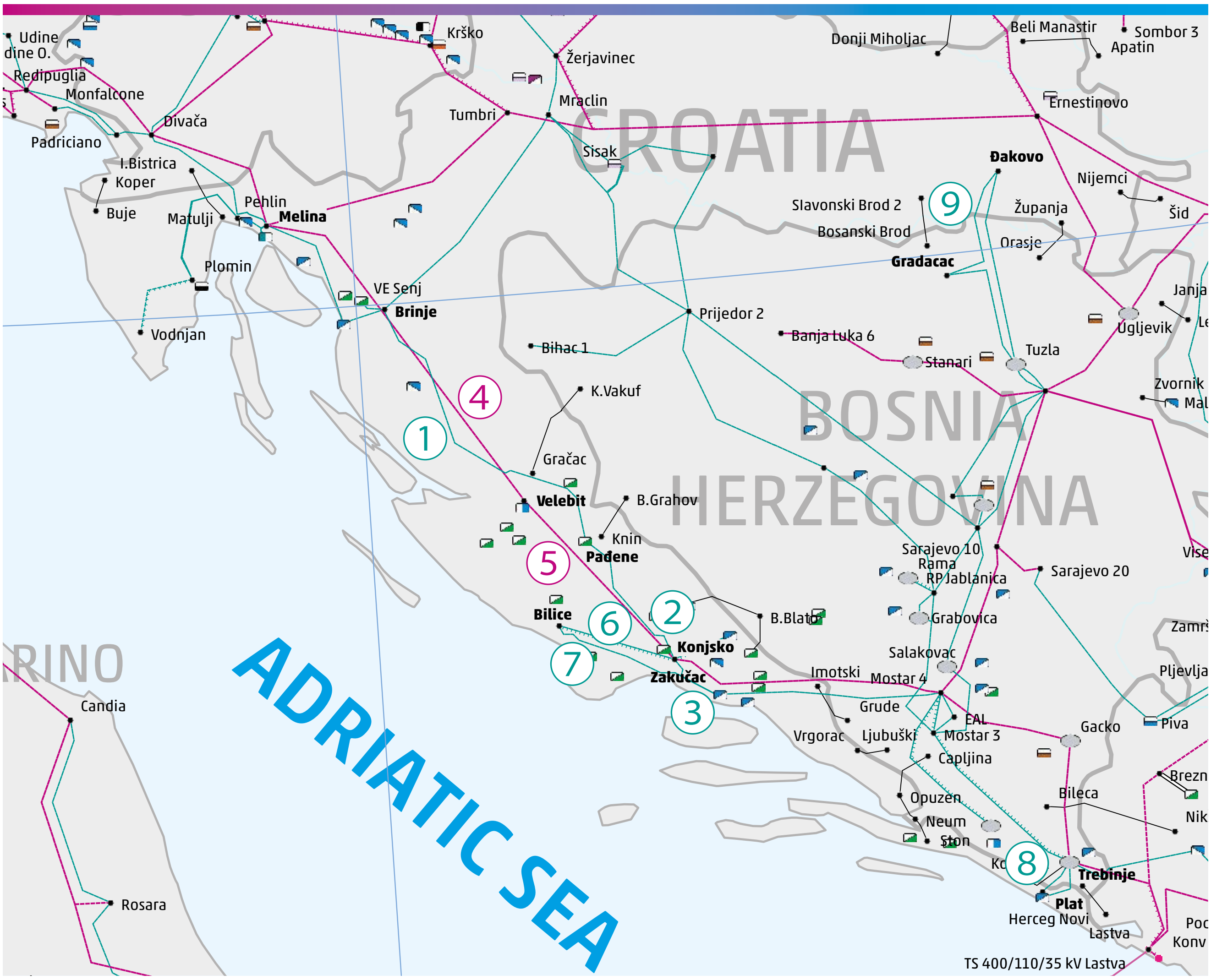


Figure 94: Step-by-step action during the restoration process in the HOPS grid

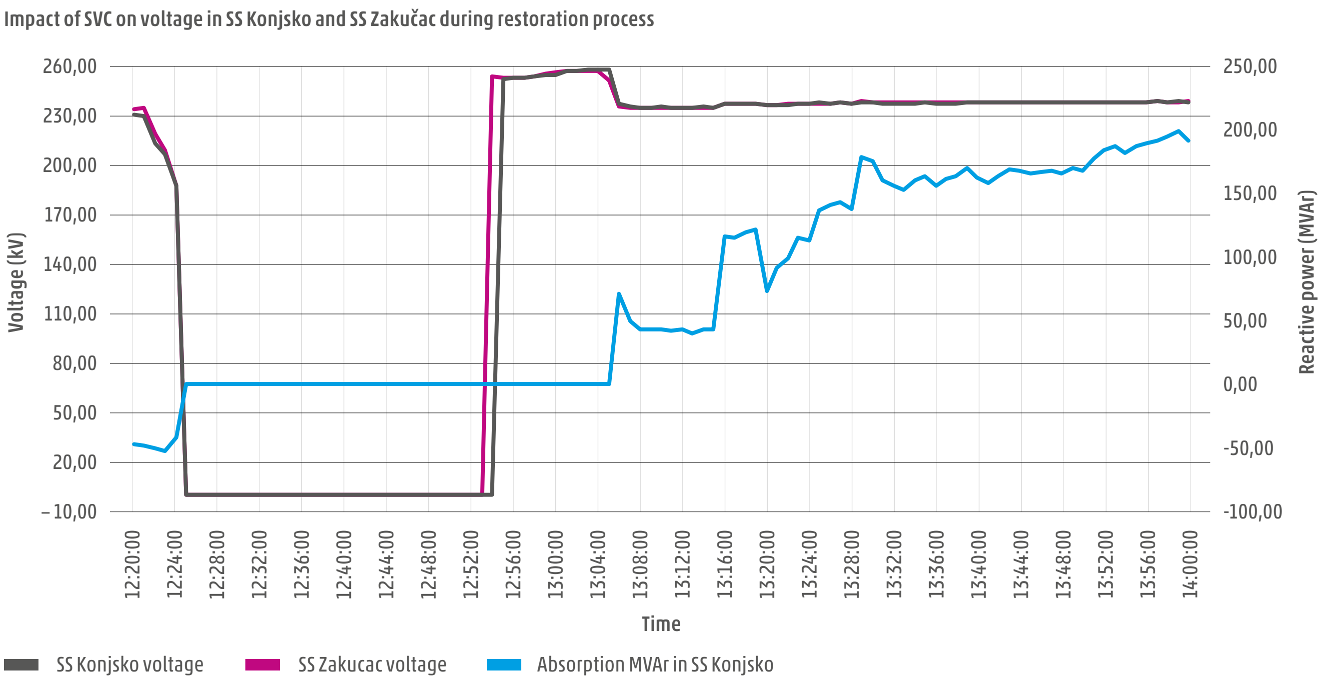


Figure 95: Impact of SVC on voltage in SS Konjsko and SS Zakučac during the restoration process

After the interruption of work on 400 kV OHL Melina – Velebit, the HOPS dispatcher started with the restoration of 400 kV voltage level.

At 13:09 switched on 400 kV OHL Melina – Velebit ④, at 13:11 switched on 400 kV OHL Velebit – Konjsko ⑤, at 13:14 and at 13:15 in SS Konjsko switched on both transformers 400/220 kV and at 13:19 switched on two transformers 220/110 kV in SS Konjsko. After these manipulations, the most important substation for this area was almost fully energised.

At 13:24 switched on 220 kV OHL Konjsko – Bilice 1 and 220 kV OHL Konjsko – Bilice 2 ⑥, 220 kV OHL Bilice – Zakučac ⑦ and at 13:51 switched on transformer 220/110 kV in SS Bilice.

At 14:04 switched on transformer 400/110 kV in SS Velebit.

Part of the HOPS grid around Dubrovnik starts being energised from NOSBiH grid. At 14:09 switched on 220 kV TIE Trebinje (BA) – Plat (HR) ⑧ and then transformer 220/110 kV in SS Plat at 14:14.

At 15:00 switched on 220 kV TIE Đakovo (HR) – Gradačac (BA) and subsequently 220 kV TIE Đakovo (HR) – TPP Tuzla (BA) are switched on ⑨. At 15:20 first transformer 220/110 kV in SS Đakovo is switched on and at 15:26 second transformer 220/110 kV is also switched on.

7.2.2 NOSBiH

After the exchange of information related to the incident with the neighbouring TSOs of Croatia (HOPS), Serbia (EMS) and Montenegro (CGES), the restoration plan was started immediately.

Interconnections with HOPS, EMS and CGES, which did not switch off, were used for restoration using a top-down method.

Before starting the restoration process, dispatchers in NOSBiH according to the Restoration plan switched off all circuit breakers in the SS.

Both 400 kV tie-lines from SS Ugljevik to Ernestinovo (HR) and Sremska Mitrovica 2 (RS) were in operations and NOSBiH dispatchers decided to start the restoration process from SS Ugljevik (as shown in Figure 60).

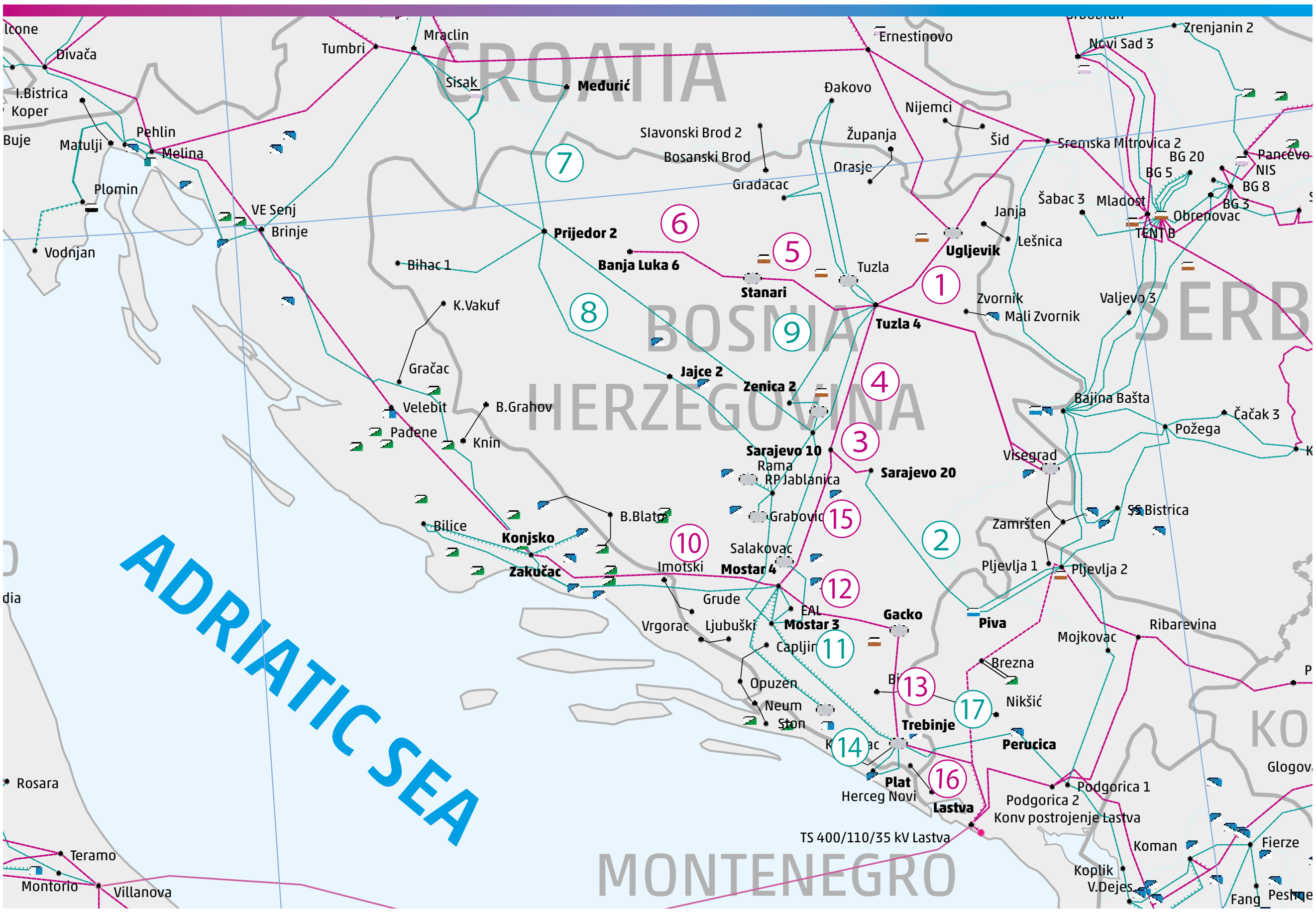


Figure 96: Step-by-step action during the restoration process in the NOSBiH grid

The start of restoration was at 12:33, when internal line 400 kV OHL Ugljevik – Tuzla 4 ① switched on and a 400 kV busbar was energised in SS Tuzla 4, which is one of most important for NOSBiH.

At 12:41 switched on 220 kV TIE Sarajevo 20 – Piva, ② reconnecting the system with the north part of CGES, immediately afterwards switched on 400 kV OHL Sarajevo 20 – Sarajevo 10 ③, energised 400 kV busbar in SS Sarajevo 10 and put in operation 400/110 kV TR in SS Sarajevo 10.

At 12:46 switched on 400 kV OHL Tuzla 4 – Sarajevo 10 ④ and immediately switched on 400 kV OHL Tuzla 4 – Stanari ⑤, at 13:05 switched on 400 kV OHL Stanari – Banja Luka 6 ⑥ and at 13:07 put in operation 400/110 kV TR in SS Banja Luka 6. From this moment on, three of the four most important 400 kV SS were energised.

At 12:55 switch on 220 kV TIE Međurić – Prijedor 2 ⑦, from SS Prijedor 2 at 13:00 started energising 220 kV SS Jajce 2 ⑧ and continue to 220 kV SS Jablanica where HPP Rama (installed capacity 170 MW) and HPP Grabovica (Installed capacity 114 MW) are connected.

After switching on 400/220 kV TR in SS Tuzla 4, at 13:28 switched on 220 kV OHL Tuzla 4 – Zenica 2 ⑨, at 13:42 switched on 220 kV OHL Zenica 2 – Kakanj V (TPP Kakanj installed capacity 215 MW) and at 13:43 connected ring of 220 kV grid with switched on 220 kV OHL SS Kakanj – Kakanj V.

Because of the high voltage caused by long underloaded lines in the power system, waiting for the presence of voltage from 400 kV SS Konjsko (HR) or 220 kV SS Zakučac (HR) to SS Mostar 4 was the fastest solution. 400 kV TIE Konjsko (HR) – Mostar 4 (BA) ⑩ is switched on at 13:47 and immediately followed by 400/220 kV TR in SS Mostar 4.The next step was energised 220 kV SS Mostar 3 from SS Mostar 4 and 220 kV Trebinje from Mostar 3 ⑪.

At 14:06 from SS 400 kV Mostar 4 was energised 400 kV SS Gacko ⑫, immediately after was energised 400 kV SS Trebinje ⑬ and at 14:07 switched on 400/220 kV TR in SS Trebinje.

Then at 14:09 switched on 220 kV TIE Trebinje (BA) – Plat (HR) ⑭.

At 15:05 switched on 400 kV OHL Sarajevo 10 – Mostar 4 ⑮ and immediately at 15:06 switched on 400 kV TIE Trebinje (BA) – Lastva (ME) ⑯ and at 15:08 switched on 220 kV TIE Trebinje (BA) – Perućica (ME) ⑰.

7.2.3 CGES

CGES was separated into the north part, which was energised, and the south part, which was not energised, and the restoration plan was to connect these two parts of CGES system, taking care of internal power flows.

Before starting the connection of lines, dispatchers in CGES according to the Restoration plan switched off all circuit breakers in SS in the south part of grid.

The sequence of reconnection of elements in the CGES network is shown in Figure 61. The fastest way to restore the south part of the power system of CGES was to synchronise the two separated parts.

The restoration process of the south part of the CGES grid started with the reconnection of 220 kV OHL Mojkovac – Podgorica 1 ① at 12:39 and immediately after that at 12:40 switched on 220 kV OHL Podgorica 1 – HPP Perućica ②. At 12:46 switched on 1 220/110 kV TR in SS Podgorica 1 and started reenergising consumers in the capital city of Montenegro, while the second transformer 220/110 kV in SS Podgorica 1 switched on at 13:23.

After that, at 13:01 switched on 400 kV TIE Tirana 2 (AL) – Podgorica 2 (ME) ③ and at 13:02 TR 2 400/110 kV in SS Podgorica 2. From this moment on, CGES was resynchronised with OST.

At 13:49 connected 400 kV OHL Podgorica 2 – Lastva ④ and both transformers in SS Lastva 400/110 kV.

At 13:49 switched on tie-lines 220 kV Trebinje in HPP Perućica to be resynchronised with the south part of NOSBiH grid, while at 15:08 HPP Perućica switched on in SS Trebinje ⑦.

At 13:58 switched on 1 400/110 kV TR in SS Podgorica 2.

At 14:01 switched on 400 kV OHL Ribarevine – Podgorica 2 and switched off after 1 minute.

At 14:51 switched on 220 kV TIE Podgorica 1 (ME) – Koplik (AL) ⑤.

At 15:05 switched on 400 kV TIE Lastva (ME) – Trebinje (BA) in SS Lastva ⑥ and at 15:16 Lastva – HVDC 1 and Lastva – HVDC 2 ⑧.

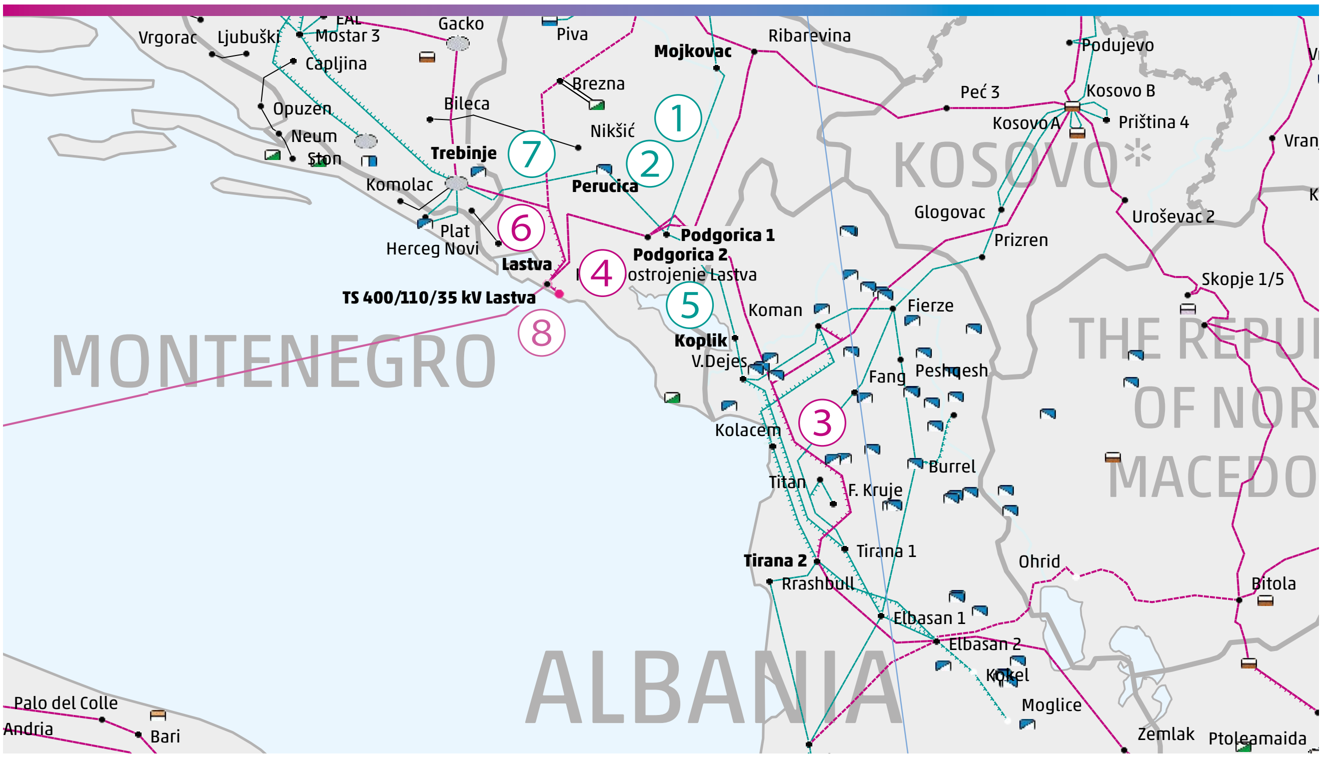


Figure 97: Step-by-step action during the restoration process in the CGES grid

7.2.4 OST

The sequence of reconnection of elements in the OST network is shown in Figure 62. Because circuit breakers in SS Zemblak, Elbasan 2 and Tirana 2 were switched on, immediately after switching on 400 kV TIE Kardia (GR) – Zemblak (AL) ① at 12:38, voltage was on 400 kV bus bar Zemblak, Elbasan 2 and Tirana 2.

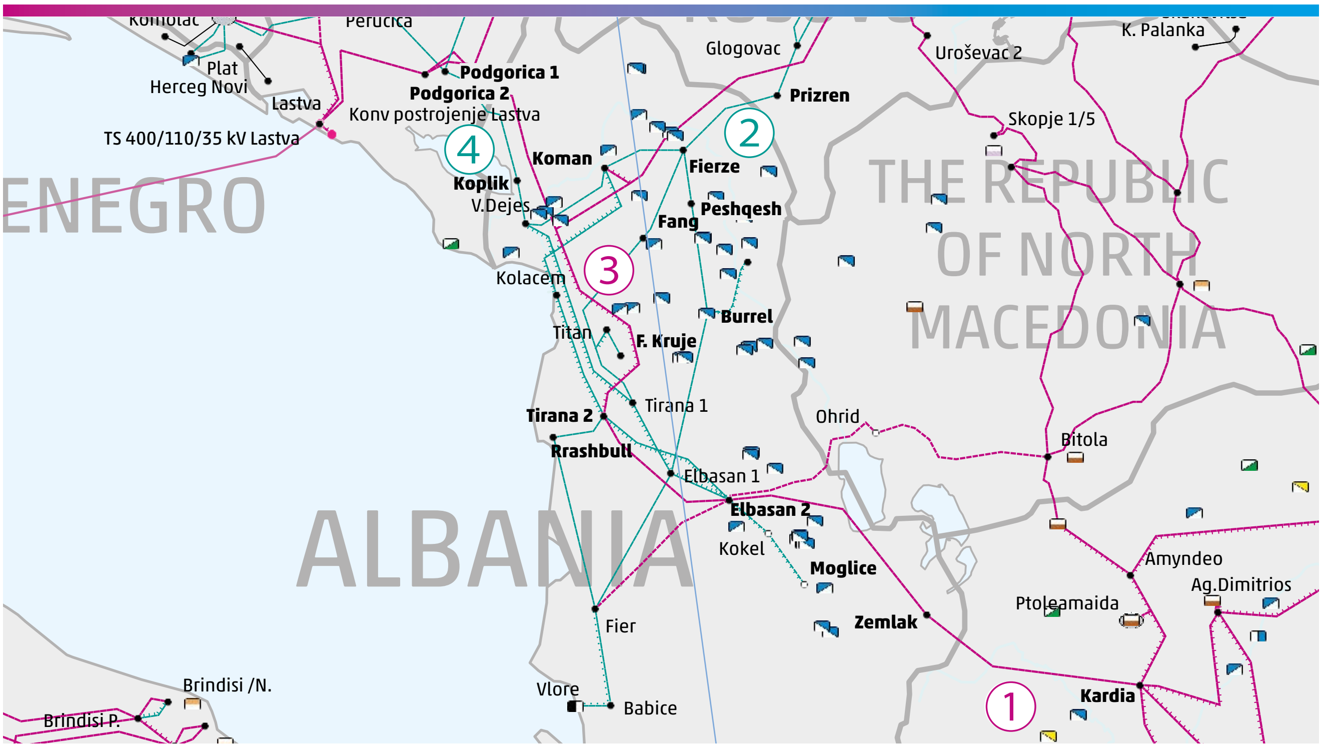


Figure 98: Step-by-step action during the restoration process in the OST grid

Circuit breakers on transformers 400/220 kV in Elbasan 2 and Tirana 2 were switched on and, because of that, busbars 220 kV in SS Elbasan 2 and Tirana 2 were energised immediately.

Circuit breakers 220 kV in SS Elbasan 2, SS Elbasan 1, SS Burelli, SS Peshquesh, SS Fier, SS Rashbull, SS Karvast, SS Moglice were switched on and energised immediately.

At 12:40 resynchronised with KOSTT via 220 kV TIE Pristina 2 – Fierza ②, bus bar at SS Koman and Fangu energised immediately.

At 12:59 resynchronised with CGES via 400 kV TIE Tirana 2 (AL) – Podgorica 2 (ME) ③ and at 13:06 via 220 kV TIE Koplik (AL) – Podgorica 1 (ME) ④.

7.3 Generation recovery actions

7.3.1 HOPS

WPP Senj in SS Brinje with total power 34 MW switched off at 12:24 and synchronised at 12:30.

HPP Dubrovnik G1 in SS Plat with total power 97 MW switched off at 12:21 and synchronised at 14:43.

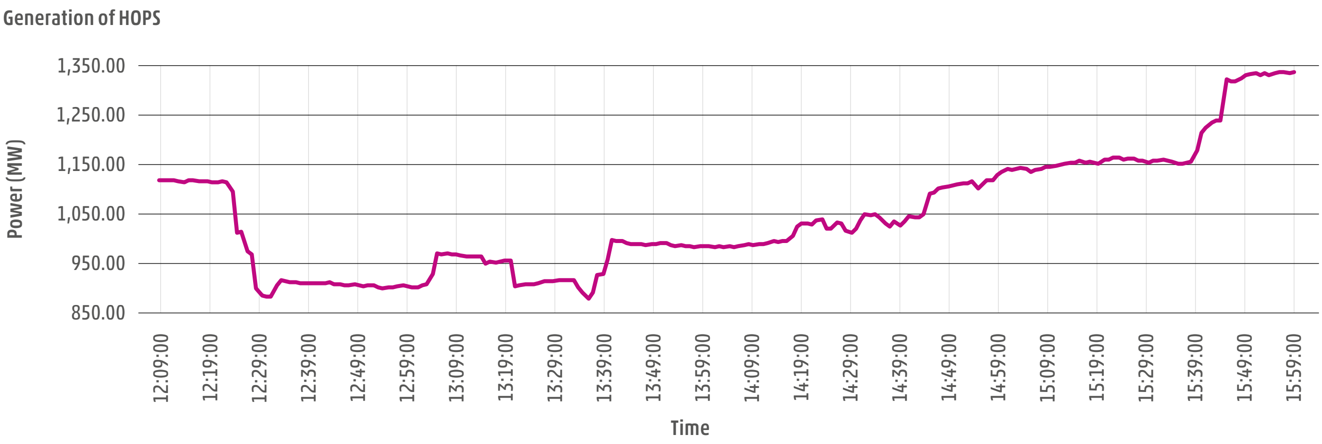


Figure 99: Generation of HOPS

7.3.2 NOSBiH

- HPP Dubrovnik G2 in SS HE Dubrovnik with total power 107 MW switched off at 12:21 and synchronised at 14:45.
- HPP Trebinje 1 in SS HE Trebinje 1 with total power 46 MW switched off at 12:21 and synchronised at 14:10.
- TPP Tuzla G4 in SS TE Tuzla with total power 169 MW switched off at 12:23 and synchronised at 20:30.
- TPP Tuzla G5 in SS TE Tuzla with total power 173 MW switched off at 12:24 and synchronised next day.
- TPP Stanari in SS TE Stanari with total power 260 MW switched off at 12:25 and synchronised next day.
- SPP Hodovo in SS SE Hodovo with total power 34 MW switched off at 12:24 and synchronised at 16:15.
- SPP Bileća in SS SE Bileća with total power 45 MW switched off at 12:24 and synchronised at 15:30.
- SPP Petnjik in SS SE Petnjik with total power 21 MW switched off at 12:24 and synchronised at 16:05.
- TPP Kakanj G5 in SS TE Kakanj with total power 81 MW switched off at 12:24 and synchronised at 21:00.
- TPP Kakanj G6 in SS TE Kakanj with total power 85 MW switched off at 12:24 and synchronised at 21:05.
- HPP Jablanica in SS HE Jablanica with total power 85 MW switched off at 12:24 and synchronised at 14:55.
- SPP Zvizdan in SS SE Zvizdan with total power 12 MW switched off at 12:24 and synchronised at 14:57.
- HPP Mostar in SS HE Mostar with total power 14 MW switched off at 12:21 and synchronised at 14:35.

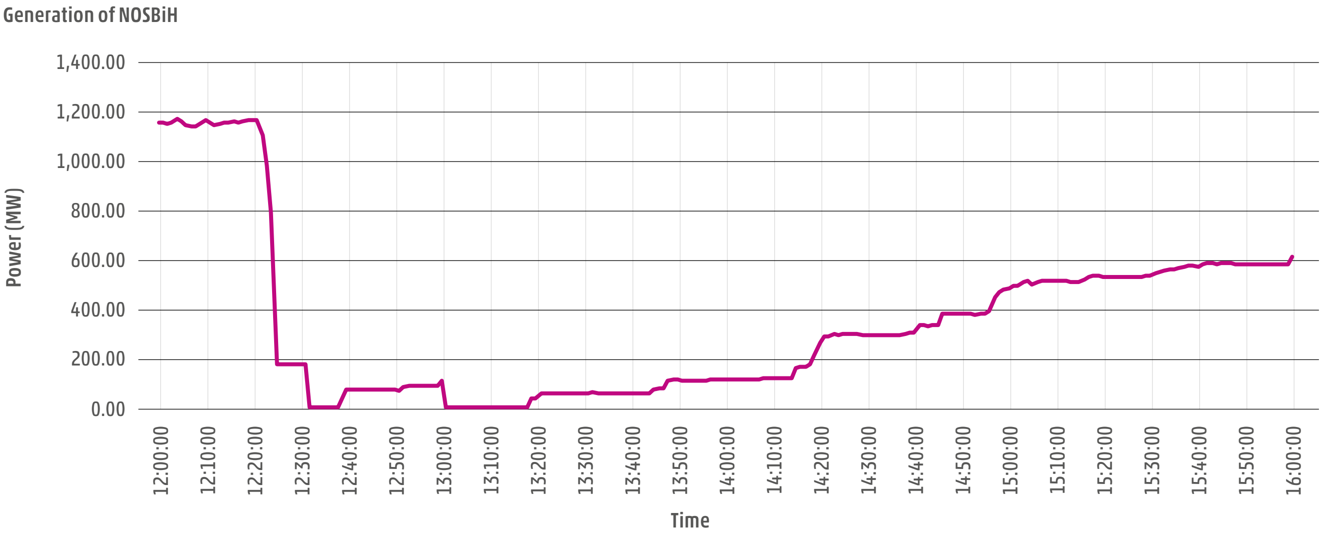


Figure 100: Generation of NOSBiH

7.3.3 CGES

- » HPP Perućica in SS Perućica at 12:22 with total power around 110 MW switched off at 12:24 and synchronised at 13:41.
- » HPP Piva in SS Piva with total power 99 MW switched off at 12:33 and synchronised at 15:15.

Generation of CGES

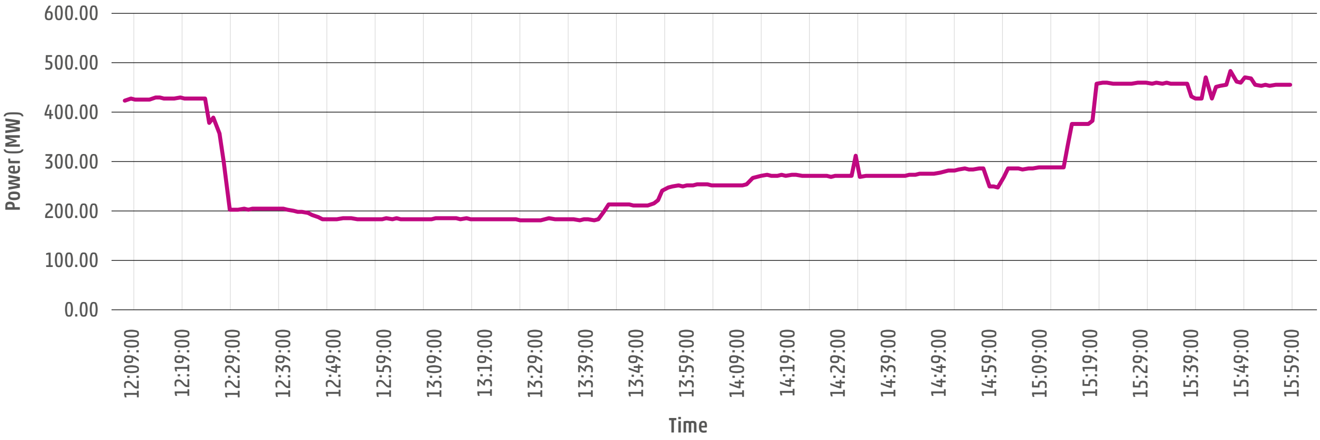


Figure 101: Generation of CGES

7.3.4 OST

- » HPP Vau Dejes in SS Vau Dejes with total power 40 MW switched off at 12:24 and synchronised at 13:11.
- » HPP Fierze in SS Fierze with total power 109 MW switched off at 12:24 and synchronised at 12:43.
- » HPP Fang in SS Fang with total power 61 MW switched off at 12:24 and synchronised at 12:48.
- » HPP Koman in SS Koman with total power 211 MW switched off at 12:24 and synchronised at 13:30.

Generation of OST

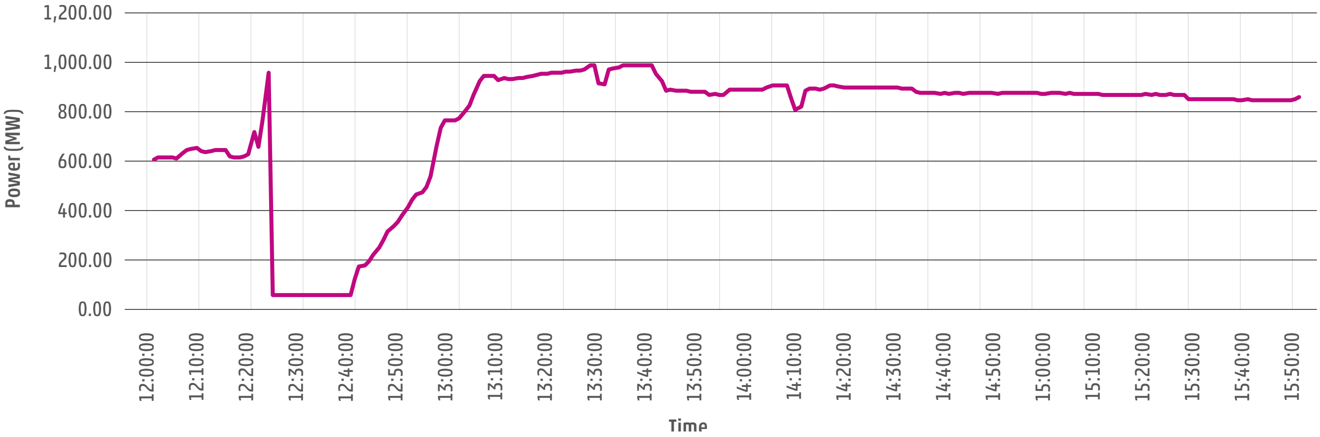


Figure 102: Generation of OST

7.4 Load recovery actions

7.4.1 HOPS

HOPS lost approximately 700 MW. The next figure presents the increase of consumption in the HOPS grid during the restoration process. The speed of returning consumption depended on DSOs and network centres.

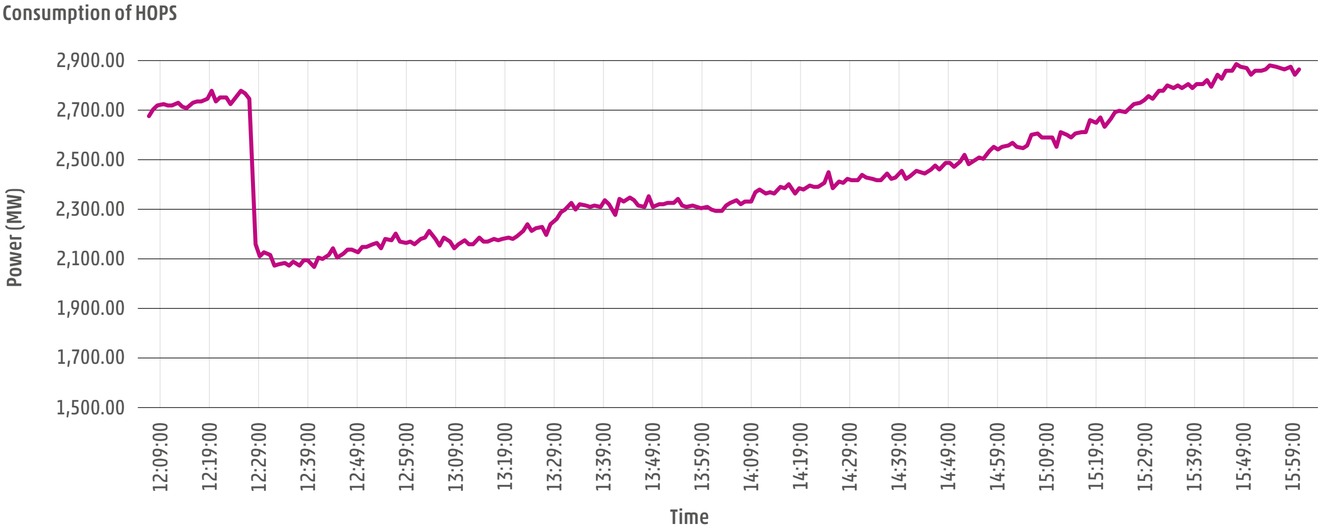


Figure 103: Consumption of HOPS

7.4.2 NOSBiH

NOSBiH lost all consumption. The next figure presents the increase of consumption in the NOSBiH grid during the restoration process. The speed of returning consumption depended on DSOs and network centres.

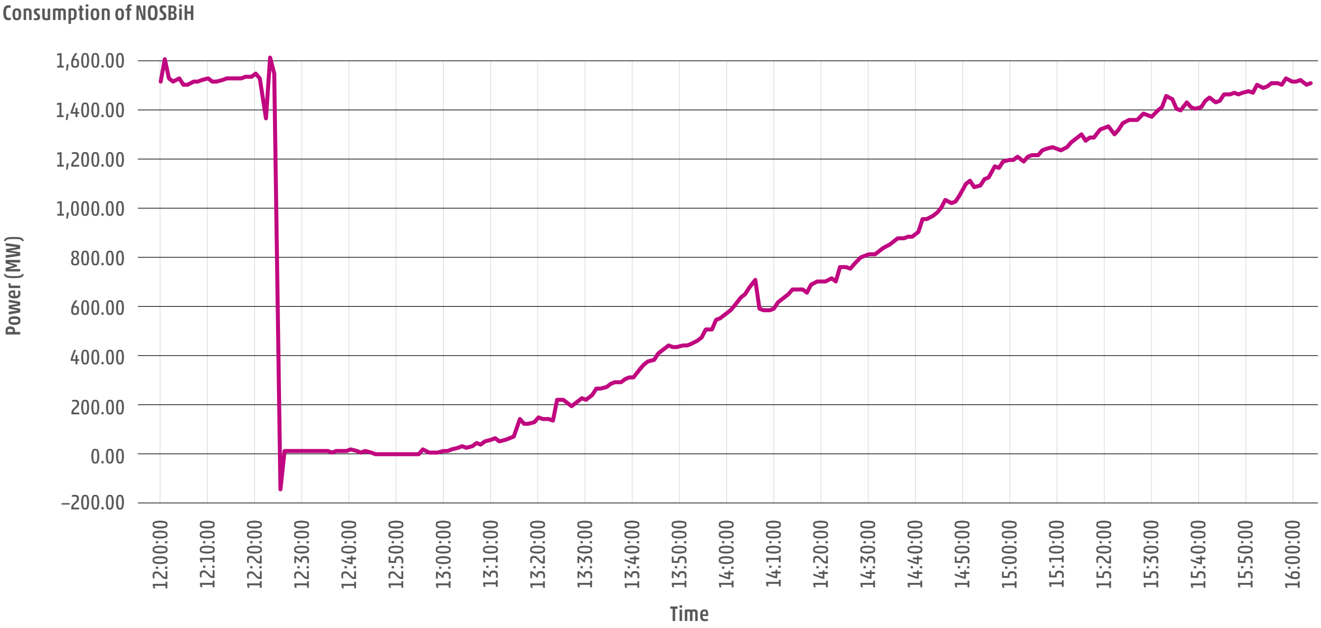


Figure 104: Consumption of NOSBiH

7.4.3 CGES

CGES lost approximately 70 % of consumption. The next figure presents the increase of consumption in the CGES grid during the restoration process. The speed of returning consumption depended on DSOs and network centres.

Consumption of CGES

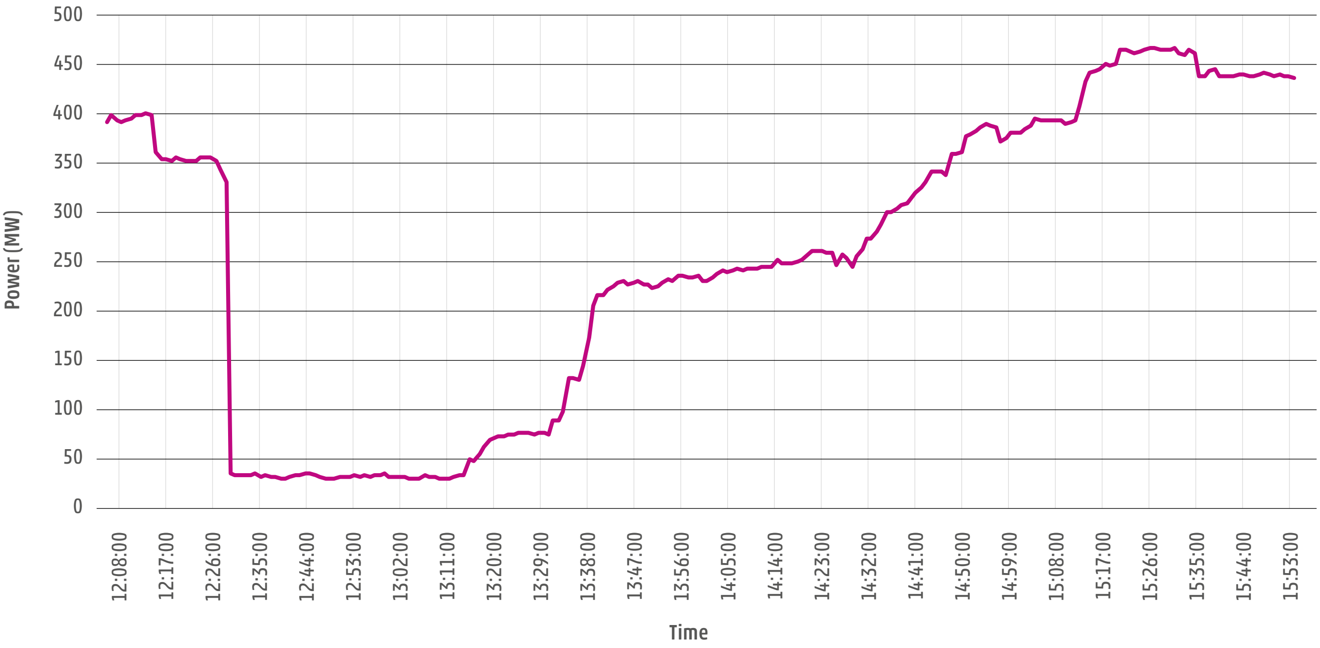


Figure 105: Consumption of CGES

7.4.4 OST

OST lost almost all consumption; only a small part of grid was radially connected to the IPTO grid. The next figure presents the increase of consumption in the OST grid during restoration process. The speed of returning consumption depended on DSOs and network centres.

Consumption of OST

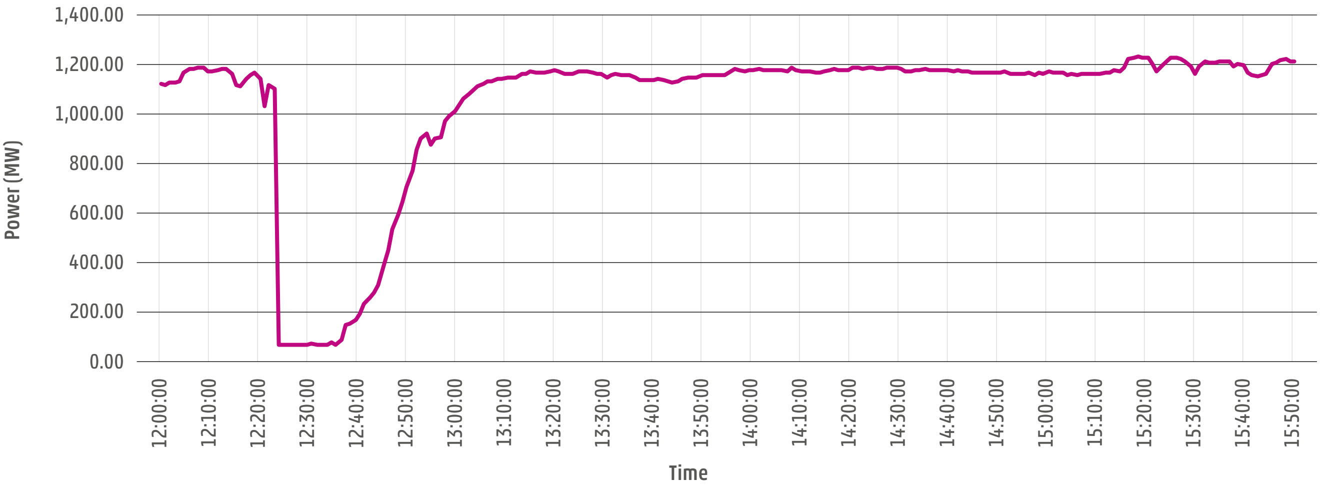


Figure 106: Consumption of OST

7.5 End of restoration and return to market

7.5.1 HOPS

The reconnection of 400/110 kV TR in TS Velebit at 14:04 can be considered the end of the restoration of the central part of the Dalmatia region because from this moment on, all important transformers for this region were switched on.

The reconnection of 220/110 kV TR in TS Plat at 14:14 can be considered the end of the restoration of the part around the city of Dubrovnik.

The reconnection of 220/110 kV TR in TS Đakovo at 15:20 can be considered the end of the restoration of the Osijek region, with a note that all substations 110/x that were in blackout had 110 kV voltage present before the reconnection of the mentioned transformers.

HOPS had no interruption of market operations.

7.5.2 NOSBiH

With the reconnection of 220/110 kV TR in TS Mostar 4 at 14:18, all important transformers for the consumption of Bosnia and Herzegovina were switched on. The speed of returning consumption depended on DSOs and network centres. The energy market in Bosnia and Herzegovina was open again at 16:00.

7.5.3 CGES

The end of the restoration of the CGES network can be seen as the moment of switching on of two 400/110 kV TR in TS Lastva at 13:49. All important transformers for the consumption of Montenegro were switched on. The speed of returning consumption depended on DSOs and network centres. CGES had no interruption of market operations.

7.5.4 OST

The switching on of two interconnections with Montenegro at 12:59 and 13:06 can be considered the end of the restoration, as most of the switches remained on, so the restoration of consumption was also fast, as can be seen in Figure 70.

7.6 Lessons learned

Both in the normal state of the system and in the emergency state of the system, it is necessary to ensure that the manipulations of switching off/on the elements are carried out according to the restoration plan and Agreement on transmission system operation between TSOs. Considering that we know that in such situations it is inevitable that mistakes happen, it is necessary to reduce them to a minimum.

In accordance with the prescribed procedures and rules for managing the transmission system, the voltage needs to be distributed as a priority to the more important load nodes, as well as production units, with the aim of resynchronising and providing the necessary electricity to cover consumption needs.

It should be noted that communication, team organisation and coordination of work with neighbouring operators are especially important. This significantly eases the newly created situation, and the common goal – to return the system to its normal state – is reached faster.

This event represented an invaluable experience for those who were “on the front line of defence” and also the already significant knowledge of the dispatchers was expanded even more by this situation.

8 CLASSIFICATION ON THE INCIDENT BASED ON THE ICS METHODOLOGY

The ICS Methodology has been developed in accordance with Regulation (EC) No 714/2009 of the European Parliament and of the Council of 13 July 2009 and updated to fulfil the objectives and the security indicator requirements laid out in Article 15 of Commission Regulation (EU) 2017/1485 of 02 August 2017 establishing a guideline on electricity transmission system operation (SOGL). The definitions are extended further to provide a realistic view of the system states, within the meaning of Article 18 of the SOGL, during incidents.

Scale 0 **Noteworthy incident**		**Scale 1** **Significant incident**		**Scale 2** **Extensive incident**		**Scale 3** **Major incident / 1TSO**	
Priority / Short definition (Criterion short code)		**Priority / Short definition (Criterion short code)**		**Priority / Short definition (Criterion short code)**		**Priority / Short definition (Criterion short code)**	
#20	Incidents on load (L0)	#11	Incidents on load (L1)	#2	Incidents on load (L2)	#1	Blackout (OB3)
#21	Incidents leading to frequency degradation (F0)	#12	Incidents leading to frequency degradation (F1)	#3	Incidents leading to frequency degradation (F2)		
#22	Incidents on transmission network elements (T0)	#13	Incidents on transmission network elements (T1)	#4	Incidents on transmission network elements (T2)		
#23	Incidents on power generating facilities (G0)	#14	Incidents on power generating facilities (G1)	#5	Incidents on power generating facilities (G2)		
		#15	N-1 violation (ON1)	#6	N violation (ON2)		
#24	Separation from the grid (RS0)	#16	Separation from the grid (RS1)	#7	Separation from the grid (RS2)		
#25	Violation of standards on voltage (OV0)	#17	Violation of standards on voltage (OV1)	#8	Violation of standards on voltage (OV2)		
#26	Reduction of reserve capacity (RRC0)	#18	Reduction of reserve capacity (RRC1)	#9	Reduction of reserve capacity (RRC2)		
#27	Loss of tools and facilities (LT0)	#19	Loss of tools and facilities (LT1)	#10	Loss of tools and facilities (LT2)		

Figure 107: Incident Classification Scale

Figure 71 shows the criteria from the methodology and the corresponding scale. In addition, they are ordered by priority. #1 marks the criterion with the highest priority and #27 marks the lowest priority. An incident can consist of multiple events and can meet multiple criteria.

In this case, the highest criterion decides the scale of the incidents. In the event of a scale 2 or scale 3, an investigation of an Expert Panel is conducted. While only the highest priority criterion is relevant for deciding the scale, the other criteria are also assessed.

8.1 Scale of the incident

The highest criterion from ICS in this incident is the OB3 criterion. This criterion is met if there is a loss of more than 50 % of demand or if there is a total absence of voltage for at least three minutes. This is assessed per TSO's control area. The lost load on 21 June 2024 was:

- » 1,102 MW for Albania (97 % of the demand before the incident)
- » 1,500 MW for Bosnia-Herzegovina (100 % of the demand before the incident)
- » 709 MW for Croatia (26 % of the demand before the incident)
- » 338 MW for Montenegro (72 % of the demand before the incident)

This means that the OB3 criterion was met for Albania, Bosnia-Herzegovina and Montenegro. For Croatia, the lost load was below 50 % but above 10 % and therefore the L2 criterion was met. In total, the incident is therefore classified as scale 3.

Abovementioned four TSOs (OST, NOSBiH, CGES and HOPS) are considered to be affected by the incident of scale 2 or 3. Whenever a term "affected TSOs" is used throughout this report, it shall be explicitly understood that the statements refers to those TSOs only.

8.2 RCC Investigation Threshold

The RCC Post-Operation and Post-Disturbances Analysis and Reporting Methodology has been developed to define the RCC task in accordance with Article 37(1)(i) of the Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity. This methodology foresees an RCC investigation in addition to the work of the Expert Panel if both of the following criteria are met:

a. as a result of actions taken by a TSO being in emergency, blackout or restoration system state, another TSO has moved from Normal or Alert System State to Emergency System State; and

b. the incident has been confirmed as at least a scale 2 incident as defined by the ICS Methodology.

Post-analysis confirmed that Albania, Bosnia and Montenegro were in emergency, blackout and restoration state during the incident and that Croatia was in an emergency state. Consequentially, the incident met the RCC Investigation Threshold and the RCC Investigation will be initiated. The conclusions of the RCC Investigation will be added as a dedicated chapter in the final report.

8.3 Scale of all events linked to the incident

Next to the OB3 and L2 criteria that were deciding for the scale of the incident, several other events are linked to the incident that meet other ICS criteria. A summary of all criteria is included in Table 20.

Chapter 3.1 lists all relevant disconnections during the incident. The first trip of Ribarevina (CGES) – Podgorica 2 (CGES) resulted in the N-1 criterion ceasing to be fulfilled (T1). The further trips resulted in violations of operational security limits (T2). The consequences were limited to OST, NOSBiH, HOPS and CGES. However, the disconnected elements included tie-lines with Terna, IPTO and KOSTT.

The G criterion assesses the lost generation during the incident. OST, HOPS and CGES experienced a loss of generation of≤600 MW which is below scale (BS). NOSBiH lost approximately 1,365 MW in their control area, which is a G0 criteria violation. The total lost generation was around 2.2 GW (G1).

The ON criterion assesses N and N-1 violations. After the tripping of Ribarevina (CGES) – Podgorica 2 (CGES) there have been violations of operational security limits in the case of Zemblak (OST) – Kardia (IPTO) tripping and the grid was no longer N-1 secure. This is in an ON1 criteria violation starting at 12:09. With the tripping of four elements at 12:21, there have been wide area deviations from operational security limits for OST, NOSBiH and HOPS resulting in the ON2 criteria violation.

The OV criterion assesses the violation of standards on voltage. The relevant threshold is <0,85 pu for >30 sec. The first voltage drop at 12:21 was for <30 sec and is therefore not in ICS criteria violation. The second drop and collapse began at 12:23:37 for CGES and 12:23:34 for HOPS and, as it impacted neighbouring TSOs, is considered OV2. For OST and NOSBiH, the elements were disconnected and dropped to 0 kV in <30 sec. Therefore, for OST and NOSBiH, they are not considered OV criteria violation.

		OST	NOSBiH	HOPS	CGES	KOSTT	IPTO	Terna	Total
OB	3	X	X		X				X
L	2			X					
	1								
	0								
F	2	Not violated during this incident							
	1								
	0								
T	2	X	X	X	X	X	X	X	X
	1				X				
	0								
G	2								
	1								X
	0		X						
	BS	X		X	X				
ON	2	X	X	X					X
	1	X	X	X					
RS	2	Not violated during this incident							
	1								
	0								
OV	2			X	X				X
	1								
	0								
	BS								
RCC	2	Not violated during this incident							
	1								
	0								
LT	2	Not violated during this incident							
	1								
	0								

Table 27: ICS criteria violations by TSO. Each violated ICS criteria has an X in the cell. The criteria frequency degradation (F), separation from the grid (RS), reduction of reserve capacity (RRC) and loss of tools, means and facilities (LT) were not violated during the scale 3 incident on 21 June 2024.

9 CONCLUSIONS, RECOMMENDATIONS AND INTERNAL ACTIONS

In this chapter, the conclusions of the incident are presented in Section 9.1. Based on the analysis of the incident, the ICS Expert Panel has proposed various recommendations.

Recommendations and internal actions are divided into different sections. They are linked either to the main causes of the incident (Section 9.2) or other critical factors not directly related to the blackout (Section 9.3).

9.1 Conclusions on the Incident

This paragraph summarises the main conclusions of the technical analysis performed on the event and defines the root causes contributing to the event.

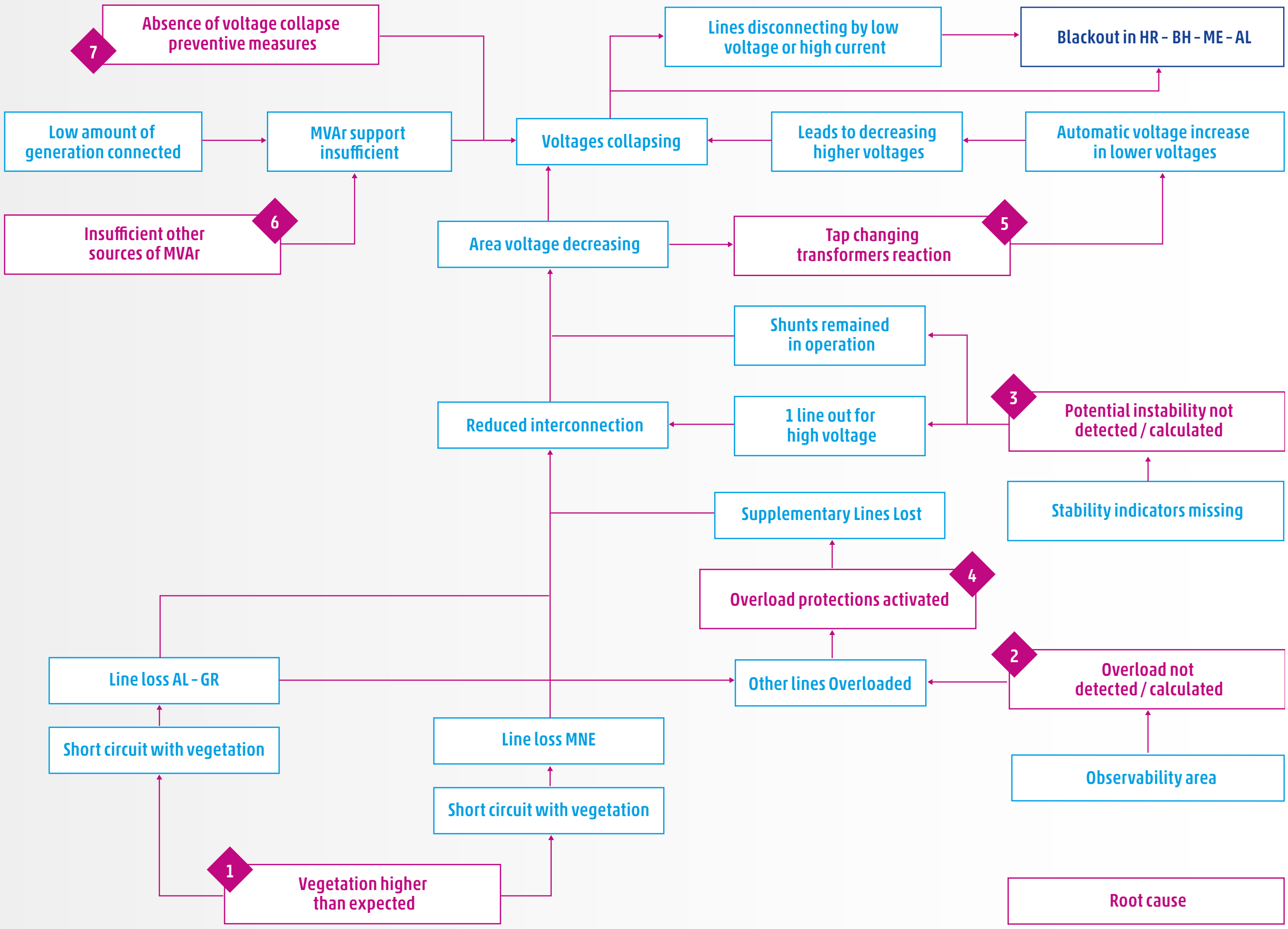


Figure 108: Root cause tree linked with conclusions

The root cause tree depicted in Figure 1 is a summary of the full root causes analysis, with the coloured boxes indicating the location of the root causes. The root causes are detailed below.

1. The short circuits on lines #1 and #2 due to vegetation proximity issue

Two distinct and independent short circuits occurred on the HV grid of the region within less than 15 minutes, both due to a shortened distance from the neighbouring vegetation. The analysis shows that the clear root cause of the trip was the vegetation not being trimmed in accordance with the operational limits (since the acceptable current is directly determined by the available clearance). The main reason behind this was the underestimation of the risk of a short circuit and the urgency of the situation. These incidents were the initiating factors of the entire incident.

2. The lack of N-1 detection of overloads after the first line outage

The real-time calculations performed between the first and second outage did not reveal any N-1 violations in the area, although subsequent analysis and the facts show that there were N-1 violations in the grid.

Due to the status of the real-time observability area and despite the recurrence of the automatic real-time N-1 calculation (every 15 minutes), it was not possible to see that the grid wasn't secure after the trip of 400 kV OHL Podgorica – Ribarevina.

Furthermore, some TSO contingency lists did not include the external contingency, which prevented them from assessing the consequences of the second trip on the grid.

3. The failure to detect the potential voltage instability of the area

The available and existing tools were, by design, not able to detect any risk of voltage instability in the region. The situation was not considered abnormal or requiring any urgent action. Voltages were regarded as normal and even better than usual, as they were below 420 kV, and this region typically struggles with voltages above 420 kV.

An ex post study was performed to analyse the influence of the disconnection of the 400 kV OHL Tuzia 4 – Višegrad during the voltage collapse. The RCC investigation team conducted the study based on the improved IDCF model, which clearly showed that including this line would not have significantly improved voltage instability prevention. Keeping the line out of service was actually crucial for maintaining the stability of HPP Višegrad.

4. The disconnection of three lines due to overcurrent protection

Subsequent to the second outage, several overloads occurred in the grid and three lines were disconnected by overload protection. These protections acted within seconds, preventing dispatchers from taking any action to reduce the flows in the grid. The analysis revealed a very quick (within 31.5 seconds) cascading trip of three lines caused by overcurrents (around 120–130 %) and the short time delay setting of the protection.

5. The automatic action of voltage transformers

ULTC transformers (HV/MV) in most areas were in automatic control mode, which keeps lower voltage levels as stable as possible within the defined voltage range. A side effect of this mode is that it tends to lower the voltages on the higher voltage level due to the increased reactive power demand of the underlying distribution grid. There was no blocking performed on these automatic tap changers, which further reduced voltages in the EHV grid.

6. Insufficient means to support the voltage

Analysis shows that during the event, the available voltage support was insufficient to stabilise the voltage. This lack of control measures contributed to the voltage collapse. Moreover, the investigation showed that there are no specific tools or procedures dedicated to monitoring and preventing a voltage collapse.

7. The need for more measures to prevent a voltage collapse

The region has no additional actions planned in the defence plan. Actions suggested by the NC E & R are not obligatory and have not been implemented by the affected TSOs, as the need had not yet been established.

9.2 Derivation of Recommendations and Internal Actions from the Main Causes of the Blackout

This section presents the recommendations and actions linked to the main causes of the incident.

These recommendations are expected to have the most significant impact on preventing future critical incidents under similar conditions. Additionally, affected TSOs have implemented and will continue to implement various small improvements based on local analysis.

The recommendations are presented in a table previously agreed upon by ENTSO-E, ACER, and NRAs to follow up on the recommendations from previous ICS Scale2 incidents.

The figure below shows where the recommendations are linked to the root cause tree, with 1 referring to recommendation R2401, 2 referring to R2402, and so on

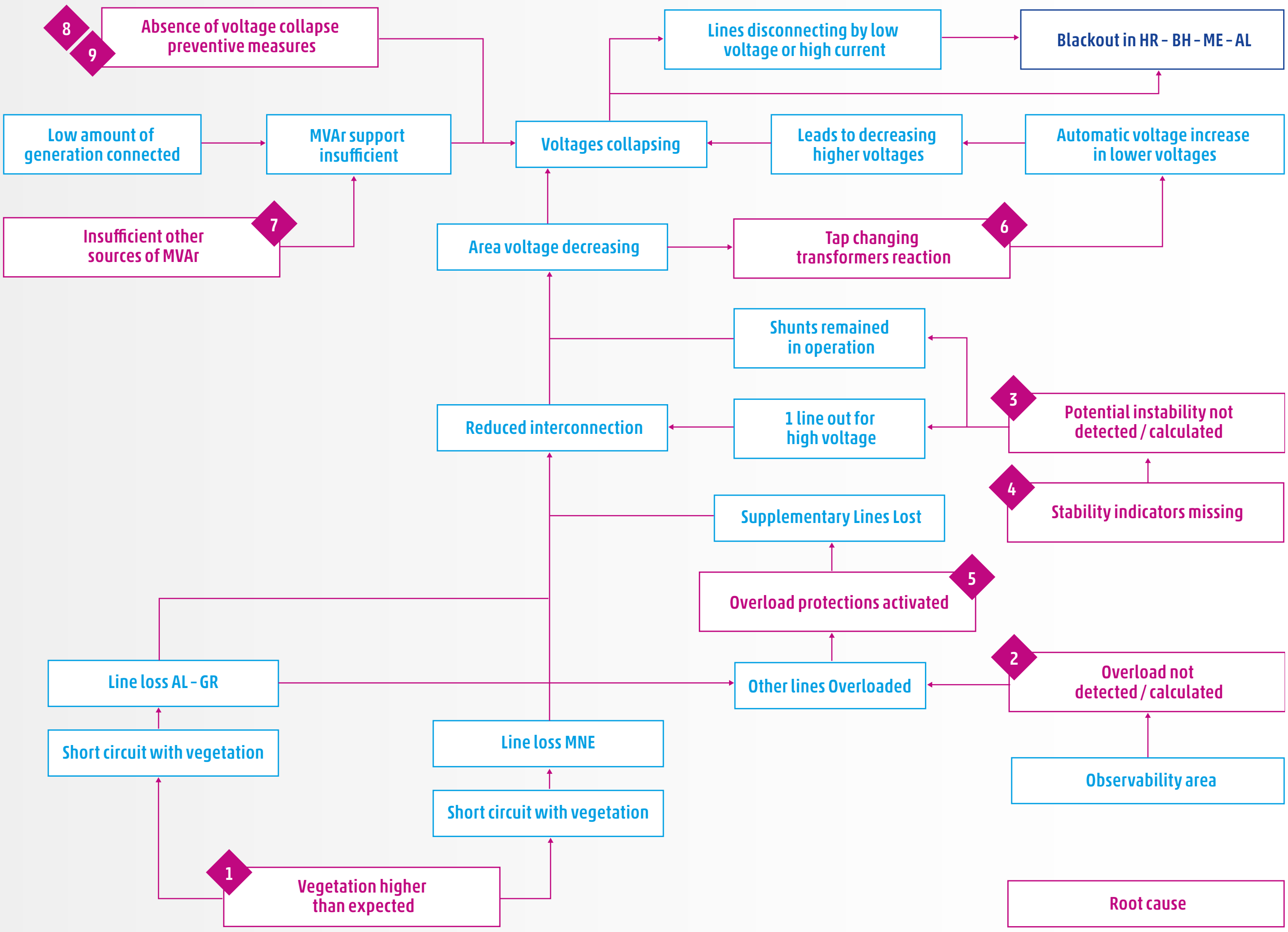


Figure 109: Root cause tree linked with recommendations

9.2.1 The Short Circuits on Lines 400 kV Podgorica – Ribarevina and 400 kV Zemblak – Kardia

R2401	Check the national policy and operational process of vegetation growth control near the OHL and review them if needed.		
Deliverable	Confirmation of the successful check or new national policy and operational process of vegetation growth control near the OHL. This check aims to improve vegetation growth control and better consider the effect of increasing OHL sag due to changing climate conditions.		
Justification	Avoid line short circuit with neighbouring vegetation.		
Delivery Owner	All ENTSO-E member TSOs	**Priority**	High

9.2.2 The Lack of N-1 Detection of Overloads After the First Line Outage

R2402	Evaluate the N-1 calculations of incidents in the neighbouring grid in the real-time EMS-SCADA systems and if needed adjust the observability areas within the SCADA systems of affected TSOs if needed.		
Deliverable	After the split of 8 January 2021, recommendation R6 was reviewed and harmonised the observability area approaches. Using the real-time EMS-SCADA systems, evaluate the applied observability area to determine what was visible in the other grids and evaluate the N-1 calculations of incidents in the neighbouring grid. Confirmation of the successful check of the observability area and the quality of the N-1 calculation, or confirmation of the improvement of the calculations. Check if RCC could help identify and bridge the gaps in the individual TSOs' observability areas. For example, RCCs could be equipped with a data acquisition and visualisation tool that allows larger observability in the RCC geographical scope. Check the observability of other grids in each SCADA system to ensure the grid elements that can impact stability and N-1 security are observable in real time and included in the contingency list as external contingencies to be simulated. Ensure proper propagation of data to other TSOs required to implement the defined observability area.		
Justification	This is a legal requirement from SOGL. Increasing situational awareness from neighbouring TSO grids will help with the timely identification of preventive or curative remedial actions. Extending N-1 calculations will help better predict the effects of incidents in neighbouring grids on potential overloads or voltage issues in the proper grid.		
Delivery Owner	All affected TSOs	**Priority**	High

9.2.3 Failure to Detect the Potential Voltage Instability of the Area

R2403	Regular assessment of voltage stability aspects in operational planning		
Deliverable	Each TSO shall perform a dynamic stability assessment at least once a year or, in the case of significant changes in the grid (e.g. unplanned topology changes/unavailability of lines or reactive power resources), to identify the stability limits and possible stability problems in its transmission system. All TSOs of each synchronous area shall coordinate the dynamic stability assessments, which shall cover all or parts of the synchronous area. This should include an assessment of any situation potentially resulting in voltage collapse. Based on this, additional voltage support or defence measures shall be identified.		
Justification	As ex post analysis identified the risk of lack of voltage stability (cf. Art 38.5 of SOGL), a regular stability check can help identify potential instabilities and suitable countermeasures. This regular check can also help identify and justify the need for additional voltage support measures in the grid.		
Delivery Owner	All affected TSOs with the support of SPD experts	**Priority**	Medium

R2404	Analyse the possibility of identifying an easy-to-use KPI or tool to proactively detect reduced voltage stability and the risk of voltage collapse.		
Deliverable	Analysis of the possibility of identifying and, if feasible, developing guidelines for indicators that detect potential reduced voltage stability and the risk of voltage collapse.		
Justification	Any indication of a weakened grid can create a sense of urgency to act before another incident occurs. This can prevent voltage collapse if action is taken quickly enough before the next incident.		
Delivery Owner	Various specialists on system (voltage) stability within ENTSO-E, mainly from SPD. Specific TF to be set up.	**Priority**	Low

9.2.4 The Disconnection of Three Lines Due to Overcurrent Protections

R2405	Review the existing ENTSO-E guidelines on overcurrent protections in OHLs to assess the potential for updating them based on the findings of this incident. Each ENTSO-E member to check their policy of installing overload (or overcurrent) protections in OHLs and review these settings, taking into account the reviewed ENTSO-E guidelines.		
Deliverable	1. Review of the guidelines to ensure that if overload or overcurrent protections are in place, the time delay for activation allows the dispatcher sufficient time to react and lower the overload to within acceptable limits. 2. Confirmation of the successful review or policy of overload or overcurrent protections in OHLs, including an explanation of the reasons and settings where required.		
Justification	Overload and overcurrent protection with a short delay and strict settings on a transmission grid should not increase the risk of cascading failures. These protection settings have also been identified as a main contributor to the system split of January 2021.		
Delivery Owner	All ENTSO-E members and PE WG	**Priority**	High

9.2.5 Automatic Action of Voltage Transformers

R2406	Blocking the ULTC (under-load tap changers) of transformers (V)HV-MV and VHV-HV where appropriate (depending on renewable infeed and load characteristics)		
Deliverable	Blocking on-load tap changers can support the voltage and avoid a short-term voltage collapse depending on renewable infeed and load characteristics. Therefore, suitable medium voltage grids must be identified for the implementation. This measure can either be implemented manually by the control room or automatically depending on the local voltage.		
Justification	To avoid voltage collapse caused by the adverse effects of automatic tap-changing transformers		
Delivery Owner	All ENTSO-E members, protection and dynamics specialists in ENTSO-E	**Priority**	High / Medium

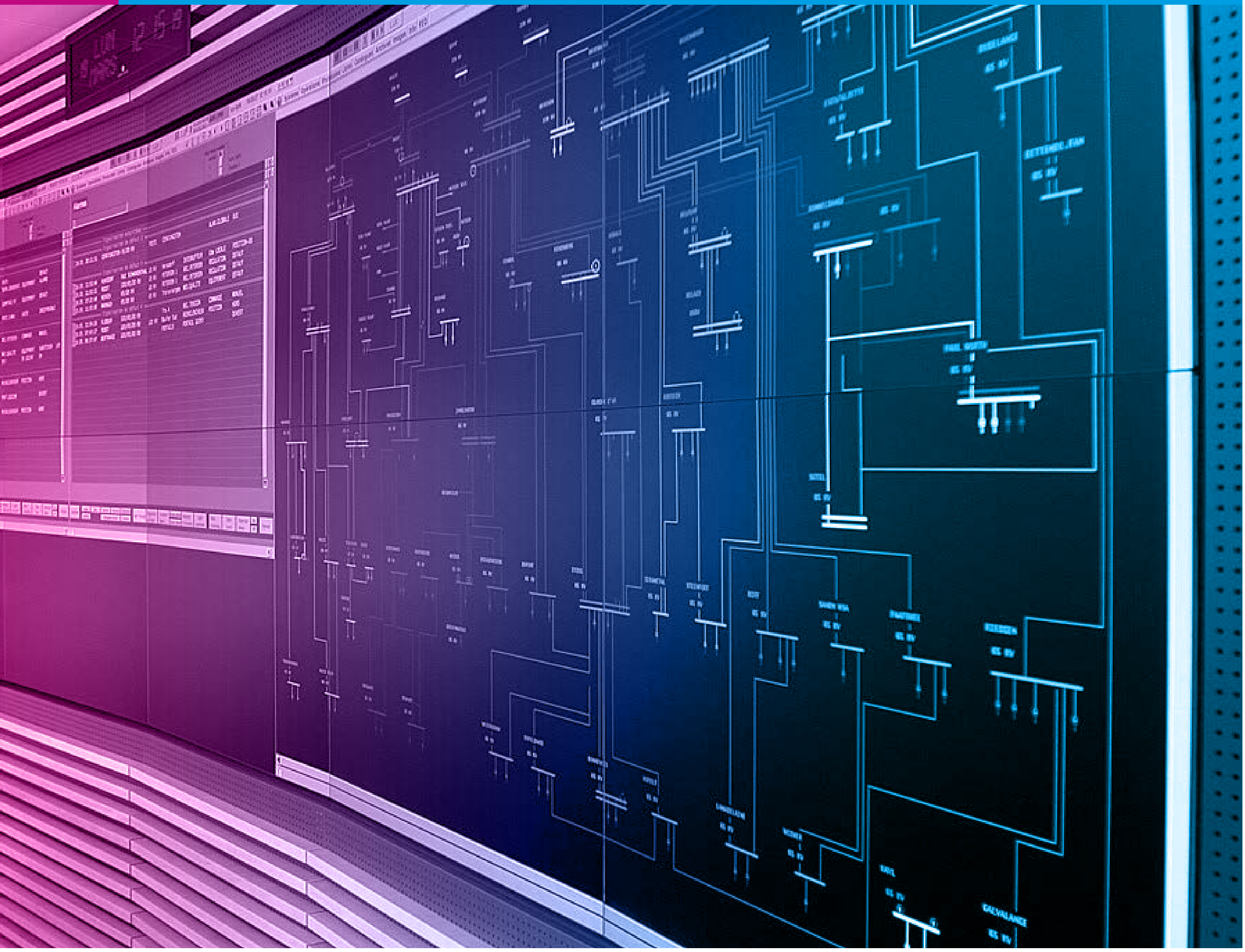
9.2.6 Insufficient Means to Support Voltage

R2407	Perform a voltage and reactive power assessment for potential low-voltage situations to be considered during the system design. Review the installation of support measures in areas where there is a risk of voltage collapse.		
Deliverable	ENTSO-E to develop best practice guidelines on voltage support measures and studies on voltage stability Affected TSOs to develop a plan to implement sufficient voltage support measures and add them to the TYNDP and national grid development plans where relevant.		
Justification	Having sufficient MVAr support meansmeasures will help avoid voltage collapse in a weakened grid.		
Delivery Owner	Affected TSOs and voltage experts in ENTSO-E StG Resilient Operation	**Priority**	High

9.2.7 Need for Additional Measures to Prevent Voltage Collapse

R2408	Investigate the possibility of implementing an automatic emergency control concept for reactive power compensation devices on MVAr sources (for instance, capacitors IN, inductors OUT) at preset extreme voltage levels.		
Deliverable	Analysis of the feasibility of implementing an automatic emergency control concept that activates inductors during high voltage situations or capacitors during low voltage situations to help stabilise the voltage and avoid voltage collapse. The analysis should consider that thresholds, activating times, etc. must be coordinated carefully to avoid unwanted control interactions. Additionally, it can be investigated whether automatic switching of a generator's control mode in extreme voltage situations can help. Reactors, such as those at the Monita converter station, require specific analysis due to the peculiarities described in the report. Investigate voltage set points for generation units and loads utilising special protection schemes.		
Justification	During a voltage collapse, manual control of reactive power devices might not be possible in time. Voltage collapse might be avoidable through automatic control of reactive power devices supporting the voltage.		
Delivery Owner	All ENTSO-E members coordinated on a local or regional level	**Priority**	Medium

R2409	Perform an assessment and consider the feasibility of installing under-voltage load shedding (UVLS) at loads that positively contribute to voltage in cases where there are insufficient alternative means of voltage support.		
Deliverable	Based on a risk analysis for potential voltage collapse cases, determine where it makes sense (risk of voltage collapse could occur after N-2) to install UVLS relays to help avoid voltage collapse. This can serve as an alternative to installing new voltage support measures and while awaiting the installation of these additional measures. In addition, suitable loads that positively contribute to voltage stability must be identified for the implementation. These relays can be set to relatively low voltage levels, such as 340 kV, as demonstrated during the event. Evaluate the possibility of manually changing the set point of the Monita, upon request, in emergency situations where alternative means of voltage support are insufficient.		
Justification	Avoid voltage collapse by having additional stabilising measures installed		
Delivery Owner	All ENTSO-E members	**Priority**	Medium



9.3 Derivation of Recommendations and Internal Actions From the Critical Factors Not Directly Related to the Blackout

This section presents the recommendations linked to the critical factors before the system separation.

9.3.1 Recommendations related to grid model data exchange

R2410	Verify the data provided for tie-lines in the IGMs (Imax, TRM, FRM, etc.)		
Deliverable	TSOs on both sides of a border to agree to use the same limits and parameters in capacity calculation and operational security processes.		
Justification	Harmonisation of parameters avoids misunderstanding between TSOs and unexpected overloads or disconnections.		
Delivery Owner	All affected TSOs	**Priority**	Medium

R2411	Perform timely update of topological changes in IGMs (RCC recommendation)		
Deliverable	All TSOs should check and adjust (if needed) their internal processes to ensure the IGMs reflect topological (scheduled and unscheduled) changes (e.g. topology status, PST, exchange, load and generation). This IGM update should be automatic.		
Justification	During the incident the IGMs were not updated for: » 400 kV OHL Tuzla 4 – Višegrad was out of operation because of high voltage in SS Višegrad and HPP Višegrad, but this was not reflected on the IGM. » The failure at 6:26 AM (TPP Gacko) was not included in the upcoming IDCF merges. » 400 kV OHL Tuzla 4 – Ugljevik was in operation while in planned outage.		
Delivery Owner	All ENTSO-E members in coordination with RCCs	**Priority**	Medium

R2412	Check the quality of voltage and reactive power calculations and identify if improvements are possible (RCC recommendation).		
Deliverable	Review the quality of voltage level calculations performed on CGMs to analyse whether improvements are possible. ENTSO-E to develop best practices guidelines for IGM creation concerning voltage and reactive power.		
Justification	» Forecast models for 21 June 2024 showed significant differences in results compared to the reality, which shows that voltage results are not always trustworthy. » TSOs have previously claimed that the voltage and reactive power accuracy from the DACF and IDCF are insufficient for taking voltage measures before real time. » RCCs do not have access to the necessary data to perform these analyses without the TSOs. » The purpose is to assess the voltage and reactive power situation.		
Delivery Owner	All ENTSO-E members in coordination with RCCs	**Priority**	Low

LIST OF ABBREVIATIONS

A	Ampere(s)
AAA	Adequacy Assessment Agent
ACE	Area Control Error
ACER	Agency for the Cooperation of Energy Regulators
AL	Albania
AVR	Automatic Voltage Regulator
BC	Before Contingency (N state)
BH	Bosnia and Herzegovina
CACM	Capacity Allocation and Congestion Management
CAO (SEE CAO)	Coordinated Auction Office in South - East Europe
CB	Circuit Breaker, Critical Branch
CC	Coordination Centre
CCR	Capacity calculation region
CCC	Coordinated Capacity Calculations
CE	Continental Europe
CEST	Central European Summer Time
CET	Central European Time
CGES	TSO of Montenegro
CGM	Common Grid Model
CGS	Critical Grid Situations
CO	Critical Outage
CSA	Coordinated Security Assessment
CZC	Cross-Zonal Capacity
DACF	Day-Ahead-Congestion-Forecast
DC	Direct Current
DFR	Disturbance Fault Recording
DIFF	Differential Protection
DIST	Distance Protection
DOPT	Daily Operational Teleconference
EAS	ENTSO-E Awareness System
ECA&D	European Climate Assessment & Dataset
EF	Earth Fault
ELES	TSO of Slovenia
EMS	TSO of Serbia
EMS-SCADA	ENTSO-E Awareness System

ENTSO-E	European Network of Transmission System Operators for Electricity
ER NC	Emergency and Restoration Network Code
FR	France
FRM	Flow Reliability Margin
G0, G1	Incidents on Generating Units
GR	Greece
GW	Gigawatt
HOPS	TSO of Croatia
HPP	Hydro Power Plant
HR	Croatia
HU	Hungary
HV	High Voltage
HVDC	High Voltage Direct Current
ICS	Incident Classification Scale
IDCF	Intra-day Congestion Forecast
IGM	Individual Grid Model
Imax	Maximum admissible current through a grid element
Inom	Nominal Current
IPTO	TSO of Greece
IT	Italy
JSC	Joint Stock Company
KOSTT	TSO of Kosovo
KPI	Key Performance Indicator
KS	Kosovo*
kV	Kilovolt(s)
L2	Incident on Load
LCC (HVDC)	Line - Commutated Convertor
LFDD	Low Frequency Demand Disconnection
LVDD	Undervoltage Demand Disconnection
MAN	Manual
ME	Montenegro
MEPSO	TSO of North Macedonia
mHz	Millihertz
MSC	Manual Shunt Capacitor

MSR	Manual Shunt Reactor
MV	Medium Voltage
MVA	Megavolt Ampere
MVAr	Unit for reactive power
MW	Megawatt
MWh	Megawatt-hour, unit of energy
N-1	Potential loss of a single grid element
NCC	National Control Center
NC ER	Emergency and Restoration Regulation
NOSBiH	TSO of Bosnia and Herzegovina
NRA	National Regulatory Authority
NTC	Net Transfer Capacity
OB	Blackout
OC	Overcurrent
OHL	Overhead Line
ON	N-1 violation
OPC	Outage Planning Coordination
OPI	Outage Planning Incompatibilities
OST	TSO of Albania
OV	Violation of voltage standards
PE WG	Protection Equipment workgroup
PMU	Phasor Measurement Unit
pu	Per Unit
PV	Photovoltaic
RAM	Remaining Available Margin
RAOC	Relevant Assets for Outage Coordination
RC	Remaining Capacity
RCC	Regional Coordination Centre
RG CE	Regional Group Continental Europe
RIAR	Regional Incident Analysis and Reporting
RS	Serbia
RSC	Regional Security Coordinator
RT	Real Time
RTSN	Real-time Snapshot
SA CE	Synchronous Area Continental Europe

SAFA	Synchronous Area Framework Agreement
SAM	Synchronous Area Monitor
SCADA	Supervisory control and data acquisition
SEE	South-East Europe
SEE MG	South-East Europe Maintenance Group
SFTP	Secure File Transfer Protocol
SO GL	System Operation Guideline
SOR	System Operation Region
SPD	System protection and Dynamics
SPP	Solar Power Plant
SS	Substation
STA	Shot-Term Adequacy
SVC	Voltage source converter, Static Var Compensator
T1, T2	Incidents on Transmission system
TERNA	TSO of Italy
TIE	Circuit (e.g. a transmission line) connecting two or more CONTROL AREAS or systems of an electric system
TPP	Thermal power plant
TR	Transformer
TRM	Transmission Reliability Margin
TSO	Transmission System Operator
TTC	Total Transfer Capacity
TYNDP	Ten-Year Network Development Plan
UCTE-DEF	Standard data exchange format for IGM and CGM
ULTC	Under-load tap changer
UTC	Universal standard time
UV	Undervoltage
UVLS	Under-voltage Load Shedding
VSC	Voltage Source Converter
VSR	Variable Shunt Reactor,
WOPT	Weekly Operational Teleconferences
WPP	Wind Power Plant

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