» Grid Incident in North Macedonia on 18 May 2025

ICS Investigation Expert Panel
Final Report

20 April 2026

Preamble

This final report has been prepared by the Expert Panel established to perform this technical investigation, in accordance with Article 15 of Commission Regulation (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation (SO GL) and the Incident Classification Scale (ICS) methodology.

The final report provides a factual, technical and objective account of the incident occurred on 18 May 2025 in North Macedonia, to transparently inform stakeholders and governance bodies. Its purpose is to identify the causes of the incident and to recommend measures that strengthen the resilience of the European power system.

The analyses, findings, and recommendations contained in this final report are based on data, documents, and other materials provided by the impacted Transmission System Operators (TSOs). While the Expert Panel has exercised due care and applied its best effort in reviewing and evaluating the information received, it does not independently verify, audit, or validate the completeness, accuracy, or reliability of the data sources. Importantly, the report is not intended to assign liability or responsibility to any party and should not be interpreted as doing so in any way.

This report has been prepared and agreed upon by the Expert Panel. Any analyses, findings, and recommendations set out in this report reflect the Expert Panel's technical assessment at the time of writing and are without prejudice to any investigation or enforcement action that may be taken by the competent authorities.

The recommendations outlined in this report represent a comprehensive set of measures designed to enhance operational robustness, improve cross-stakeholder information exchange, and contribute to maintaining a high level of security of supply across the European power system. The monitoring of the recommendations' implementation provided in this report does not fall within the mandate or remit of the Expert Panel. While voluntary in nature, the recommendations are intended to prompt and support concrete action to help prevent the recurrence of similar events in the future. Any responsibility for the consideration, follow-up and implementation of the recommendations lies with each addressee.

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1 MANAGEMENT SUMMARY

1.1 Introduction

On 18 May 2025, at 04:59 Central European Summer Time (CEST), the power system of North Macedonia experienced an overvoltage episode that led to a separation of the 400 kV and 110 kV voltage levels. The separation led to a loss of stability, supply, and load in the 110 kV transmission network, resulting in a blackout across the entire 110 kV system (to which all the demand is connected). Throughout the event, the 400 kV transmission network remained operational. On the same day, the Bulgarian transmission system was in an alert state for eight hours due to high voltages in the western part of their system. The remainder of the Continental Europe (CE) power system experienced no significant disturbances.

Following the incident, MEPSO, the transmission system operator (TSO) of North Macedonia, immediately activated their system restoration plan, as well as other relevant national operational procedures. The system restoration was completed by 07:47 on 18 May 2025.

Prior to the incident, MEPSO had already identified overvoltage[1] during nighttime in the mid-season (spring and autumn) periods of 2025, as well as previous years and implemented preventive measures, including transformer protection setting optimisation and the disconnection of one internal 400 kV overhead line (OHL). During these periods, consumer demand and active power transits were low, while transmission lines remained energised and lightly loaded, causing reactive power injection into the network. As a result, voltage levels in some 400 kV substations exceeded the normal operational range (360–420 kV).

1 In this report, voltage levels above 420 kV are considered overvoltage situations, as they exceed the normal operating range according to the **North Macedonia Transmission Grid Code.**

1.1.1 Expert Panel and Structure of the Final Report

The incident has been classified as a scale 3 event – the highest severity level under the **Incident Classification Scale (ICS) methodology**.[2] Consequently, pursuant to the same legal framework, an Expert Panel was established and began investigating the incident on 10 July 2025, with the aim of delivering a factual report followed by the final report. Both reports were prepared in line with the ICS methodology applicable at the time of the incident.

In accordance with the ICS methodology, the Expert Panel comprises representatives from both affected and non-affected TSOs, the Agency for the Cooperation of Energy Regulators (ACER), National Regulatory Authorities (NRAs), and convenors from relevant ENTSO-E bodies. The panel is led by an expert from a TSO not directly affected by the incident: Ana Cigarán Romero from 50Hertz (Germany). Overall, the Expert Panel comprises 18 experts: nine from ACER and NRAs, and nine from TSOs and ENTSO-E bodies across Europe (the complete list of Expert Panel members is available on the final page of this report).

One member from each of the affected TSOs participated in and actively contributed to the plenary Expert Panel. In line with the terms of reference, their role was to provide input and suggestions for specific chapters in a transparent and constructive manner, without acting as primary authors of either the factual or the final reports.

This final report builds on the **factual report** published by the Expert Panel on 11 November 2025, as foreseen by the ICS methodology. It presents the collected facts and an analysis of the root causes, offering a comprehensive understanding of the incident and its impact on the power system in North Macedonia and neighbouring countries. The report also includes the Expert Panel's conclusions and recommendations aimed at preventing the recurrence of similar events in the future.

Remarks

- In this report, all times are in CEST, which corresponds to UTC+02:00.
- In this report, the South-East Europe (SEE) region refers to the geographical region covered by the following TSOs: CGES, ELES, HOPS, EMS, ESO, IPTO, MAVIR, MEPSO and NOSBiH

1.1.2 Data Collection

The ICS methodology provides that an Expert Panel established to investigate a scale 2 or 3 incident carries out its investigation based on data reported by the affected TSOs, as listed in Annexes 1 ("Common data for reporting"), 2 ("Specific data reported for depending on the ICS criterion") and 3 ("Additional data for the investigation of scale 2 and scale 3 incidents"). The methodology also indicates that the Expert Panel shall request additional data and information deemed necessary for the investigation, including data owned by third parties not represented in the Expert Panel (e.g. distribution system operators (DSOs) and generators), to be provided by the affected and other relevant TSOs.

In April 2025, MEPSO experienced a failure of the UPS system, resulting in the loss of access to the SCADA historical information system, which remained unavailable during the incident on 18 May 2025. Intensive recovery efforts were undertaken by both the vendor and MEPSO. However, despite these efforts, recovery of historical SCADA data for the time of the incident was unsuccessful. In accordance with the outlined requirements, the necessary operational data have been gathered and delivered by MEPSO, (local SCADA systems at substations and protection device event recordings), and neighbouring TSOs (EMS, ESO, IPTO, OST).

Following the publication of the factual report, neighbouring TSOs provided additional information at the request of the Expert Panel, including frequency measurement data and data from studies and projects carried out in the SEE region, particularly those related to voltage support and reactive power capabilities.

The Expert Panel reviewed this supplementary information and took it into account for the purposes of the final report, contributing to a more comprehensive assessment of system behaviour and operational conditions.

Treatment of Confidential Information

The data collection for this investigation, as well as the preparation of the factual and final reports by the Expert Panel, was conducted in accordance with the ICS methodology and the confidentiality requirements established under both European and relevant national regulatory frameworks.

2 The ICS methodology was developed pursuant to Regulation (EC) No 714/2009 of the European Parliament and of the Council of 13 July 2009, which was repealed by Regulation (EU) 2019/943 and updated to fulfil the objectives under Article 15 (5) of the Commission Regulation (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation (SO GL).

1.2 System and Market Conditions Before the Incident

Chapter 2 summarises the system conditions in the transmission system of MEPSO and neighbouring TSOs before the incident in the early morning hours of 18 May 2025 by investigating the differences between the scheduled and real-time topology, weather conditions during the day, voltage measurements and power exchanges during the three-month period prior the incident, load and production patterns, market conditions, and the results of security analysis conducted before the incident.

Outage planning in the SEE region is coordinated through TSOs and Regional Coordination Centres (RCCs), with annual and weekly meetings to harmonise maintenance plans for transmission elements. Several lines (eight 220 kV and 15 400 kV lines) in the SEE region were disconnected according to planned outages for Calendar Week (CW) 21 (17–23 May 2025). No unplanned outages were reported in the SEE region during this period. The results of the various tasks performed by the RCCs before the incident on 18 May 2025 indicate that the grid was considered secure based on the information available to RCCs, with no major issues detected in the affected area:

- The outage planning coordination (OPC) task, conducted by SEleNe CC and the Security Coordination Centre (SCC), showed no overcurrent 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 coordinated security analysis (CSA) performed by SEleNe CC and SCC revealed no violations on both branches and tie-line (TIE) loadings. The grid was deemed N-1 secure (in terms of power flows). Notably, there was one security breach detected: all 400 kV nodes in the MEPSO control area were predicted to exceed acceptable operational voltage limits[3]. There were no other significant operational security risks.
- For the creation of the common grid model (CGM), MEPSO did not deliver the individual grid model (IGM) for 18 May 2025. This was due to resource allocation and process management constraints. As a result, SCC activated its backup procedure for missing IGMs. Specifically, to create the CGM for the day of the incident, SCC used the most recent IGM provided by MEPSO on 13 May 2025. Regarding the RCC task coordinated capacity calculation (CCC), MEPSO is still in a test-run phase, and the service is not fully implemented.
- For the final report, a comparison was conducted between voltage values from snapshots (SNs), day-ahead congestion forecast (DACF) procedures, and local SCADA measurements for 18 May 2025. The analysis shows that local SCADA voltage measurements align closely with both the original and additional DACF results, while significant deviations are observed in the SN data. These deviations arise because the SN was generated after the incident using an isolated network model of North Macedonia and relying on the State Estimator. As a result, it does not fully reflect the real operating conditions of the interconnected system at the time, particularly regarding cross-border exchanges.

3 In this report, voltage levels above 420 kV are considered overvoltage situations, as they exceed the normal operating range according to the **North Macedonia Transmission Grid Code**.

1.3 Evolution of System Conditions During the Event

The incident on 18 May 2025 involved multiple power transformer (TR) outages across various substations (SS) in the MEPSO control area at the 400 kV voltage level. Significantly, it led to the separation of the 400 kV and 110 kV network. Overvoltage conditions triggered the overvoltage protection of all 400/110 kV transformers (see Chapter 3.2), resulting in two trips at 02:26: TR2 in SS Bitola 2 and TR2 in SS Skopje 5. A few minutes later, at 02:49 and 02:52, respectively, the two power transformers were put back into operation. Shortly after, at 02:59, the TR2 at SS Bitola 2 tripped again, and a second reconnection attempt was unsuccessful. At 03:34, a second trip of the TR2 in SS Skopje 5 400/110 kV was recorded, and a reconnection attempt was unsuccessful. As a consequence of all previous events, at 04:59 CEST, a separation of the 400 kV network from the 110 kV network occurred. The system restoration was completed by 07:47 on 18 May 2025.

The analysis carried out by the Expert Panel concludes, that the incident was initiated by overvoltage[4] conditions in the 400 kV network. These increased voltage levels caused the transformer overvoltage protection to activate, resulting in successive transformer disconnections, the separation of the 400 kV network from the 110 kV network and thus the blackout in the 110 kV network and below.

The event caused a loss of load and generation, with a total generation loss of 313 MW and a load loss of approximately 485 MW in the 110 kV network. The incident affected only the neighbouring Bulgarian TSO (ESO), leaving other neighbouring TSOs unaffected. However, voltage levels above 420 kV during the day of the incident were observed across all neighbouring TSOs. These high voltage levels were not a consequence of the incident, but rather reflected the prevailing system conditions in the SEE region.

1.4 Restoration Process

Following the incident, MEPSO activated their system restoration plan in accordance with Commission Regulation (EU) 2017/2196 of 24 November 2017 establishing a network code on electricity emergency and restoration (NC ER), and national operational procedures. The restoration sequences started at 06:05 CEST and ended at 07:47 CEST. During the incident, communication via mobile phone was established between MEPSO and neighbouring TSOs to coordinate the system restoration process.

During the restoration process, it was observed that reactive power was flowing from the neighbouring systems of EMS and KOSTT into MEPSO's 400 kV network through the interconnections, contributing to increased voltage levels within MEPSO's control area. To reduce the voltages and enable synchronisation of the 400/110 kV transformers, both 400 kV interconnections – Skopje 5 (MEPSO)–Ferizaj (KOSTT) and Štip (MEPSO)–Vranje (EMS) – were disconnected.

This measure allowed voltage stabilisation within the Macedonian network and facilitated the controlled energisation and synchronisation of the 400/110 kV substations, restoring the system to a normal operating state. During the incident, the balancing market and imbalance settlement were suspended from 05:00 to 7:00. The total imbalance of the power transmission system was 250 MWh in the 110 kV grid between 05:00 and 06:00, and 140 MWh in the 400 kV grid between 06:00 and 07:00. The load plan summary for all balance responsible parties was 490 MWh between 04:00 and 05:00, and 423 MWh between 05:00 and 06:00. By 07:00, all market activities had been restored, and all market participants had resumed operation according to their energy production plan, except for generating unit Block 1 at Thermal Power Plant (TPP) Bitola. This unit, connected to the 110 kV busbar in SS Bitola 2 400/110 kV, remained offline until 19:47 CET due to internal operational procedures for synchronising the thermal unit.

4 In this report, voltage levels above 420 kV are considered overvoltage situations, as they exceed the normal operating range according to the **North Macedonia Transmission Grid Code.**

1.5 Communication and Coordination During the Incident

The established communication of coordination is presented in Chapter 5 in chronological order to provide the available information on this matter, while incident-related data are further examined in subsequent chapters. Communication with neighbouring TSOs was established to verify the condition of interconnecting transmission lines, while contact with TPP Bitola confirmed the status of Block 1 and Block 3. At the same time, the MEPSO national control centre (NCC) mobilised a portion of the dispatching team via mobile telephone due to the failure of telecommunication and IT equipment.

Finally, the DSO's dispatching centre provided information on the status of all 110 kV substations.

These assessments and organisational measures created the necessary conditions to begin system restoration. Communication with the RCC was not established at any time during the incident or the restoration process. There was no detected frequency deviation impacting the Synchronous Area Continental Europe (SA CE); therefore, no communication was established with the synchronous area monitor (SAM).

The ENTSO-E Awareness System (EAS) and its corresponding usage procedure were not employed to raise awareness among European TSOs. Thus, the Expert Panel highlights the need to further strengthen effective communication during incidents and the subsequent restoration process.

1.6 Classification of the Incident Based on the ICS Methodology

The ICS methodology was developed in accordance with Regulation (EC) No 714/2009 of the European Parliament and of the Council of 13 July 2009, which was repealed by the Regulation (EU) 2019/943 and updated to fulfil the objectives under Article 15 (5) of the Commission Regulation (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation (SO GL). The ICS methodology aims to provide a realistic view of system states during incidents. The incident classification criteria are ranked by priority, with the highest-priority criterion determining the incident scale.

The methodology stipulates that every incident classified as scale 2 or 3 must be investigated by an Expert Panel.

On 18 May 2025, the scale 3 of incident severity was met in North Macedonia as a result of loss of load in the 110 kV network (classified as OB3). Consequently, the Expert Panel was established based on the requirements of the applicable legislation. Additionally, as neither of these areas was in an emergency state during or after the incident, the incident did not meet the RCC investigation threshold. Additional information is provided in Chapter 6.

1.7 Voltage Control

This chapter analyses the causes, regulatory context, and management of the persistent high-voltage situation in the MEPSO transmission system, with particular focus on the incident of 18 May 2025. It takes into account the applicable technical and regulatory framework, observed voltage conditions at the national and regional levels, the effectiveness of available voltage control methods, and the adequacy of the System Defence Plan. The chapter also outlines measures already implemented and identifies areas that require further action in the field of voltage control.

Regulatory and Technical Framework

The North Macedonian Grid Code incorporates the relevant European Network Codes (SO GL, requirements for generators (RfG), DCC, and NC ER) and assigns MEPSO responsibility for maintaining voltage levels within defined operational limits at both the 400 kV and 110 kV levels. Articles 122, 126, and 195 establish a comprehensive framework for voltage and reactive power management, covering operational measures, permissible voltage ranges, and the procurement and use of reactive power services.

Observed Voltage Situation and Regional Context

The analysis shows a **continuous and systemic increase in voltage levels** in the MEPSO control area from February to May 2025, particularly during nighttime low load periods. The upper voltage limit of 420 kV (under normal conditions) was consistently exceeded, and from mid-April onwards, the short-term limit of **440 kV was exceeded almost daily**. On the day of the incident, voltage levels at several substations approached **450 kV.**

This situation is not unique to North Macedonia but reflects a **regional phenomenon in the SEE region**, driven by:

- Low electricity demand during night hours
- High capacitive reactive power generation of transmission and distribution networks
- Low active power flows and limited cross-border transits
- Lack of sufficient reactive power compensation assets

Reactive power flow patterns on interconnectors further contributed to voltage increases, particularly where neighbouring control areas operated at higher voltage levels.

Operational Measures and Identified Limitations

MEPSO relied primarily on operational measures to manage overvoltage conditions, including:

- Disconnection of internal 400 kV transmission lines
- Transformer tap changer adjustments
- Utilisation of available reactive power capabilities of generating units

However, these measures could not have addressed the structural nature of the problem. Key identified limitations include:

- The absence of shunt reactors or other dedicated reactive power compensation devices in the MEPSO control area
- Reduced reactive power capability of ageing thermal generating units
- Limited operational flexibility under prolonged low-load, high-voltage conditions

Assessment of the System Defence Plan

The MEPSO System Defence Plan is structurally aligned with the NC ER and the Policy on Emergency and Restoration[5] of the Synchronous Area Framework Agreement (SAFA) for Regional Group Continental Europe (RG CE) Annex 5. Nevertheless, it primarily focuses on underfrequency events and system separation scenarios. High-voltage/low-load operating regimes, which are becoming increasingly frequent, are not explicitly addressed as standalone scenarios. As a result, voltage-related risks and preventive actions are not sufficiently reflected. In addition, a gap exists between documented measures and their operational implementation, particularly at the TSO–DSO interface.

Measures Taken and Outlook

Following the incident, MEPSO implemented several targeted measures, including:

- Activating Q-night mode on inverters of large photovoltaic (PV) power plants, connected to the transmission network, to enable reactive power absorption during nighttime hours
- Testing under-excitation operation of conventional generation units (e.g. CCGT TETO Skopje) to support voltage reduction
- Enhancing coordination of transformer tap settings and control modes

In parallel, investment measures at the regional (SEE) level, notably the installation of shunt reactors, are planned as part of a Regional Feasibility Study. These measures are considered essential to address the structural drivers of overvoltage conditions. The ongoing update of the North Macedonian Grid Code, in line with the new Energy Law, aims to further strengthen and clarify voltage and reactive power requirements in line with European best practices.

Key Conclusion

The high-voltage situation in the MEPSO transmission network is a structural and regional challenge, amplified by changing generation patterns, increasing renewable penetration, and low-load operating conditions. While national operational measures are necessary, they are not sufficient on their own. A sustainable solution requires:

- Coordinated regional action
- Deployment of dedicated reactive power compensation assets
- Enhanced operational procedures and planning
- Stronger involvement of all system users in voltage and reactive power management

5 SAFA Policy on Emergency and Restoration

1.8 Actions Taken After the Incident, Root Causes, Recommendations, and Next Steps

This chapter presents the internal actions undertaken in North Macedonia following the incident, the root causes of the event, and the resulting recommendations. The recommendations aim at strengthening voltage control, operational reliability, and system security both nationally and in the SEE region.

Root Causes

The Expert Panel identified that the incident occurred in a system already experiencing recurrent high-voltage conditions, particularly during low-load periods. The main root causes can be summarised as:

- Operating the system above defined voltage limits
- Reduced awareness of risks due to overvoltage in operational planning
- Insufficient reactive power reserves with adequate activation times and limited reactive power support
- Limited availability of effective voltage control assets

While operational countermeasures were taken, including line disconnections and protection setting adjustments, these proved insufficient to prevent the incident.

Recommendations

Based on these findings, the Expert Panel has formulated three comprehensive sets of recommendations:

1/ The continuation and reinforcement of **previously agreed-upon ENTSO-E recommendations** on voltage and reactive power modelling quality, and the development of operationally usable key performance indicators to detect reduced voltage stability and abnormal high-voltage conditions.

2/ The proposal of new **regional recommendations for the SEE region**, focusing on systematic monitoring of voltage limit violations, the development of a coordinated action plan to mitigate high-voltage conditions, and stronger alignment among TSOs on operational voltage control measures, with support from RCCs and ENTSO-E.

3/ The proposal of **specific recommendations for MEPSO to enhance their System Defence Plan**. These include expanding System Defence Plan scenarios to cover low-load, high-renewable, and low-inertia operating conditions; operationalising load frequency defence and restoration procedures at the distribution level; clarifying responsibilities and signalling between TSOs and DSOs; and developing a coordinated system-level protection strategy distinct from asset protection.

Actions Taken After the Incident in North Macedonia

Following the incident, immediate corrective actions were implemented by MEPSO and overseen by the competent NRA of North Macedonia (ERC).

In view of the Expert Panel and SEleNe CC, MEPSO significantly improved the quality and consistency of its IGM delivery, supporting more reliable regional operational planning and voltage assessments. Between December 2025 and February 2026, high-quality IGMs were provided on a nearly daily basis for both day-ahead and intraday coordination processes, contributing positively to regional security analysis performed by the RCC (SEleNe CC).

To address structural voltage control limitations, MEPSO initiated investments in reactive power support, including the procurement of a 150 MVAr variable shunt reactor equipped with automatic voltage control, planned for commissioning by 2027.

In parallel, regulatory measures are being introduced to enable the systematic application of generator reactive power control through amendments to secondary legislation and tariff frameworks. Improvements have also been reported in real-time security analysis, situational awareness, and the use of the EAS for cross-border information exchange.

From a regulatory perspective, ERC undertook inspections and monitoring activities and introduced several regulatory changes. These include updated tariff rules for reactive power consumption and absorption by system users, strengthened obligations for SCADA system readiness and staffing, new licensing requirements linking temporary generation licences to successful compliance testing, and an emphasis on timely planning and financing of voltage control investments. These measures aim to reinforce the TSO's operational role and align national practices with European requirements.

Next Steps

Finally, the chapter highlights ongoing and future work at the regional level, notably through the ENTSO-E RGCE Project Group (PG) on Voltage Control in the SEE Region. This work supports improved regional visibility of voltage and reactive power flows, enhanced coordination in operational planning, and the integration of voltage control considerations into grid development planning. Together, the implemented actions and proposed recommendations provide a structured pathway to address the root causes of the incident and to improve voltage control and system resilience across the SEE region.

2 OPERATIONAL ENVIRONMENT, SYSTEM AND MARKET CONDITIONS BEFORE THE INCIDENT

This chapter describes the existing preconditions and operational environment prior to the incident, as well as the system conditions in the transmission system of MEPSO and of the neighbouring TSOs in the early morning hours before the separation of the 400 kV and 110 kV networks at 04:59 on 18 May 2025.

The chapter further includes an overview of:

» The topology of the transmission system in North Macedonia
» Regional outage coordination in the SEE region[6], including planned and unplanned outages
» Weather conditions during the day
» Electric Power exchanges during the three-month period prior to the incident
» Load and production patterns
» Market conditions
» Results of RCC security analysis before the incident

6 In this report, the SEE region refers to the geographical region covered by the following TSOs: ELES, HOPS, NOSBiH, EMS, KOSTT, MEPSO, OST, CGES, ESO, IPTO, and MAVIR.

2.1 Operational Environment and Preconditions

2.1.1 Topology of the Transmission System in North Macedonia

Figure 2.1 shows the topology of MEPSO's transmission system, as well as its geographical location in the region. Both the 400 kV grid and the 110 kV grid are operated by MEPSO. The transmission system of North Macedonia is connected to the transmission systems of Serbia, Bulgaria, Greece, and the Kosovo[7] via seven interconnectors: five at the 400 kV level and two at the 110 kV level. Hence, the transmission grid of North Macedonia is part of the SEE region.

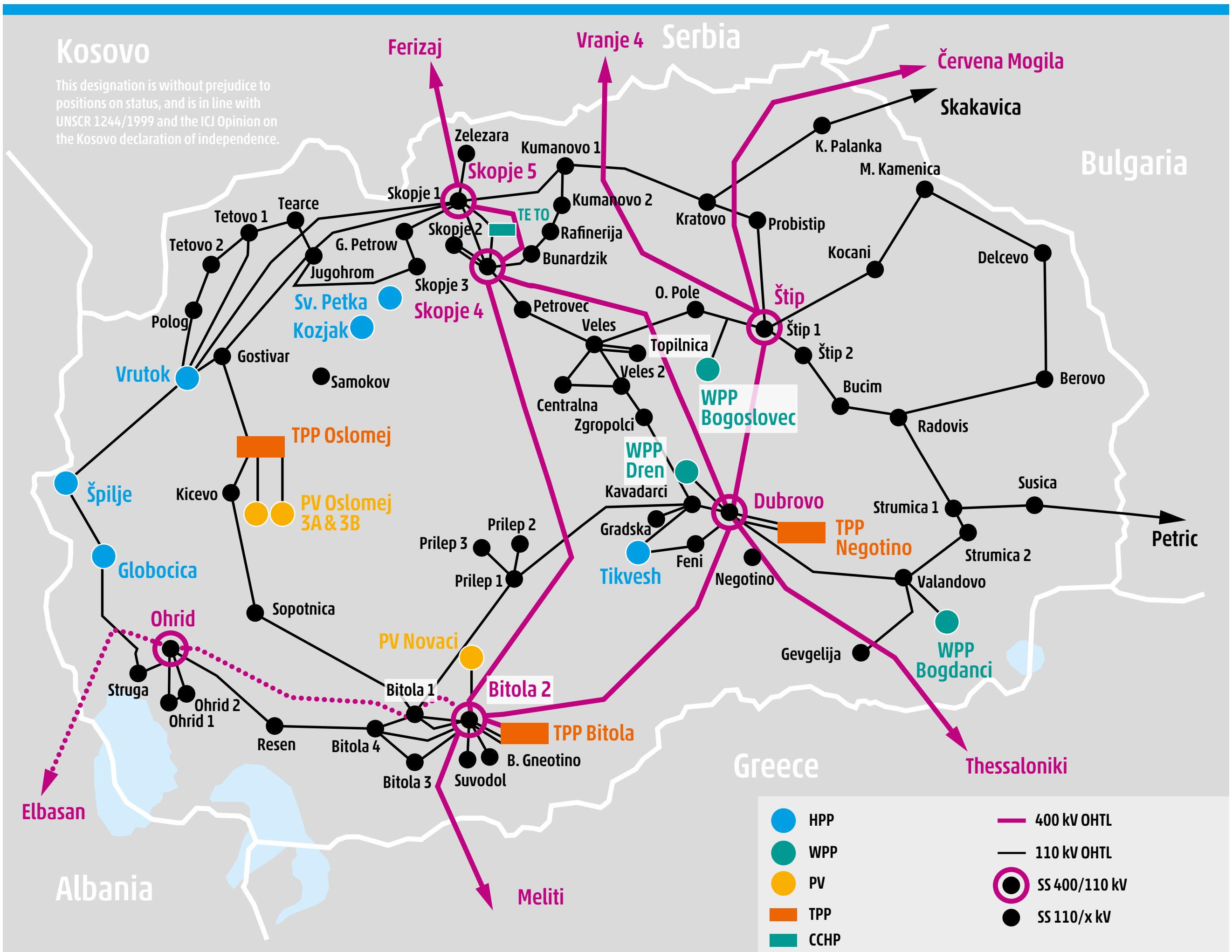


Figure 2.1: Topology of the transmission system of North Macedonia

7 This designation is without prejudice to positions on status and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo declaration of independence.

Table 2.1 shows the generation units connected to the transmission system of North Macedonia, including technical parameters (P_{max}, P_{min}, Q_{max}, Q_{min}).

While only two generators (TTPs) are connected to the 400 kV network (450 MW), more than 800 MW of generation units (including HPP, PV, Wind) are connected to the 110 kV network.

Fuel Type	Name	Connected voltage (kV)	P_{max} (MW)	P_{min} (MW)	Q_{max} (MVAr)	Q_{min} (MVAr)
Coal	BITOLA 110, BLOCK 1	110/15.8	225	135	84	–54
Coal	BITOLA 400, BLOCK 2	400/15.75	225	135	80	–54
Coal	BITOLA 400, BLOCK 3	400/15.75	225	135	80	–54
Coal	OSLOMEJ	110/13.8	130	80	59	0
Heavy Oil	TPP NEGOTINO	110/15.8	210	160	98	0
Gas	TETO-ST	110/15	51	11	46	0
Gas	TETO-GT	110/15	206	6	119	–54
Gas	KOGEL	110/10.5	30	2	6	0
Gas	KOGEL_ELEM	110/6.3	15	9	3	2
Gas	KOGEL_ELEM	110/6.3	15	9	3	2
Hydro	VRUTOK	110/12	43	10	20.8	–18
Hydro	VRUTOK	110/12	43	10	20.8	–18
Hydro	VRUTOK	110/12	43	10	20.8	–18
Hydro	VRUTOK	110/12	43	10	20.8	–18
Hydro	VRBEN	110/35	8.6	4	4.1	0
Hydro	VRBEN	110/35	8.6	4	4.1	0
Hydro	RAVEN	110/35	8.1	4	3.9	0
Hydro	RAVEN	110/35	8.1	4	3.9	0
Hydro	RAVEN	110/35	8.1	4	3.9	0
Hydro	KOZJAK	110/13.8	44	31	33	–32
Hydro	KOZJAK	110/13.8	44	31	33	–32
Hydro	SV. PETKA	110/10.5	18.5	6	9	–10
Hydro	SV. PETKA	110/10.5	18.5	6	9	–10
Hydro	TIKVES	110/10.5	29	15	14	–12
Hydro	TIKVES	110/10.5	29	15	14	–12
Hydro	TIKVES	110/10.5	29	15	14	–12
Hydro	TIKVES	110/10.5	29	15	14	–12
Hydro	ŠPILJE	110/10.5	28	15	13.6	–12
Hydro	ŠPILJE	110/10.5	28	15	13.6	–12
Hydro	ŠPILJE	110/10.5	28	15	13.6	–12
Hydro	GLOBOCIC	110/10.5	21	8	12	–15.8
Hydro	GLOBOCIC	110/10.5	21	8	12	–15.8
Wind	DREN 1	110/20	34	0	2.795	–2.795
Wind	DREN 2	110/20	10	0	0.822	–0.822
Wind	BOGDANCI 1A	110/20	37	0	3.041	–3.041
Wind	BOGOSLOVEC	110/20	36	0	14	–14
Solar	OSLOMEJ ELEM	110/20	20	0	7	–7
Solar	OSLOMEJ 3A	110/20	50	0	16	–16
Solar	OSLOMEJ 3B	110/20	50	0	16	–16
Solar	NOVACI71	110/35	50	0	16	–16

Table 2.1: Technical parameters of generating units connected to the Macedonian transmission system

2.1.2 Regional Outage Coordination

As a part of regional outage coordination, all TSOs from the SEE region – OST (Albania), NOS BiH (Bosnia and Herzegovina), ELES (Slovenia), ESO (Bulgaria), IPTO (Greece), HOPS (Croatia), MAVIR (Hungary), KOSTT (Kosovo[8]), CGES (Montenegro), MEPSO (North Macedonia), Transelectrica (Romania), EMS (Serbia), and TEIAŞ[9] (Türkiye) – regularly participate in the pan-European Outage Planning Coordination (OPC) process under the framework of the SEE Maintenance Group (SEE MG).

The SEE MG is a dedicated regional forum composed of EU and non-EU TSOs and Regional Coordination Centres (RCCs) – SEleNe CC, and SCC. Its primary role is to coordinate planned outages of relevant elements across the SEE region on the 400 kV internal overhead lines (OHLs) and tie-lines (TIEs), as well as the relevant[10] 220 kV OHLs and TIEs. The OPC process does not consider generation or load outages. In terms of potential security limit violations, the OPC process only assesses violations of maximum current limits, not voltage limit violations.

Note: *As of 1 November 2025, SeleneCC is the RCC for coordinating planned outages involving the transmission system of MEPSO.*

Outage coordination within the SEE MG follows a structured process covering several planning time frames:

1/ Year-ahead coordination, where TSOs exchange and harmonise annual maintenance plans to ensure security of supply and sufficient cross-border capacity

2/ Month-ahead coordination, where amended maintenance schedules are communicated and confirmed among all involved TSOs, ensuring continued alignment

3/ Week-ahead coordination, during which planned outages are confirmed or adjusted based on updated system conditions and interdependencies

4/ Real-time information exchange, ensuring continuous monitoring and adaptation in case of unexpected events or changes in system topology

This coordinated approach enhances operational reliability, regional transparency, and alignment with the ENTSO-E OPC process at the pan-European level.

8 This designation is without prejudice to positions on status and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo declaration of independence.

9 TEIAŞ is an observer member.

10 Here, relevant means "impacting the transmission system of a neighbouring TSO".

2.1.2.1 Planned Outages in the Transmission System of MEPSO and Neighbouring TSOs

Planned outages for calendar week (CW) 21 (17–23 May 2025) are shown in Table 2.2. There were no outages planned in the transmission system of MEPSO during this week.

Element	Start Date	Start Time	End Date	End Time	Daily/ Permanently	Restitution Time [h]
OHL 220 kV Kolacem (OST) – Tirana 2 (OST) CKT 1	17.2.2025	00:00	01.6.2025	23:00	P	N
OHL 220 kV Tirana 2 (OST) – Koman (OST) CKT 1	17.2.2025	00:00	01.6.2025	23:00	P	N
TIE 400 kV Arachthos (IPTO) – Galatina (TERNA) CKT 1	23.2.2025	13:37	29.5.2025	15:00	P	N
OHL 220 kV Brinje (HOPS) – Padene (HOPS) CKT 1	24.4.2025	07:00	01.7.2025	19:00	P	N
OHL 400 kV KOZLODUY (ESO) – SOFIA ZAPAD (ESO) CKT 1	10.5.2025	06:00	23.5.2025	18:00	D	3
OHL 400 kV MARITSA IZTOK (ESO) – BURGAS (ESO) CKT 1	12.5.2025	07:00	23.6.2025	16:00	P	N
OHL 400 kV HAMITABAT (TEIAŞ) – ALIBEYKOY (TEIAŞ) CKT 1	19.5.2025	06:00	19.5.2025	18:00	D	N
OHL 400 kV Bucuresti Sud (TRANSELECTRICA) – Slatina (TRANSELECTRICA) CKT 1	19.5.2025	07:00	19.5.2025	12:00	D	0.5
OHL 220 kV Fireze (OST) – Peshqesh (OST) CKT 1	19.5.2025	08:00	20.5.2025	16:00	D	1
OHL 400 kV Smederevo 3 (EMS) – Drmno (EMS) CKT 1	19.5.2025	08:00	20.5.2025	16:00	P	N
OHL 400 kV TSAREVETS (ESO) – VARNA (ESO) CKT 1	19.5.2025	07:00	20.5.2025	16:00	D	1
OHL 400 kV Novi Sad 3 (EMS) – Srbobran (EMS) CKT 1	19.5.2025	08:00	22.5.2025	18:00	P	N
OHL 220 kV Timisoara (TRANSELECTRICA) – Sacalaz (TRANSELECTRICA) CKT 1	19.5.2025	06:00	23.5.2025	17:00	D	2
TIE 220 kV Djakovo (HOPS) – Gradacac (NOS BiH) CKT 1	19.5.2025	07:00	23.5.2025	15:00	P	N
OHL 400 kV Meliti (IPTO) – Amynteo (IPTO) CKT 1	19.5.2025	07:00	23.5.2025	17:00	D	N
TIE 220 kV Krusevac 1 (EMS) – Podujevo (KOSTT) CKT 1	19.5.2025	07:00	23.5.2025	18:00	D	1
OHL 220 kV FNE Hodovo (NOS BiH) – Trebinje (NOS BiH) CKT 1	19.5.2025	08:00	23.5.2025	14:00	D	1
TIE 400 kV DOBRUDZHA (ESO) – MEDGIDIA SUD (TRANSELECTRICA) CKT 1*	19.5.2025	07:00	30.5.2025	17:00	D	3
OHL 400 kV Paks (MAVIR) – Sandorfalva (MAVIR) CKT 1	19.5.2025	07:00	6.6.2025	19:00	D	5
TIE 400 kV Konjsko (HOPS) – Mostar 4 (NOS BiH) CKT 1	20.5.2025	08:00	20.5.2025	15:00	D	N
TIE 220 kV Djakovo (HOPS) – Gradacac (NOS BiH) CKT 1	20.5.2025	09:00	20.5.2025	14:00	D	0.5
OHL 400 kV Smederevo 3 (EMS) – Drmno (EMS) CKT 1	21.5.2025	08:00	23.5.2025	16:00	D	1
OHL 400 kV Kosovo** B (KOSTT) – Uroševac 2 (KOSTT) CKT 1***	23.5.2025	08:00	29.5.2025	18:00	D	2
OHL 400 kV Novi Sad 3 (EMS) – Srbobran (EMS) CKT 1	23.5.2025	07:00	23.5.2025	18:00	D	1

* Without 24.05.2025 and 25.05.2025
** Kosovo: This designation is without prejudice to positions on status and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo declaration of independence.
*** Without Sunday 25.05.2025

Table 2.2: Planned outages for CW 21 (17–23 May 2025), as of Friday 16 May at 1:00 PM in the SEE region.

As shown in Table 2.2 and Figure 2.2, on the **day of the incident**, there were no relevant outages planned in the transmission system of MEPSO and no relevant planned outages in the neighbouring transmission systems of EMS and KOSTT. Several outages were planned in the neighbouring transmission systems of ESO, IPTO, and OST, which are long-term/permanent over a period of several weeks or months. Moreover, the outage elements in these TSOs are not geographically close to the MEPSO system.

Figure 2.2 below shows the planned disconnections for CW 21 (17–23) May 2025 across the entire SEE MG region.

Figure 2.2: Planned outages for CW 21 (17–23 May 2025), as of Friday 16 May at 1:00 PM in the SEE MG

2.1.2.2 Unplanned Outages in the Transmission Systems of MEPSO and Neighbouring TSOs

No unplanned transmission outages occurred in the transmission systems of EMS, ESO, IPTO and KOSTT and MEPSO

2.1.3 Weather Conditions

The weather on Sunday, 18 May 2025 was clear throughout the day, with a nighttime temperature of 5 °C and a daytime temperature reaching up to 25 °C in the city of Skopje, as shown in Figure 2.5. In the morning, winds from the northwest reached a speed of 2 km/h. In this part of Southeast Europe, this time of year is characterised by rising day and night temperatures, when households typically do not use cooling or heating. These weather conditions can be considered a prerequisite for the "spring effect" – a seasonal phenomenon in which low electricity demand coincides with higher levels of renewable generation.

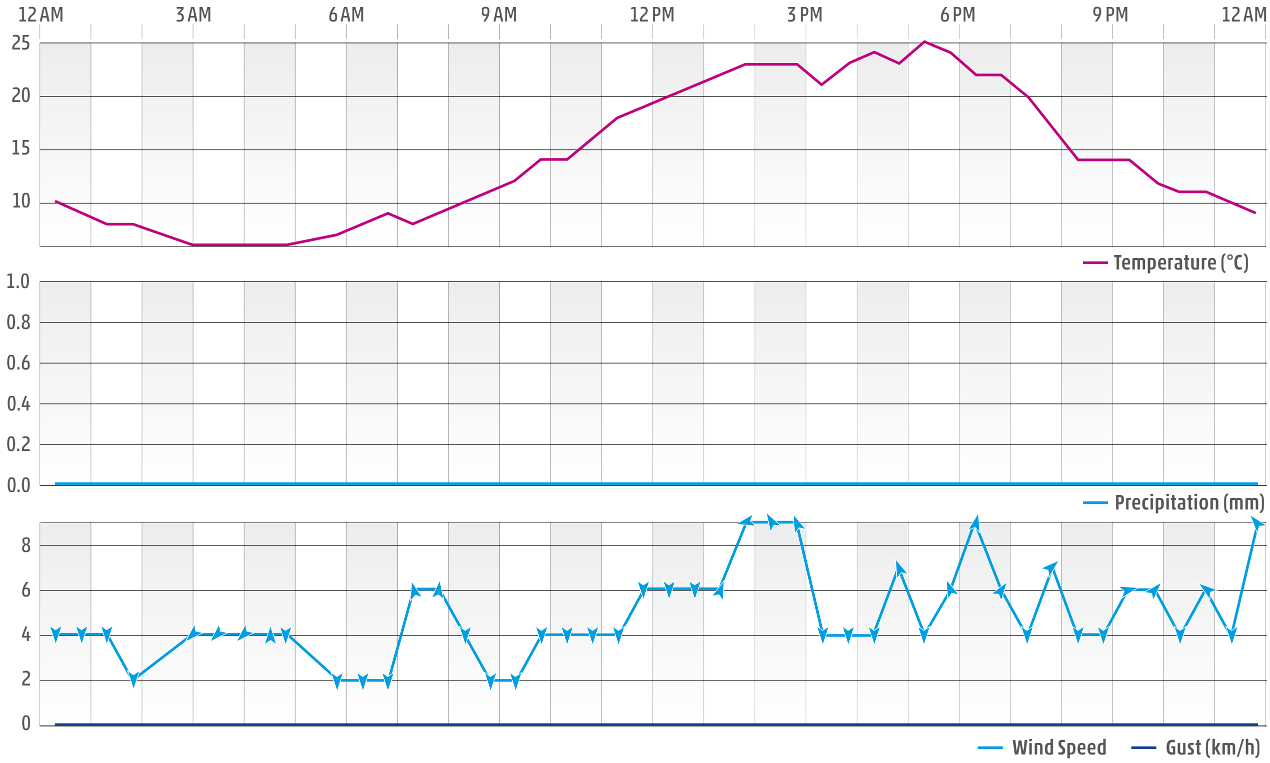


Figure 2.3: Weather conditions in the city of Skopje, North Macedonia, on 18 May 2025[11]

2.1.4 Situation of Tools and Facilities

The main control centre (Skopje) operates with two independent uninterruptible power supply (UPS) systems, i.e. primary and secondary UPS. Before April 2025, all SCADA/Energy Management System (EMS) components were connected to the primary UPS.

On 19 April 2025, a failure occurred in the primary UPS. As a result, MEPSO had a complete SCADA/EMS outage from 22:45 to 00:15 (the following day). SCADA functionalities (monitoring and control) were restored by 00:15, but the Historian (HIS) servers and archiving functions remained unavailable until 21 July 2025.

Nevertheless, SCADA Enterprise storage and Spectrum Sub-Distribution Board (SDB) faced corruption issues, and the dispatch centre workstations and video wall were without UPS power until 31 July 2025.

MEPSO took the following corrective actions:

» Migration of SCADA/EMS and critical systems to the secondary UPS

» Launch of procurement for servicing the defective UPS

» Recovery and redesign of enterprise storage (migration of databases to local disks)

11 Source: https://www.wunderground.com/history/daily/mk/ilinden/LWSK/date/2025-5-18.

On 18 May 2025, the second incident affecting the SCADA system occurred. The cause was a national power outage at 04:59, where:

- SCADA/EMS remained available.
- Dispatch centre workstations and video wall were unavailable until 06:15.
- Dispatchers were temporarily relocated to the SCADA administrative area to monitor the system.

The following issues remained unresolved from 19 April until 21 July 2025:

- HIS (archiving) and modelling remained non-functional.
- Dispatch centre equipment remained without UPS power.

Following this event, MEPSO took the following corrective actions:

- National Dispatching Centre (NDC) equipment (workstations, video wall, switches) was connected to the secondary UPS.
- HIS servers were upgraded, and the SCADA backup system was redesigned.

Since July 2025, the SCADA/EMS system and both primary and secondary UPS have been fully operational.

2.2 System Conditions Before the Incident

2.2.2 Active Power Flows Before the Incident

2.2.2.1 Load Pattern

The daily load profile of the transmission system of MEPSO on 18 May 2025 is presented in Figure 2.4, which shows the load in the distribution system, large consumers, and the total system load. The marked period clearly highlights the significant drop in load around 06:00, corresponding to the incident, followed by a gradual recovery and increase throughout the day.

Overall, the registered load pattern is typical for this time of year and does not indicate any extraordinary deviation.

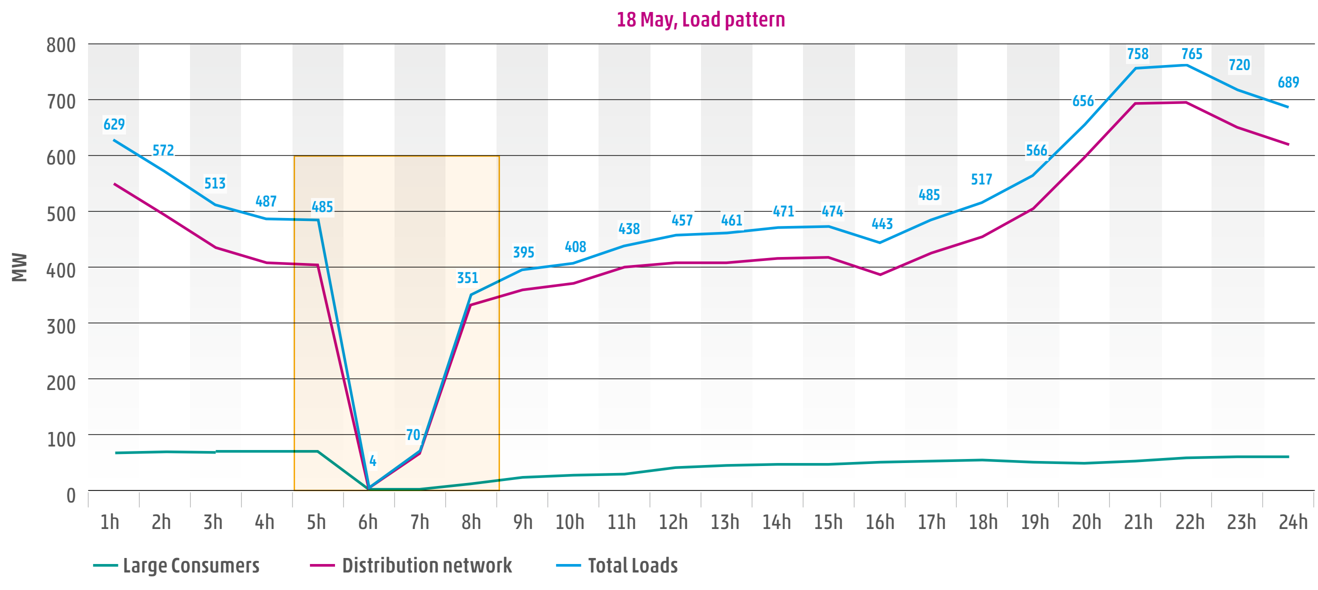


Figure 2.4: Load pattern in the transmission system of MEPSO on 18 May 2025, with the black box illustrating the hours impacted by the incident

2.2.2.2 Production Pattern

Figure 2.5 illustrates the hourly electricity production by generation type on 18 May 2025. At around 06:00, almost all generation units were disconnected from the grid. Only Thermal Power Plant (TPP) Bitola Block 3, connected to the 400 kV busbar in Substation (SS) Bitola 2, remained in operation. This unit provided the only local generation during the blackout, supporting voltage stability and enabling the subsequent restoration process. Generation from Hydropower Plants (HPP), Photovoltaic Plants (PV), and Wind Power Plants (WPP) resumed gradually as the system was restored throughout the morning.

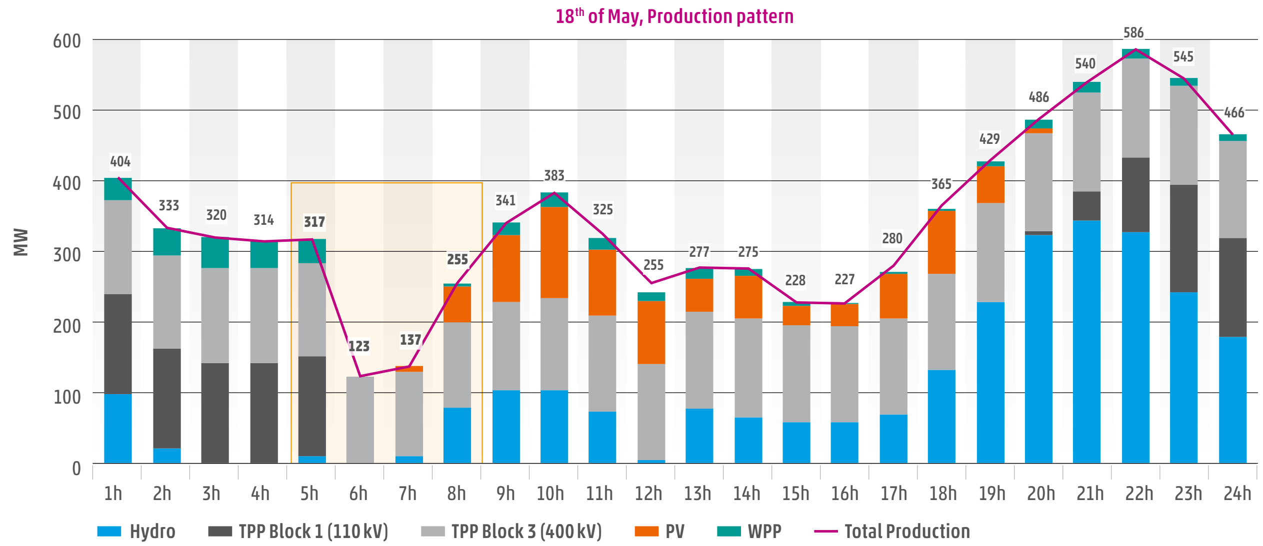


Figure 2.5: Hourly electricity production by generation type on 18 May 2025, with the black box illustrating the hours impacted by the blackout

2.2.2.3 Cross-Border Flows

Figure 2.6 presents the hourly cross-border active power flows between MEPSO and the neighbouring TSOs on 18 May 2025. Despite the system disturbance that occurred early in the morning, no interruption of electric power exchange was recorded on the 400 kV interconnections. Both national transmission and interconnection lines remained in operation, ensuring stable power exchange and system coordination throughout the day. The direction and magnitude of power flows reflect normal regional operation, with no extraordinary deviations observed.

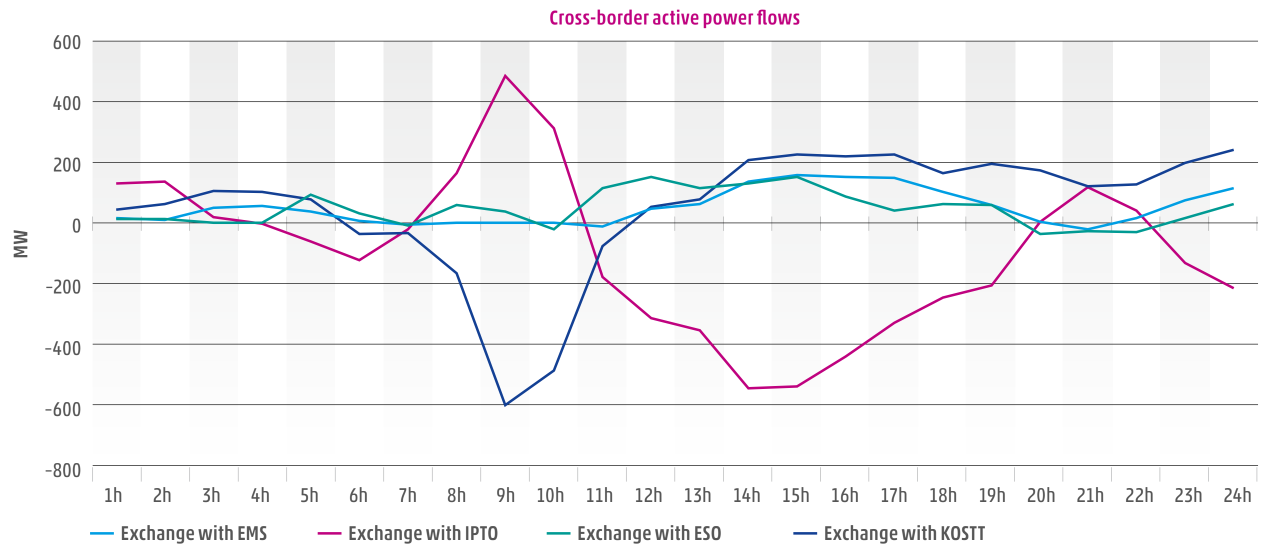


Figure 2.6: Active power exchange profile with neighbouring transmission systems, 18 May 2025

Prior to the system disturbance, the power system of North Macedonia was in an importing position, with a total net import by MEPSO of around 155 MW at 04:00 and 151 MW at 05:00, as shown in Figure 2.7. This means that generation was lower than load, and the deficit was covered through imports. During the incident, imports dropped sharply, and exports increased. The exchange directions turned, and MEPSO became a net exporter.

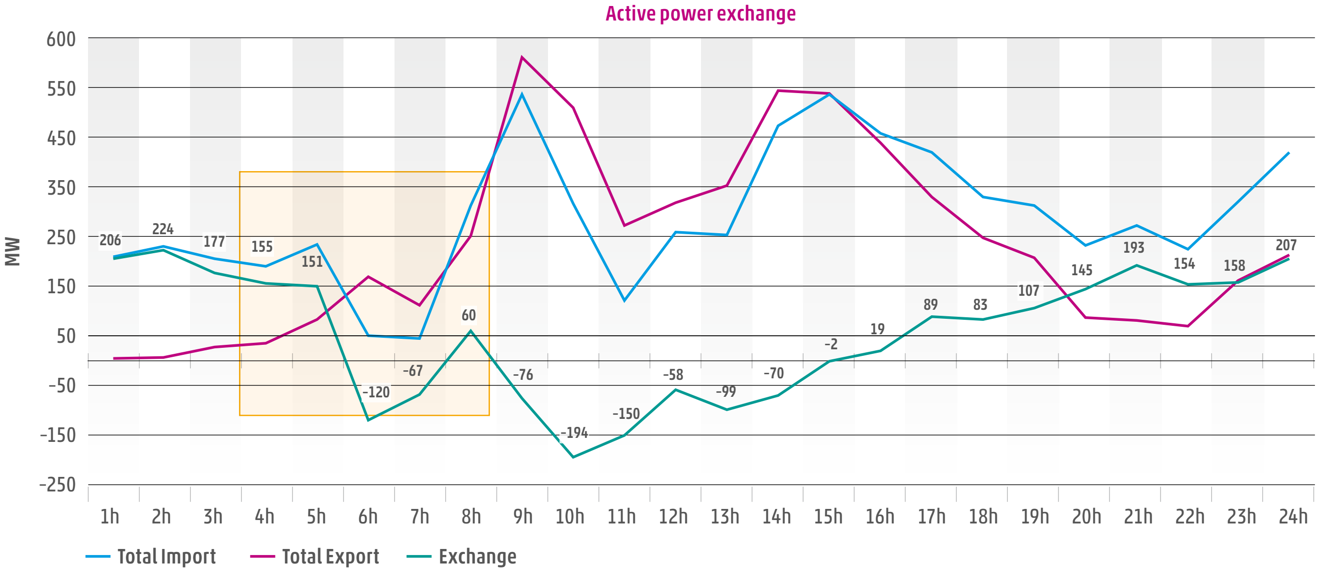


Figure 2.7: Hourly variation of cross-border active power exchange

The following Figures (Figures 2.7–2.11) present the active power flow patterns across MEPSO's 400 kV interconnections. The Figures show a long-term series (March–May 2025), illustrating the typical variability and direction of power exchange.

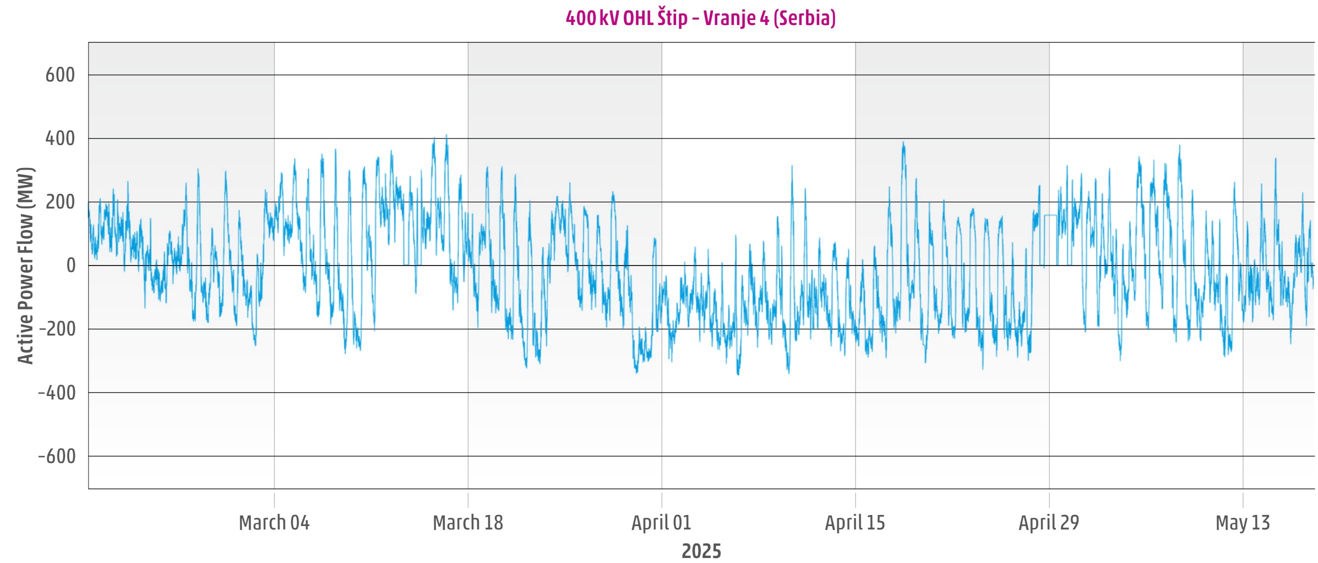


Figure 2.8: Active power flow on the 400 kV OHL Štip–Vranje 4 (EMS)

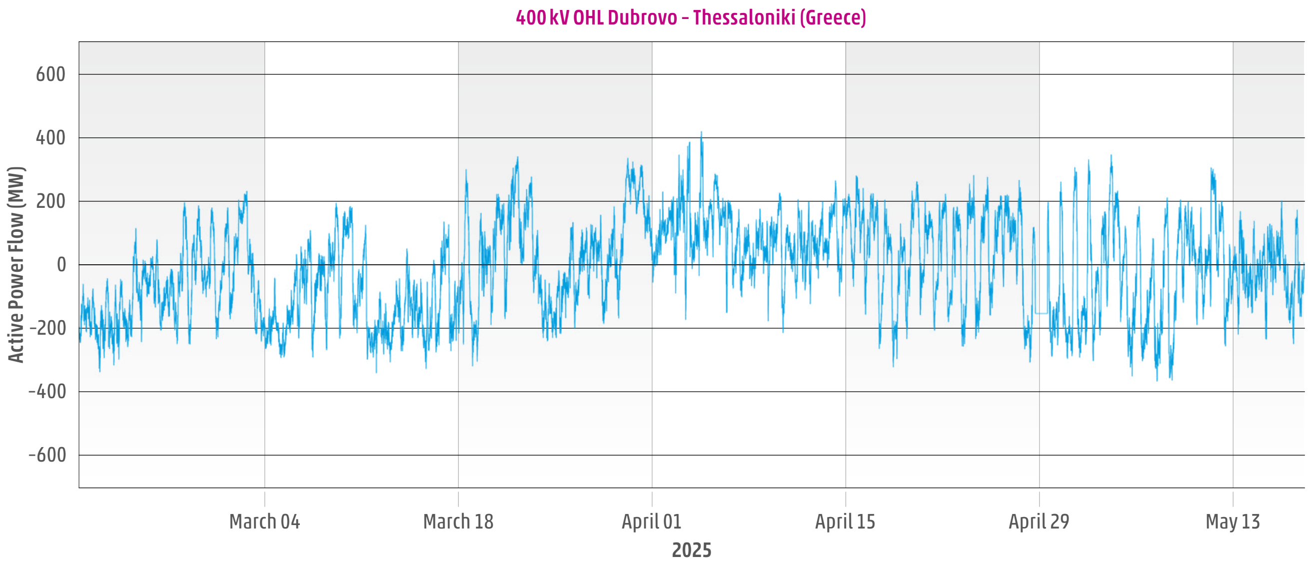


Figure 2.9: Active power flow on the 400 kV OHL Dubrovo–Thessaloniki (IPTO)

The long-term trend of active power flows towards IPTO shows high variability, with alternating import and export flows.

The interconnection is frequently used for power balancing and reflects strong cross-border dependency with the Greek system.

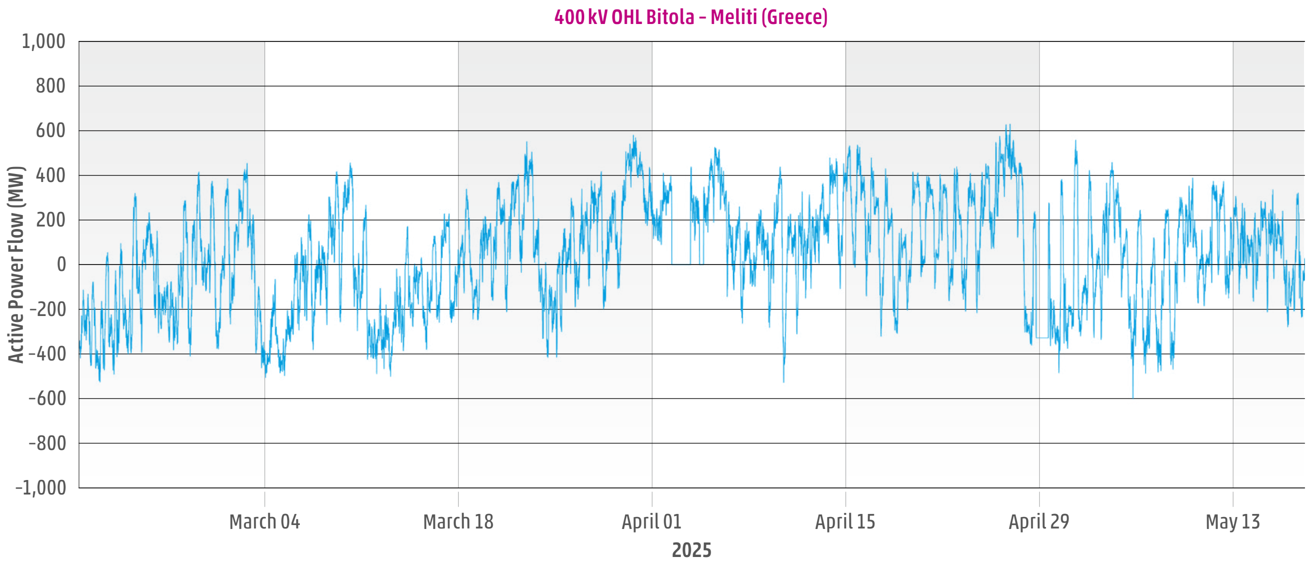


Figure 2.10: Active power flow on the 400 kV OHL Bitola–Meliti (IPTO)

The interconnection with Meliti (IPTO) shows a consistent export tendency from North Macedonia, particularly during the daytime.

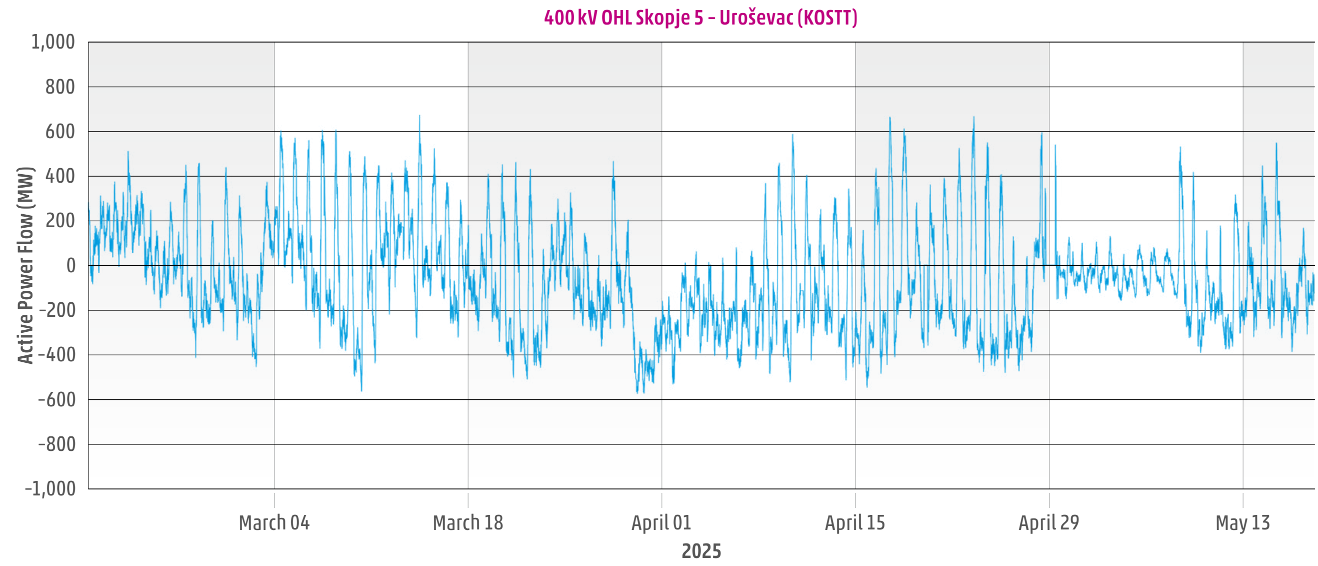


Figure 2.11: Active power flow on the 400 kV OHL Skopje 5–Urosevac (KOSTT)

The interconnection with the KOSTT transmission system shows rapid fluctuations and frequent direction changes.

2.2.2.4 Scheduled Commercial Exchanges

This subsection contains the scheduled exchanges between MEPSO and all neighbouring transmission system operators, as shown in Figures 2.11–15. Scheduled exchanges were exported from the ENTSO-E Transparency Platform, while the physical flows were derived from hourly average measurements from the interconnection transmission lines. The data is presented for the first five hours of the day of the incident.

A divergence between scheduled and physical exchanges can be observed across all borders, especially around 05:00, coinciding with the incident. These deviations indicate unplanned energy flows, which could be caused by transient frequency deviations, cross-border redispatch actions, and unbalanced generation-load conditions within the interconnected system, as well as loop flows.

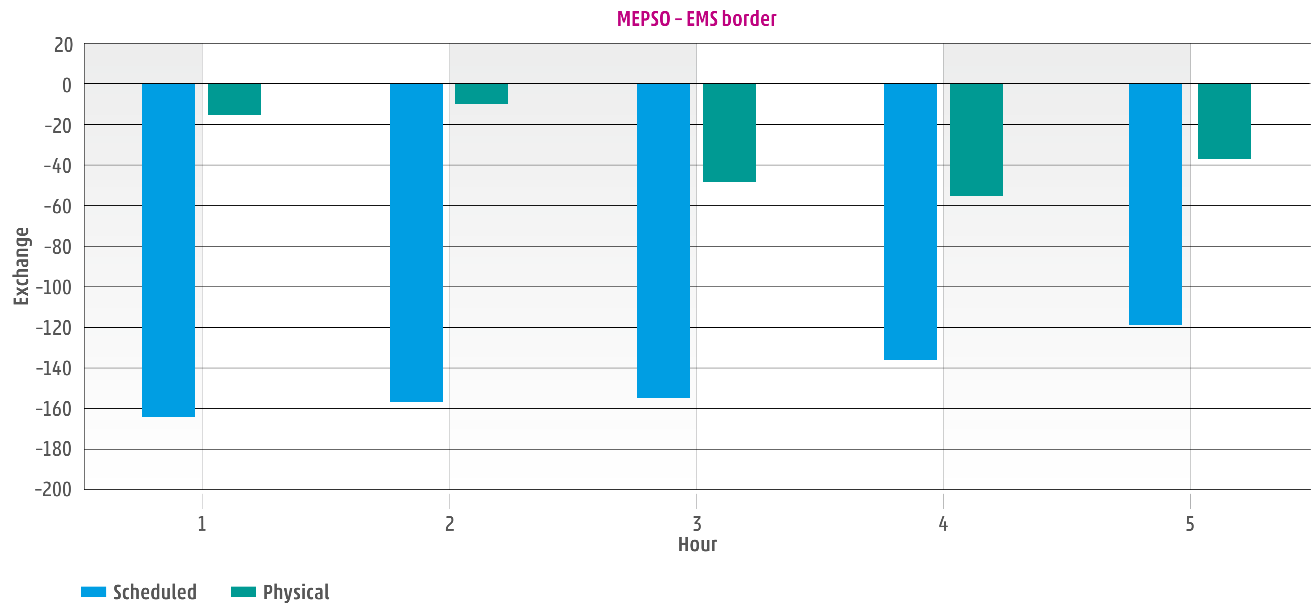


Figure 2.12: Scheduled and physical flows on the MEPSO–EMS bidding zone border

During the observed hours, the scheduled flow indicates continuous export from MEPSO towards EMS (around −160 MW). However, the physical flow was significantly smaller in magnitude.

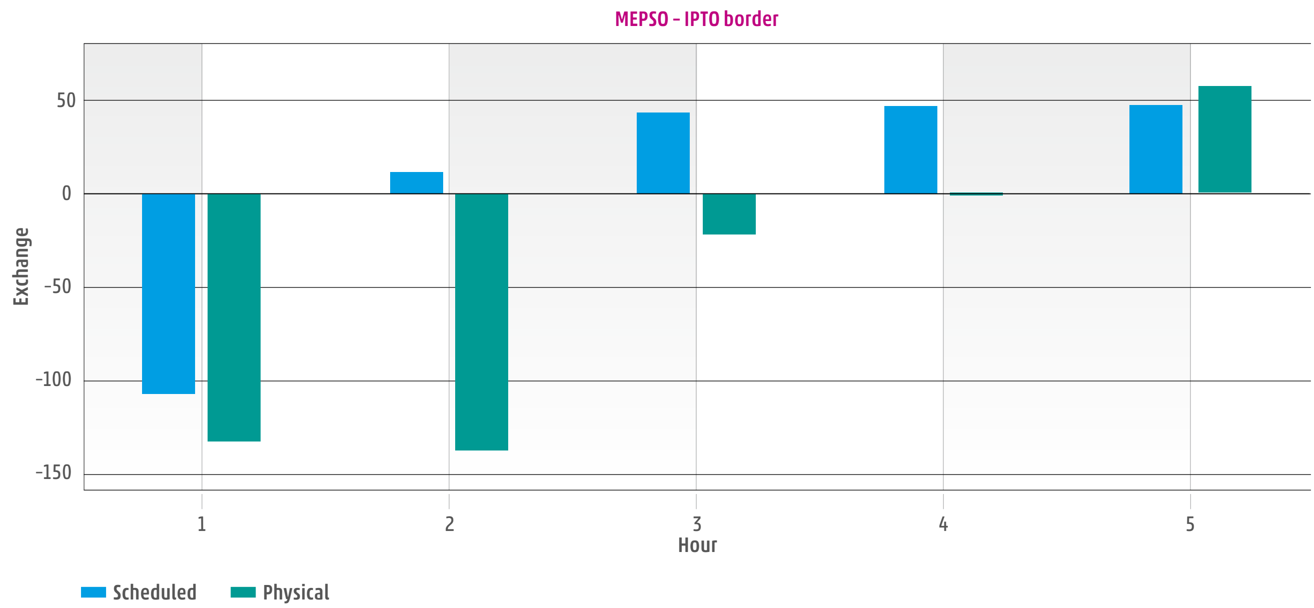


Figure 2.13: Scheduled and physical flows on the MEPSO–IPTO bidding zone border

While schedules show alternating import and export values, the physical flows deviate strongly, especially between 02:00 and 04:00, when the measured exchange was substantially lower than planned.

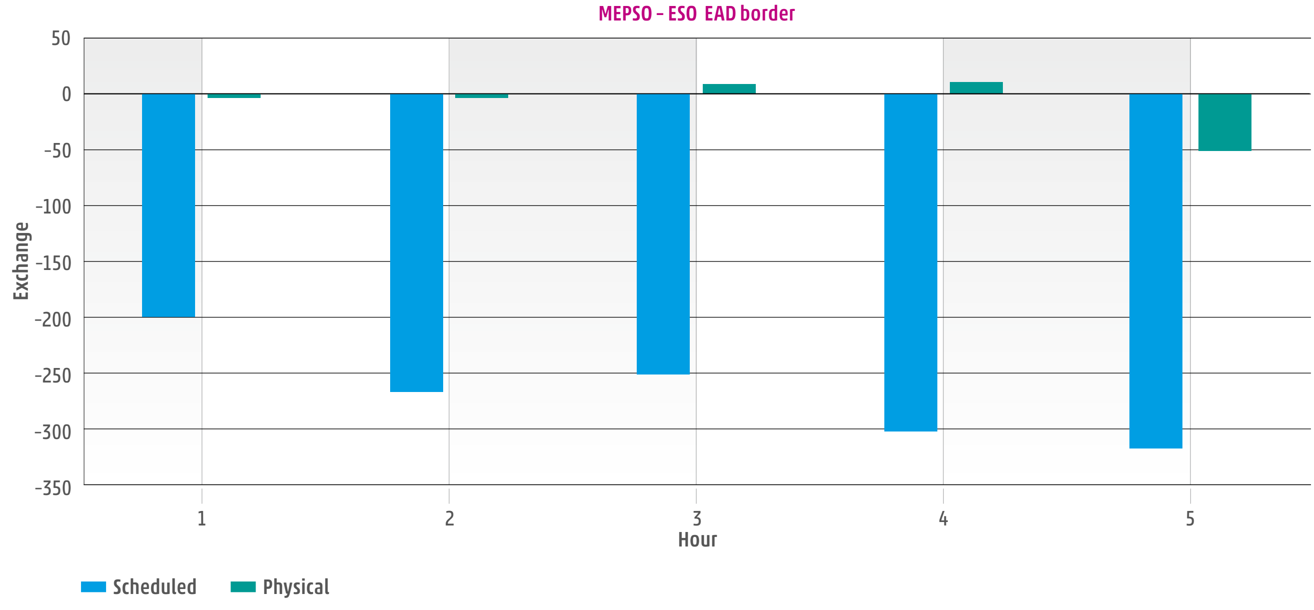


Figure 2.14: Scheduled and physical flows on the MEPSO-ESO bidding zone border

The scheduled values indicate a stable export from MEPSO towards ESO (around –250 MW). The physical flow, however, remained close to zero until 05:00.

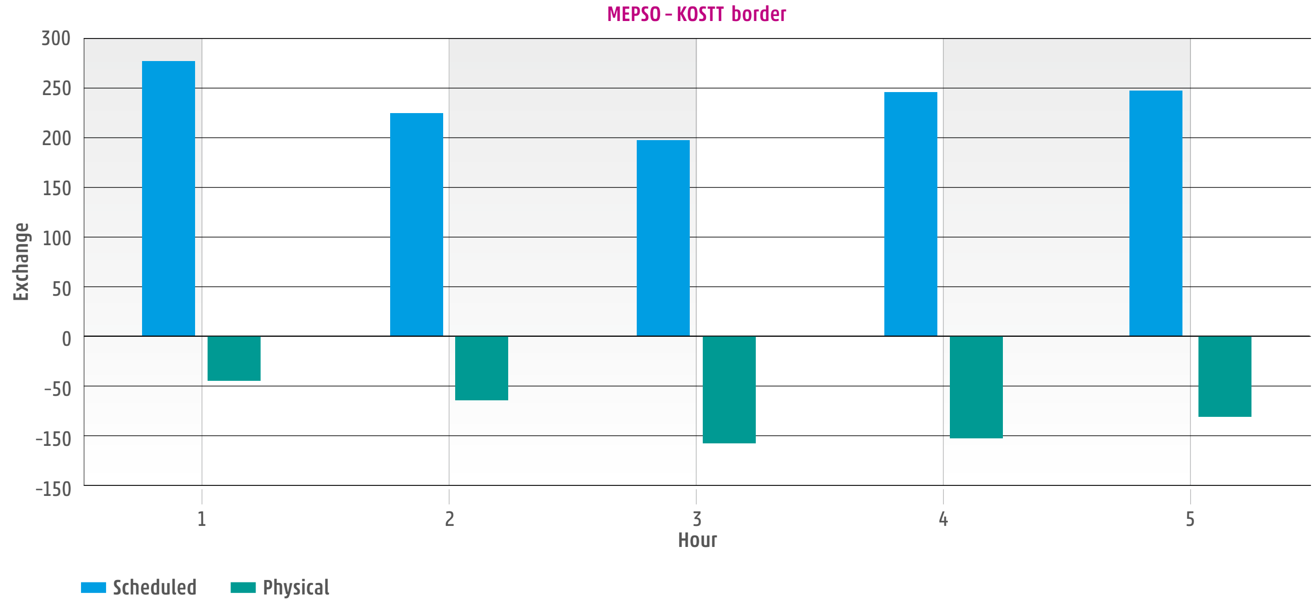


Figure 2.15: Scheduled and physical flows on the MEPSO-KOSTT bidding zone border

A significant mismatch is evident between the scheduled imports (around +200–250 MW) and the measured physical flows on the MEPSO-KOSTT bidding zone border, which were in the opposite direction (exports from MEPSO).

2.3 RCC Analysis

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. In this report, for the sake of simplicity, both RSC and RCCs will be referred to as RCC, and the word "task" will be used for both RSC services and RCC tasks.

The services delivered by RCCs are described in Regulation (EU) 2019/943 of 5 June 2019 on the internal market for electricity (Article 37 and Annex I), read alongside provisions on tasks of regional relevance outlined in Regulation (EU) 2017/1485 of 2 August 2017, establishing a guideline on electricity transmission system operation. The following subchapters will describe the results from tasks (OPC, STA, CGM, and CSA) that SCC, as the responsible RSC at the moment of the incident, delivered to MEPSO and which are relevant for the incident.

2.3.1 Outage Planning Coordination

The OPC process is divided into yearly (Y-1), monthly (M-1), and weekly (W-1) processes. For each process, TSOs are required 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 for its outage coordination region (OCR), i.e. the TSOs of the region. The W-1 OPC process covers a seven-day planning period, beginning on Saturday and ending on the following Friday. TSOs must report preliminary planned disconnections on Wednesdays by 12:00. They receive a report from the OPC tool after the first merge (on Wednesdays at 12:00) containing all reported outages and possible TIE inconsistencies with neighbouring TSOs. TSOs are required to correct these TIE inconsistencies by 16:00, when the second merge is triggered.

The results of the second merge are used by RCCs as input data for regional security analysis calculations.

After the security analysis performed by RCCs and the analysis carried out by TSOs, the TSOs have the right to revise the disconnection plan and submit an updated version until Thursday at 16:00, when the third merge is triggered. TSOs may also request additional security analyses if, between the second and third merge, they identify significant changes that could have a major impact on the previously delivered results.

The results of the third merge are presented at the regular weekly operational teleconference (WOPT), held for the SEE region every Friday at 09:00. The meeting is moderated by SCC and SEleNe CC on a yearly rotating basis since both RCCs operate in the SEE region. During the WOPT, the final reconciliations of the disconnection plan for the next week are made, and TSOs must submit all changes to the OPC tool by 13:00, when the fourth and final merge is triggered, which is used as the relevant disconnection plan for the next week.

Therefore, only disconnections reported in the pan-European Outage Planning Coordination (pan-EU OPC) tool before Friday at 13:00 are considered planned. Disconnections reported after that time are considered unplanned.

2.3.1.1 W-1 Outage Planning Incompatibilities Result

Outage Planning Incompatibilities (OPI) assessments are performed on a week-ahead basis using input data derived from the pan-European OPC process, including the merged Unavailability Plan (UAP) and merged Element List (EL), as well as predefined scenarios (seasonal CGMs), contingency lists and monitoring lists. Remedial actions, where applicable, may also be applied within the CGM.

For the period when the incident occurred (18 May 2025), the OPI assessment process (as shown in Figure 2.16) was performed by SCC in cooperation with the TSOs.

The initial OPI assessment was conducted on 15 May 2025, covering the week ahead period (Saturday to Friday). In line with the methodology applied at that time, calculations were performed only for selected critical timestamps on working days. Consequently, no OPI results were available for Sunday, 18 May 2025.

Following the transition of RCC services for MEPSO to SEleNe CC (as of 1 November 2025), the OPI assessment process has been further enhanced and aligned with the SEleNe CC operational framework.

Under the current process, OPI assessments are performed twice per week:

Initial OPI assessment is performed on Wednesdays following the second merge of the UAP and EL in the pan-European OPC tool (17:05 EET), with calculations starting at 18:15 EET.

Final OPI assessment is performed on Thursdays, based on the validated UAP from the third merge.

The week-ahead OPI assessment is performed for three predefined timestamps per day (base, peak and off-peak), resulting in a total of 21 timestamps for the business week. The process includes mapping outages to CGMs, performing iterative N-X security analyses, and applying remedial actions in coordination with TSOs. The assessment is conducted iteratively until all involved parties approve the results.

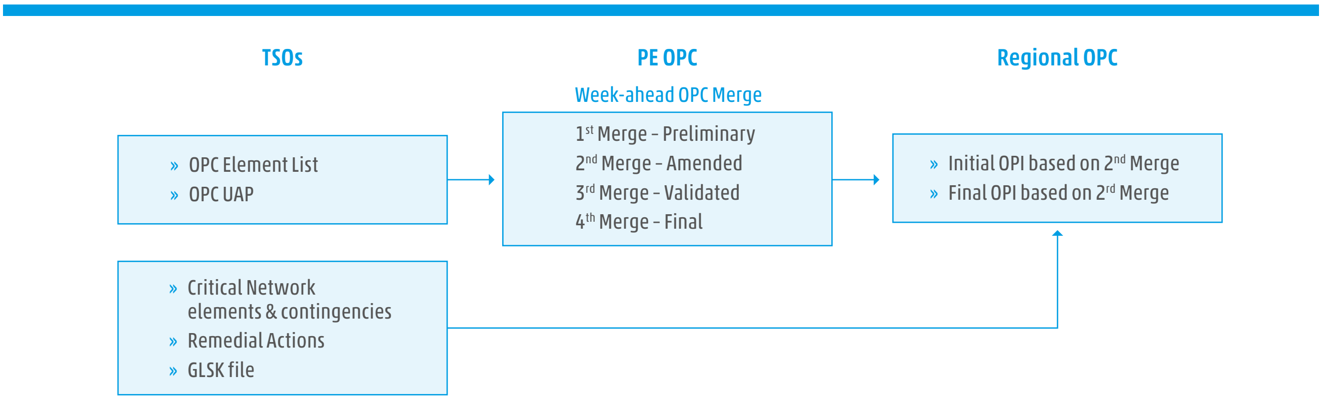


Figure 2.16: RCC framework for Outage Planning Processes

2.3.1.2 Short-Term Adequacy

All SEE TSOs and RCCs participate in the pan-European (also known as cross-regional) short-term adequacy (STA) process. All SEE TSOs are required to submit input data (net transfer capacity (NTC) files, week-ahead generation, and week-ahead load files) for the STA process. The process is triggered daily at the pan-European level, executed automatically, and monitored by the main or backup RCC. Deterministic and STA probabilistic calculations are performed on a daily basis.

If necessary, the regional STA process is also triggered. A regional STA process is triggered if the results of deterministic calculation show adequacy issues, for a time horizon of D+3 or less. However, since the implementation of the regional STA in SEE, the regional STA process has never been triggered in practice. In the few cases where there were indications that the process might be triggered, they were typically related to errors in data upload or inconsistencies in the input data. The activation of the regional STA is rare due to the following reasons: the sum of generation capacities in the region is significantly higher than electricity demand, meaning the region does not rely on imports and can cover its consumption with its own generation. In addition, there are substantial NTC capacities that can compensate for any local generation shortfalls.

SEleNe CC was the main adequacy assessment agent (AAA) for the pan-EU process during the week of the incident. Coreso was in charge of the backup.

2.3.1.3 Input Data

MEPSO did not provide input data (STA gen, STA load, and STA NTC) files for the period in which the incident occurred. Therefore, in its calculations, the STA tool treats the MEPSO bidding zone as a transit zone. In that case, cross-zonal capacities (CZC) are available for the exchange of energy in calculations; however, that region has neither load nor generation.

Figure 2.17 shows CZC and initial remaining capacities (RCs) from the STA tool for timestamp 04:30. The green bidding zone on the map indicates satisfied adequacy, while the red shared areas indicate an initially inadequate zone requiring energy import. If a bidding zone is initially adequate, it can meet its entire load demand with its own production, without requiring energy imports.

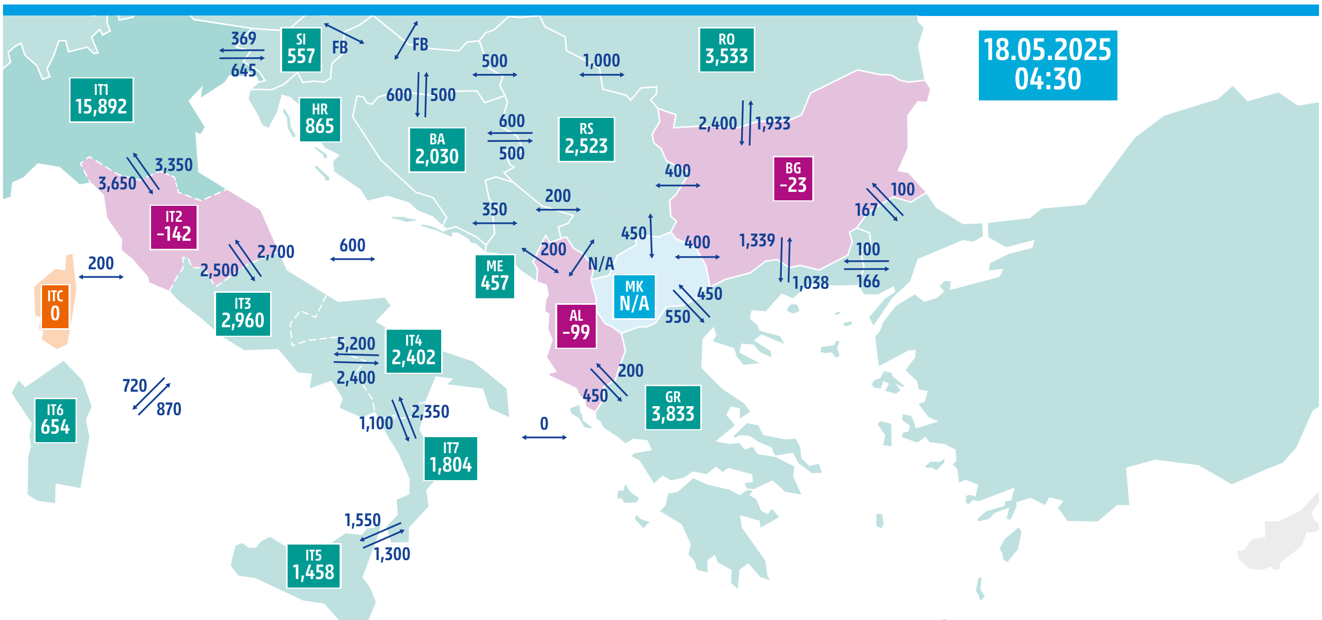


Figure 2.17: Input CZC values and initial RC from the STA tool for 04:30

Cross-Regional Adequacy Results

The STA calculation (first run) was completed in the usual time frame of approximately 30 minutes. This corresponds to the standard duration observed in everyday STA processes.

For the 04:30 timestamp on 18 May 2025, the results for the MEPSO (MK) bidding zone indicated the unavailability of input data (N/A).

In such a case, the STA algorithm treats the respective bidding zone as a transit zone, and the adequacy assessment is based on exchanges with neighbouring zones.

Figure 2.18 shows final exchanges and RCs from the STA tool for timestamp 04:30.

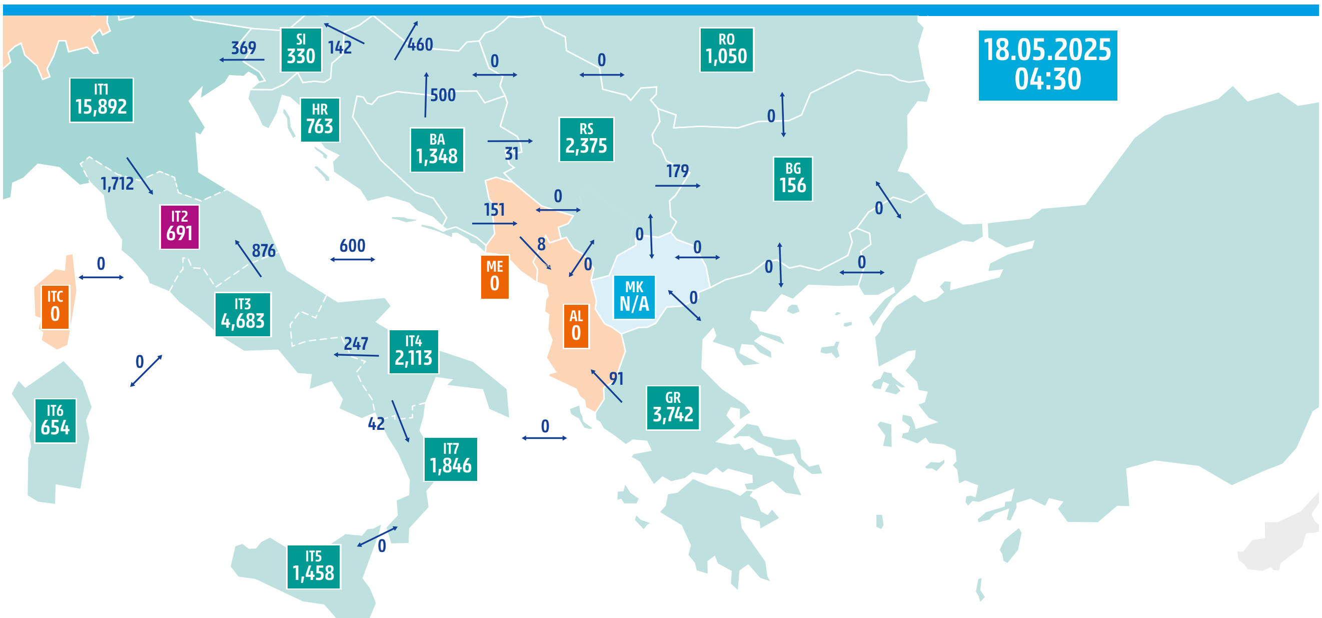


Figure 2.18: Final exchanges and RC from the STA tool for 04:30

The final exchanges and RCs for the analysed period show that all neighbouring TSOs ensured system adequacy despite the absence of MEPSO input data. The framed RC values on the map represent the available RC after calculation. Zones with zero RC are not considered inadequate; instead, they indicate fully utilised local production and load covered by a combination of internal generation and imports from adjacent zones, in accordance with STA algorithm rules.

Based on these results, the system adequacy situation in the SEE region at the given timestamp was stable. All neighbouring TSOs provided sufficient system adequacy to maintain security of supply. The absence of MEPSO data did not result in observable system adequacy issues for the analysed timestamp.

It is important to note that the pan-EU STA process is limited to input data on production, load, and exchanges, without considering the physical power of the grid model. Therefore, while no adequacy problems were detected, the process cannot draw valid conclusions regarding potential operational incidents. A regional STA process that incorporates the grid models is under development but was not triggered on this calculation day.

2.3.2 Common Grid Model Creation

There are two processes for building a Common Grid Model (CGM):

» CGMES format – in line with the respective regulations and methodologies, the future format, which is in the implementation and testing phase

» UCTE format – a legacy process that is still used to execute all RCC's other services.

All further content in this chapter refers to the CGM in the UCTE format, as CGMs in this format are used in SCC for subsequent security analysis within the day-ahead congestion forecast (DACF) and intraday congestion forecast (IDCF) processes.

After creation by TSOs, Individual Grid Models (IGMs) are provided to RCCs to perform their validation (checking syntax and semantic errors). After the IGMs have been validated and any necessary corrections made, the IGM merging process is launched. The result of this process is a CGM for CE SA. The CGM is the basis for all other RCC services, since they all include load flow calculations. Based on the collected IGMs, the CGMs of CE SA are created for all upcoming hours.

CGM creation is performed by SCC for the purpose of Coordinates Security Analysis (CSA):

» Every day for all hours of the upcoming day within the DACF procedure

» Three times for the eight upcoming hours within the IDCF procedure

Regular CGM creation within the DACF/IDCF process in SCC is performed when all IGMs are delivered by TSOs and successfully validated. Backup CGM creation within the DACF/IDCF process in SCC is performed if an IGM is not available (or if the IGM did not pass the validation) using the replacement strategy (Steps 1–4, as shown in Figure 2.19, which represents settings from the tool used for CGM creation in SCC):

1/ The original IGM is replaced with an IGM for the same day and procedure type (D2CF, DACF, IDCF, etc.) but for a different hour, following the priority defined in the Step 1 matrix. Users can edit priorities manually.

2/ If unavailable, the older IGM of the same day type (workday, weekend), procedure type (D2CF, DACF, IDCF, etc.), and hour is used. If the same hour is not available, the same priority is followed as in Step 1 – the user can manually define the number of days in the past/future, which will be searched for a replacement.

3/ If unavailable, the IGM from the same day and hour but a different procedure (DACF, D2CF, IDCF) is used. If the same hour is not available, the same priority is followed as in Step 1 – the procedure priority can be manually chosen.

4/ If unavailable, the older IGM from a different day type (workday, weekend) and the same procedure type (DACF, D2CF, IDCF) and hour is used. If the same hour is not available, the same priority is followed as in Step 1 – the user can manually define a number of days in the past/future, which will be searched for a replacement.

For Steps 2 and 4, the IGMs are used from the last seven days.

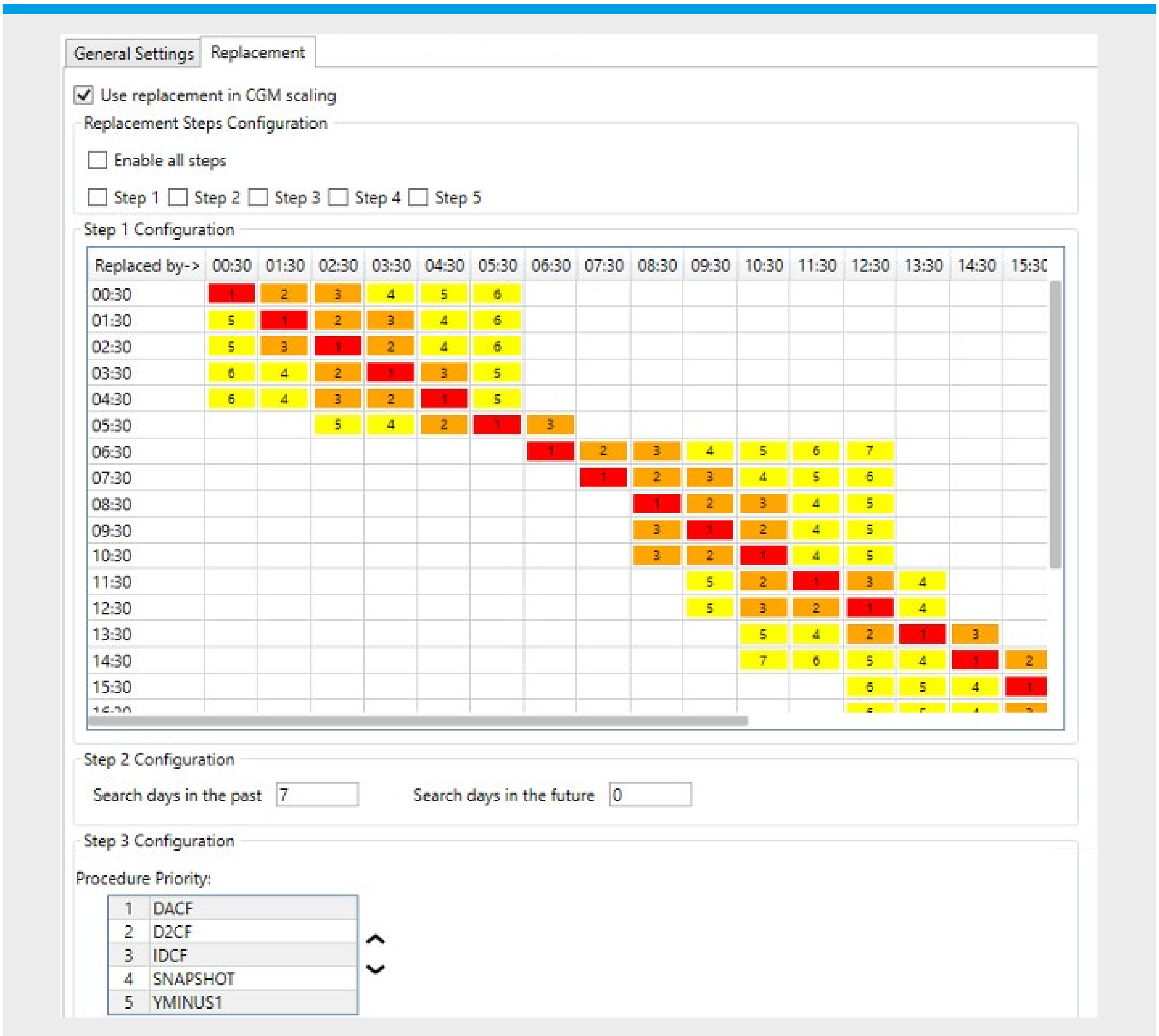


Figure 2.19: CGM replacement strategy

For Sunday, 18 May 2025 (Sunday), MEPSO did not deliver any DACF or IDCF models. The last MEPSO IGMs delivered for weekend days were for 3 May 2025 (Saturday), which is more than seven days before the incident date. Therefore, SCC used Step 4 of its backup process, using the most recently delivered MEPSO IGMs dated 13 May 2025 (Tuesday) for both the IDCF and DACF processes. Therefore, the results from these processes should be interpreted with caution, given that the MEPSO IGMs were outdated relative to the incident date.

However, the results of the Alternating Current load flow calculation performed on the CGM from the DACF process for the hour of the incident (04:30) show voltage values similar to those observed in real time, despite the use of outdated IGMs MEPSO. Table 2.3 shows voltage values for 04:30 in all 400 kV nodes in the MEPSO system. All node voltages at the 400 kV voltage level exceed 447 kV, with the highest calculated voltage (449.24 kV) in the Dubrovo node.

Name	UCTE Code	Voltage [kV]
Dubrovo	YDUBRO1	449.24
Bitola	YBITOL1	449.02
Skopje 4	YSK 41	448.56
Skopje 5	YSK 5 1	447.79
Štip	YSTIP 1	447.30

Table 2.3: Calculated voltages in the 400 kV grid of MEPSO for 18 May 2025 at 04:30

Tables 2.4 and 2.5 represent the number of delivered DACF and IDCF MEPSO IGMs for the period between January and June 2025, per month and day type.

DACF	Working Day	Saturday	Sunday
January	9	1	0
February	5	2	0
March	4	0	0
April	4	0	0
May	11	2	1
June	8	3	1
SUM	**41**	**8**	**2**

Table 2.4: Number of delivered MEPSO DACF IGMs per month and day type

IDCF	Working Day	Saturday	Sunday
January	10	1	0
February	5	2	0
March	3	0	0
April	5	1	0
May	11	2	1
June	7	1	0
SUM	**41**	**7**	**1**

Table 2.5: Number of delivered MEPSO IDCF IGMs per month and day type

To compare the quality of CGMs from regular DACF and backup DACF procedures when the IGM is missing, SCC conducted an additional DACF analysis for 13 May 2025 using MEPSO DACF IGMs for 9 May 2025 (Step 2 replacement strategies).

Table 2.6 shows a comparison of U, P, and Q in 400 kV nodes between Snapshots Ns delivered by MEPSO, CGM from the regular DACF procedure, and CGM from the backup DACF procedure for timestamps 03:30, 10:30, and 19:30 on 13 May 2025.

	SN for 13.5.2025								
Nodes	03:30			10:30			19:30		
	U	P	Q	U	P	Q	U	P	Q
YSTIP 1	433.78	48.04	6.83	434.24	27.66	3.17	429.79	70.06	24.48
YSK 5 1	429.75	101.12	23.42	431.13	69.36	12.74	426.03	90.36	44.3
YSK 41	429.93	93.92	18.18	431.11	61.14	7.18	426.46	121.36	48.84
YDUBRO1	431.94	31.58	6.33	432.38	16.18	2.67	428.9	76.04	25.15
YBITOL1	425	−50.33	−16.63	425	−68.45	−23.35	425	−44.28	0.75
XCM_ST11	433.97			434.51			429.89		
XFL_BI11	424.9			424.97			425.06		
XST_VR11	434.74			434.84			430.45		
XTH_DU11	432.64			432.68			429.99		
XUR_SK11	429.87			431.24			426.14		
	DACF procedure for 13.5.2025								
Nodes	03:30			10:30			19:30		
	U	P	Q	U	P	Q	U	P	Q
YSTIP 1	432.06	48	2.49	424.05	26.95	−2.83	421.61	64.16	20.52
YSK 5 1	432.06	127.76	29.4	422.09	36.66	17.66	418.06	115.62	40.1
YSK 41	432.85	104.54	24.88	424.12	53.96	20.54	419.45	131.32	44.54
YDUBRO1	433.63	30.71	4.98	427.04	11.94	3.51	422.36	55.47	16.8
YBITOL1	421	−58.42	−6.81	421	54.11	−8.11	421	130.69	−36.41
XCM_ST11	429.74			421.43			420.19		
XFL_BI11	432.49			428.24			422.26		
XST_VR11	434.09			424.88			423.44		
XTH_DU11	433.53			429.27			422.97		
XUR_SK11	431.59			420.02			417.08		
	Backup DACF procedure for 13.5.2025								
Nodes	03:30			10:30			19:30		
	U	P	Q	U	P	Q	U	P	Q
YSTIP 1	432.3	50.8	−0.7	426.17	7.91	−10.66	421.74	57.51	19.24
YSK 5 1	432.93	91.02	3.7	425.82	−26.94	−15.18	418.25	81	41.22
YSK 41	433.65	82.94	13.64	427.78	0.54	1.18	419.51	99.6	49.4
YDUBRO1	433.97	43.97	1.91	429.53	5.26	−4.39	422.41	49.11	12.27
YBITOL1	421	31.43	−2.34	421	9.3	−10.45	421	39.08	22.09
XCM_ST11	429.95			423.25			420.32		
XFL_BI11	432.63			429.89			422.03		
XST_VR11	434.22			426.64			423.64		
XTH_DU11	433.79			431.2			423.01		
XUR_SK11	432.09			423.08			417.47		

Table 2.6: U, P, and Q values in 400 kV nodes in SNs, CGM from the regular DACF procedure, and the backup DACF procedure for 13 May 2025

Delta values are shown in Table 2.7.

	Δ (SN–DACF)								
Nodes	03:30			10:30			19:30		
	U	P	Q	U	P	Q	U	P	Q
YSTIP 1	1.72	0.04	4.34	10.19	0.71	6	8.18	5.9	3.96
YSK 5 1	–2.31	–26.64	–5.98	9.04	32.7	–4.92	7.97	–25.26	4.2
YSK 41	–2.92	–10.62	–6.7	6.99	7.18	–13.36	7.01	–9.96	4.3
YDUBRO1	–1.69	0.87	1.35	5.34	4.24	–0.84	6.54	20.57	8.35
YBITOL1	4	8.09	–9.82	4	–122.56	–15.24	4	–174.97	37.16
XCM_ST11	4.23			13.08			9.7		
XFL_BI11	–7.59			–3.27			2.8		
XST_VR11	0.65			9.96			7.01		
XTH_DU11	–0.89			3.41			7.02		
XUR_SK11	–1.72			11.22			9.06		
	Δ (SN–Backup)								
Nodes	03:30			10:30			19:30		
	U	P	Q	U	P	Q	U	P	Q
YSTIP 1	1.48	–2.76	7.53	8.07	19.75	13.83	8.05	12.55	5.24
YSK 5 1	–3.18	10.1	19.72	5.31	96.3	27.92	7.78	9.36	3.08
YSK 41	–3.72	10.98	4.54	3.33	60.6	6	6.95	21.76	–0.56
YDUBRO1	–2.03	–12.39	4.42	2.85	10.92	7.06	6.49	26.93	12.88
YBITOL1	4	–81.76	–14.29	4	–77.75	–12.9	4	–83.36	–21.34
XCM_ST11	4.02			11.26			9.57		
XFL_BI11	–7.73			–4.92			3.03		
XST_VR11	0.52			8.2			6.81		
XTH_DU11	–1.15			1.48			6.98		
XUR_SK11	–2.22			8.16			8.67		
	Δ (DACF–Backup)								
Nodes	03:30			10:30			19:30		
	U	P	Q	U	P	Q	U	P	Q
YSTIP 1	–0.24	–2.8	3.19	–2.12	19.04	7.83	–0.13	6.65	1.28
YSK 5 1	–0.87	36.74	25.7	–3.73	63.6	32.84	–0.19	34.62	–1.12
YSK 41	–0.8	21.6	11.24	–3.66	53.42	19.36	–0.06	31.72	–4.86
YDUBRO1	–0.34	–13.26	3.07	–2.49	6.68	7.9	–0.05	6.36	4.53
YBITOL1	0	–89.85	–4.47	0	44.81	2.34	0	91.61	–58.5
XCM_ST11	–0.21			–1.82			–0.13		
XFL_BI11	–0.14			–1.65			0.23		
XST_VR11	–0.13			–1.76			–0.2		
XTH_DU11	–0.26			–1.93			–0.04		
XUR_SK11	–0.5			–3.06			–0.39		

Table 2.7: Differences in U, P, and Q values in 400 kV nodes between SNs, CGM from regular DACF procedure, and backup DACF procedure for 13 May 2025

At the request of the Expert Panel, MEPSO delivered the subsequently created DACF IGMs for 18 May 2025. To compare the quality of CGMs from the original DACF procedure (or the backup DACF procedure when MEPSO IGMs were not delivered and replaced with DACF IGMs for 13 May 2025) and the regular DACF procedure for 18 May 2025, SCC conducted additional DACF analysis for 18 May 2025, including subsequently created MEPSO DACF IGMs in the CGM. Table 2.8 presents a comparison of U, P, and Q in 400 kV nodes between SNs, CGM from the original DACF procedure, and the additional DACF procedure for timestamps 03:30, 04:30, and 06:30 on 18 May 2025.

	SN for 18.5.2025								
Nodes	03:30			04:30			06:30		
	U	P	Q	U	P	Q	U	P	Q
YSTIP 1	425.42	46.52	9.8	425.69	34.48	9.23	428.35	6.13	−1.87
YSK 5 1	421.68	113.76	27.08	421.9	99.64	26.94	426.69	12.52	−5.94
YSK 41	421.93	108.1	21.98	422.13	95.42	22.38	426.34	14.62	−8.42
YDUBRO1	423.98	40.26	8.73	424.14	37.4	9.99	426.82	10.16	−7.68
YBITOL1	418	−35.4	−14.82	418	−41.74	−14.08	418	5.88	−27.5
XCM_ST11	425.53			425.9			428.44		
XFL_BI11	418.06			418			417.98		
XST_VR11	426.2			426.29			428.77		
XTH_DU11	424.77			424.9			427.55		
XUR_SK11	421.79			422.01			426.8		
	Original DACF procedure for 18.5.2025 (Backup DACF procedure – MEPSO IGMs not delivered)								
Nodes	03:30			04:30			06:30		
	U	P	Q	U	P	Q	U	P	Q
YSTIP 1	446.79	47.16	1.41	447.3	48.48	1.33	431.24	45.01	5.54
YSK 5 1	447.31	118.46	30.08	447.79	116.96	31.26	427.6	80.72	22.46
YSK 41	448.07	108.58	24.6	448.56	107	25.72	429.49	90.26	15.8
YDUBRO1	448.72	33.07	4.04	449.24	31.62	4.3	432.73	27.73	5.45
YBITOL1	421	−49.43	−10.61	421	−50.86	−9.88	421	−56.97	−7.33
XCM_ST11	444.74			445.2			429.48		
XFL_BI11	447.37			447.9			432.57		
XST_VR11	447.81			448.39			432.28		
XTH_DU11	448.93			449.51			433.89		
XUR_SK11	425.78			447.33			446.84		
	Additional DACF procedure for 18.5.2025 (with MEPSO IGMs later delivered)								
Nodes	03:30			04:30			06:30		
	U	P	Q	U	P	Q	U	P	Q
YSTIP 1	445.8	104.99	4.56	446.43	103.91	4.76	433.13	73.85	1.96
YSK 5 1	447.57	104.69	34.25	448.21	102.08	34.71	436.08	78.8	28.72
YSK 41	448.05	109.55	29.49	448.7	106.39	29.97	436.48	82.31	24.52
YDUBRO1	448.2	0	0	448.85	0	0	436.07	0	0
YBITOL1	416	−58.75	−9.69	416	−60.24	−9.34	416	−74.37	−10.09
XCM_ST11	443.76			444.33			431.06		
XFL_BI11	446.91			447.55			435.23		
XST_VR11	446.55			447.25			433.2		
XTH_DU11	448.4			449.08			436.43		
XUR_SK11	400			400			400		

Table 2.8: U, P, and Q values in 400 kV nodes in SNs, CGM from the original DACF procedure, and the additional DACF procedure for 18 May 2025

Delta values are shown in Table 2.9.

	Δ (SN–DACF)								
Nodes	**03:30**			**04:30**			**06:30**		
	U	**P**	**Q**	**U**	**P**	**Q**	**U**	**P**	**Q**
YSTIP 1	−21.37	−0.64	8.39	−21.61	−14	7.9	−2.89	−38.88	−7.41
YSK 5 1	−25.63	−4.7	−3	−25.89	−17.32	−4.32	−0.91	−68.2	−28.4
YSK 41	−26.14	−0.48	−2.62	−26.43	−11.58	−3.34	−3.15	−75.64	−24.22
YDUBRO1	−24.74	7.19	4.69	−25.1	5.78	5.69	−5.91	−17.57	−13.13
YBITOL1	−3	14.03	−4.21	−3	9.12	−4.2	−3	62.85	−20.17
XCM_ST11	−19.21			−19.3			−1.04		
XFL_BI11	−29.31			−29.9			−14.59		
XST_VR11	−21.61			−22.1			−3.51		
XTH_DU11	−24.16			−24.61			−6.34		
XUR_SK11	−3.99			−25.32			−20.04		
	Δ (SN–Backup)								
Nodes	**03:30**			**04:30**			**06:30**		
	U	**P**	**Q**	**U**	**P**	**Q**	**U**	**P**	**Q**
YSTIP 1	−20.38	−58.47	5.24	−20.74	−69.43	4.47	−4.78	−67.72	−3.83
YSK 5 1	−25.89	9.07	−7.17	−26.31	−2.44	−7.77	−9.39	−66.28	−34.66
YSK 41	−26.12	−1.45	−7.51	−26.57	−10.97	−7.59	−10.14	−67.69	−32.94
YDUBRO1	−24.22	40.26	8.73	−24.71	37.4	9.99	−9.25	10.16	−7.68
YBITOL1	2	23.35	−5.13	2	18.5	−4.74	2	80.25	−17.41
XCM_ST11	−18.23			−18.43			−2.62		
XFL_BI11	−28.85			−29.55			−17.25		
XST_VR11	−20.35			−20.96			−4.43		
XTH_DU11	−23.63			−24.18			−8.88		
XUR_SK11	21.79			22.01			26.8		
	Δ (DACF–Backup)								
Nodes	**03:30**			**04:30**			**06:30**		
	U	**P**	**Q**	**U**	**P**	**Q**	**U**	**P**	**Q**
YSTIP 1	0.99	−57.83	−3.15	0.87	−55.43	−3.43	−1.89	−28.84	3.58
YSK 5 1	−0.26	13.77	−4.17	−0.42	14.88	−3.45	−8.48	1.92	−6.26
YSK 41	0.02	−0.97	−4.89	−0.14	0.61	−4.25	−6.99	7.95	−8.72
YDUBRO1	0.52	33.07	4.04	0.39	31.62	4.3	−3.34	27.73	5.45
YBITOL1	5	9.32	−0.92	5	9.38	−0.54	5	17.4	2.76
XCM_ST11	0.98			0.87			−1.58		
XFL_BI11	0.46			0.35			−2.66		
XST_VR11	1.26			1.14			−0.92		
XTH_DU11	0.53			0.43			−2.54		
XUR_SK11	25.78			47.33			46.84		

Table 2.9: Differences in U, P, and Q values in 400 kV nodes between SNs, CGM from the original DACF procedure, and the additional DACF procedure for 18 May 2025.

The results of the applied backup procedure (and corresponding delta between DACF and backup DACF procedures) are of acceptable quality. In comparison, the difference of around 20 kV between the SN and the DACF (applying regular and backup procedure) is significant.

The reasons for deviation between the SN and DACF procedures warrant further investigation by MEPSO, as the values from the DACF procedure are closer to the real-time situation during the incident.

Node XSK_UR11 is unpaired in the CGM for the additional DACF procedure for 18 May 2025 due to an incorrect representation in subsequently created MEPSO IGMs (listed as XUR_SK11 instead of XSK_UR11), which will be updated by MEPSO.

2.3.3 Voltage Comparison of Local Measurement Values with SN Values

In order to compare voltage values from Table 2.8 with subsequently provided local SCADA measurements in several substations, SCC created the table below to better represent the differences.

Voltage comparison for 18.05.2025						
Substation	Node	Timestamp	U (SN value)	U (SCADA value)	U (Original DACF procedure)	U (Additional DACF procedure)
Skopje 4	YSK 41	4:30	422.13	445.764	448.56	448.7
Dubrovo	YDUBRO1	3:30	423.98	439.922	448.72	448.2
Bitola	YBITOL1	6:30	418	429.866	421	416
Interconnection MK-GR	XFL_BI11	4:30	418	440.093	447.90	447.55

Table 2.10: Voltage comparison of local measurement values with SN and DACF values for 18 May 2025

As seen in Table 2.10, voltage values from local SCADA measurements are much closer to the DACF procedure (original and additional) than those provided in SNs. This deviation is explained by the fact that the SN was prepared ex-post using an isolated North Macedonia network model (and using the State Estimator functionality), based on measured values available for the respective hour. As such, the SN does not fully represent the actual system-wide operating conditions and cross-border interactions at the time of interest.

Consequently, the SN results should not be considered fully representative for this type of voltage analysis and should not influence the overall conclusions. In contrast, the DACF procedures and local SCADA measurements consistently capture real-time cross-border reactive power exchanges, which are the dominant factor affecting voltage levels in the 400 kV transmission network.

2.3.4 Coordinated Security Analysis

Article 37 (1)(b) of Regulation (EU) 2019/943 on the internal market for electricity (as incorporated into the Energy Community Legal Framework by Ministerial Council Decision 2022/03/MC-EnC), requires RCCs established in Energy Community Contracting Parties to perform Coordinated Security Analysis (CSA) according to the CSA methodology. At the time of the incident, the legal act was not yet applicable in Serbia. Therefore, for the time being, SCC performs a legacy security analysis for its service-receiving TSOs, including MEPSO. This relies on IGMs from the TSOs in the standard UCTE-DEF data exchange format. The CGMES-based processes are not yet live. After creating CGMs, SCC continues the DACF and IDCF procedure by conducting security analysis. The security analysis consists of a DACF and an IDCF. For each day, 24 timestamps are considered, CGMs are generated, and N-X security analysis is performed. SCC performs security analysis four times per day – once for the upcoming 24 hours in the DACF procedure and three times for the upcoming eight hours within the IDCF process.

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

- Con list: Containing the contingencies detected by the TSOs based on Article 7 of the CSA methodology
- Mon list: Containing all the elements that certain TSOs consider relevant for monitoring during security assessment in the DACF and IDCF processes, taking into account Article 15 (1) of the CSA methodology

These lists are not limited to elements and scenarios within the TSO's system but may include neighbouring TSOs' elements. Each TSO is responsible for maintaining its Con and Mon lists and announcing expected changes in advance. The lists are then merged.

The N-X security analysis assesses ordinary and exceptional contingencies but does not include the combination of all multiple unrelated contingencies (N-2, N-3, etc.). These are considered "out-of-range" according to Article 7 (1)(c) of the CSA methodology.

However, the Con list does not necessarily include only single outages; it may also contain combinations of outages of specific elements, allowing, for example, the simulation of selected double or even triple outages. In addition, scenarios involving the outages of entire busbar systems are also considered for some specific cases based on TSOs' requests.

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

The N-X statistics report Day ahead congestion forecast (DACF) or Intraday congestion forecast (IDCF) security analysis results delivered by SCC to its TSO service users consists of the following columns:

- Year, Month, Day: Date of DACF/IDCF procedure
- Timestamp: In
- Critical Outage (CO) Name: The element whose outage is simulated as part of the contingency analysis
- CB Unom (critical branch nominal voltage)
- CB Name (critical branch name): The element being monitored for potential overload or violation of operational limits because of the simulated outage
- Loading_BC: Loading of critical branch in base case [%]
- Loading after outage [%]: Loading of critical branch after outage of contingency element in %.

2.3.4.1 Original DACF and IDCF Security Analysis Results for 18 May 2025

According to agreements on the provision of operational services, which are concluded among SCC and its service users, DACF CGMs and security analysis results for 18 May 2025 were delivered to the MEPSO via SFTP server at 19:40 on 17 May 2025. DACF security analysis results did not indicate a possible critical grid situation due to overloading in the affected area (Table 2.11).

N-X STATISTICS SORTED BY LOADING

Year	Month	Day	Time stamp	CO Name	CB Unom	CB Name	Loading_BC [%]	Loading after outage [%]
2025	5	18	08:30	TIE 400 kV Peć 3 - Ribarevine & TIE 400 kV Tirana 2 - Podgorica 2	220	OHL 220 kV Vau Dejes - Koplik	69.56	146.92
2025	5	18	08:30	TIE 400 kV Peć 3 - Ribarevine & TIE 400 kV Tirana 2 - Podgorica 2	220	TIE 220 kV Podgorica 1 - Koplik (AL)	66.60	142.66
2025	5	18	08:30	TIE 400 kV Peć 3 - Ribarevine & TIE 400 kV Tirana 2 - Podgorica 2	220	TIE 220 kV Koplik - Podgorica 1 (ME)	59.44	128.06
2025	5	18	18:30	TIE 400 kV Peć 3 - Ribarevine & TIE 400 kV Tirana 2 - Podgorica 2	220	TIE 220 kV Podgorica 1 - Koplik (AL)	51.05	115.59
2025	5	18	18:30	TIE 400 kV Peć 3 - Ribarevine & TIE 400 kV Tirana 2 - Podgorica 2	220	OHL 220 kV Vau Dejes - Koplik	48.66	113.67
2025	5	18	18:30	TIE 400 kV Peć 3 - Ribarevine & TIE 400 kV Tirana 2 - Podgorica 2	220	TIE 220 kV Koplik - Podgorica 1 (ME)	45.46	103.86
2025	5	18	23:30	TIE 400 kV Peć 3 - Ribarevine & TIE 400 kV Tirana 2 - Podgorica 2	220	TIE 220 kV Podgorica 1 - Koplik (AL)	37.34	102.01
2025	5	18	23:30	TIE 400 kV Peć 3 - Ribarevine & TIE 400 kV Tirana 2 - Podgorica 2	220	OHL 220 kV Vau Dejes - Koplik	35.49	100.79
2025	5	18	22:30	400 kV Bitola busbar fault	110	OHL 110 kV Bitola 1 - Prilep 1	26.98	99.95
2025	5	18	07:30	TIE 400 kV Peć 3 - Ribarevine & TIE 400 kV Tirana 2 - Podgorica 2	220	OHL 220 kV Vau Dejes - Koplik	49.15	98.81
2025	5	18	08:30	TIE 400 kV Tirana 2 - Podgorica 2	220	OHL 220 kV Vau Dejes - Koplik	69.56	98.25
2025	5	18	22:30	TIE 400 kV Peć 3 - Ribarevine & TIE 400 kV Tirana 2 - Podgorica 2	220	TIE 220 kV Podgorica 1 - Koplik (AL)	40.46	97.87
2025	5	18	19:30	400 kV Bitola busbar fault	110	OHL 110 kV Bitola 1 - Prilep 1	24.71	97.62
2025	5	18	18:30	400 kV Bitola busbar fault	110	OHL 110 kV Bitola 1 - Prilep 1	18.45	96.23
2025	5	18	22:30	TIE 400 kV Peć 3 - Ribarevine & TIE 400 kV Tirana 2 - Podgorica 2	220	OHL 220 kV Vau Dejes - Koplik	38.75	96.20
2025	5	18	19:30	TIE 400 kV Peć 3 - Ribarevine & TIE 400 kV Tirana 2 - Podgorica 2	220	TIE 220 kV Podgorica 1 - Koplik (AL)	40.77	95.97
2025	5	18	07:30	TIE 400 kV Peć 3 - Ribarevine & TIE 400 kV Tirana 2 - Podgorica 2	220	TIE 220 kV Podgorica 1 - Koplik (AL)	46.68	95.42
2025	5	18	08:30	TIE 400 kV Tirana 2 - Podgorica 2	220	TIE 220 kV Podgorica 1 - Koplik (AL)	66.60	94.76
2025	5	18	23:30	400 kV Bitola busbar fault	110	OHL 110 kV Bitola 1 - Prilep 1	24.24	94.53
2025	5	18	17:30	400 kV Bitola busbar fault	110	OHL 110 kV Bitola 1 - Prilep 1	19.27	93.81
2025	5	18	19:30	TIE 400 kV Peć 3 - Ribarevine & TIE 400 kV Tirana 2 - Podgorica 2	220	OHL 220 kV Vau Dejes - Koplik	38.75	93.67
2025	5	18	21:30	400 kV Bitola busbar fault	110	OHL 110 kV Bitola 1 - Prilep 1	23.77	93.31
2025	5	18	20:30	400 kV Bitola busbar fault	110	OHL 110 kV Bitola 1 - Prilep 1	24.71	92.91
2025	5	18	23:30	TIE 400 kV Peć 3 - Ribarevine & TIE 400 kV Tirana 2 - Podgorica 2	220	TIE 220 kV Koplik - Podgorica 1 (ME)	33.21	91.68
2025	5	18	15:30	TIE 400 kV Peć 3 - Ribarevine & TIE 400 kV Tirana 2 - Podgorica 2	220	TIE 220 kV Podgorica 1 - Koplik (AL)	41.74	91.10
2025	5	18	15:30	TIE 400 kV Peć 3 - Ribarevine & TIE 400 kV Tirana 2 - Podgorica 2	220	OHL 220 kV Vau Dejes - Koplik	40.78	90.65

Table 2.11: SCC's original DACF security analysis results for MEPSO for 18 May 2025

IDCF CGMs and security analysis results were delivered by SCC to MEPSO on 18 May 2025 at 00:25.

The most recent N-X results relevant to this incident were calculated during the first IDCF process for 18 May 2025 (performed for the period from 0:30 AM to 7:30 AM).

IDCF security analysis results are presented below. As shown, there was no indication of a possible critical situation due to overloading in the affected area.

N-X STATISTICS SORTED BY LOADING

Year	Month	Day	Time stamp	CO Name	CB Unom	CB Name	Loading_BC [%]	Loading after outage [%]
2025	5	18	07:30	OHL 110 kV Bitola 1 - Sopotnica & OHL 110 kV HEC Vrutok - HEC Špilje	110	OHL 110 kV HEC Globočica - Struga	18.16	103.62
2025	5	18	07:30	OHL 110 kV Bitola 1 - Sopotnica & OHL 110 kV HEC Vrutok - HEC Špilje	110	OHL 110 kV Ohrid 1 - Struga	16.97	101.7
2025	5	18	07:30	OHL 110 kV Bitola 1 - Sopotnica & OHL 110 kV HEC Vrutok - HEC Špilje	110	OHL 110 kV Ohrid 1 - Ohrid 2	16.78	100.45
2025	5	18	07:30	110 kV Vrutok busbar fault	110	OHL 110 kV HEC Globočica - Struga	18.16	100.19
2025	5	18	07:30	OHL 110 kV Bitola 1 - Sopotnica & OHL 110 kV HEC Vrutok - HEC Špilje	110	OHL 110 kV Ohrid 2 - Resen	17.25	100.03
2025	5	18	07:30	OHL 110 kV HEC Vrutok - HEC Špilje	110	OHL 110 kV HEC Globočica - Struga	18.16	99.89
2025	5	18	07:30	OHL 110 kV Bitola 1 - Sopotnica & OHL 110 kV HEC Vrutok - HEC Špilje	110	OHL 110 kV Bitola 4 - Resen	16.79	99.08
2025	5	18	07:30	110 kV Vrutok busbar fault	110	OHL 110 kV Ohrid 1 - Struga	16.97	98.19
2025	5	18	07:30	OHL 110 kV HEC Vrutok - HEC Špilje	110	OHL 110 kV Ohrid 1 - Struga	16.97	97.88
2025	5	18	07:30	110 kV Vrutok busbar fault	110	OHL 110 kV Ohrid 1 - Ohrid 2	16.78	96.87
2025	5	18	07:30	TIE 400 kV Peć 3 - Ribarevine & TIE 400 kV Tirana 2 - Podgorica 2	220	OHL 220 kV Vau Dejes - Koplik	47.74	96.68
2025	5	18	07:30	OHL 110 kV HEC Vrutok - HEC Špilje	110	OHL 110 kV Ohrid 1 - Ohrid 2	16.78	96.56
2025	5	18	07:30	110 kV Vrutok busbar fault	110	OHL 110 kV Ohrid 2 - Resen	17.25	96.41
2025	5	18	07:30	OHL 110 kV HEC Vrutok - HEC Špilje	110	OHL 110 kV Ohrid 2 - Resen	17.25	96.11
2025	5	18	07:30	110 kV Vrutok busbar fault	110	OHL 110 kV Bitola 4 - Resen	16.79	95.43
2025	5	18	07:30	OHL 110 kV HEC Vrutok - HEC Špilje	110	OHL 110 kV Bitola 4 - Resen	16.79	95.12
2025	5	18	07:30	OHL 110 kV Bitola 1 - Sopotnica & OHL 110 kV HEC Vrutok - HEC Špilje	110	OHL 110 kV HEC Globočica - HEC Špilje	17.98	94.28
2025	5	18	07:30	TIE 400 kV Peć 3 - Ribarevine & TIE 400 kV Tirana 2 - Podgorica 2	220	TIE 220 kV Podgorica 1 - Koplik (AL)	45.23	93.31
2025	5	18	07:30	110 kV Vrutok busbar fault	110	OHL 110 kV HEC Globočica - HEC Špilje	17.98	91.29
2025	5	18	07:30	OHL 110 kV HEC Vrutok - HEC Špilje	110	OHL 110 kV HEC Globočica - HEC Špilje	17.98	91.02

Table 2.12: SCC's original IDCF security analysis results for MEPSO for 18 May 2025

The MEPSO transmission system consists of 400 kV and 110 kV components, as well as 400/110 kV transformers. The 220 kV voltage level is not part of MEPSO's transmission infrastructure. However, within the results of the security analyses, certain monitored elements at the 220 kV voltage level may appear (as indicated in the "CB Name" column). These elements are not operated by MEPSO but rather by the neighbouring TSOs. Nevertheless, MEPSO includes these elements in its Mon list and observes their potential overloading in the event of outages of relevant elements from the Con list. For example, the OHL 220 kV Vau Dejes–Koplik is an internal element of OST.

Although node voltages can be monitored at the request of the TSO, MEPSO made no such request. Therefore, corresponding results for 18 May 2025 were not presented. Voltages are available in a separate file, which is not regularly delivered to TSOs within the DACF and IDCF procedures.

2.3.4.2 Additional DACF Security Analysis Results for 18 May 2025

As previously noted, to compare results between the original and regular DACF procedures (as if MEPSO IGMs were delivered on time) for 18 May 2025, SCC conducted additional DACF analysis for 18 May 2025, including subsequently created MEPSO DACF IGMs.

Security analysis results from the additional DACF procedure for 18 May 2025 are shown in Table 2.13.

N-X STATISTICS SORTED BY LOADING

Year	Month	Day	Time stamp	CO Name	CB Unom	CB Name	Loading_BC [%]	Loading after outage [%]
2025	5	18	11:30	400 kV Bitola busbar fault	110	OHL 110 kV Bitola 1 - Sopotnica	13.44	151.69
2025	5	18	11:30	400 kV Bitola busbar fault	110	OHL 110 kV Kičevo - Sopotnica	12.94	151.55
2025	5	18	11:30	400 kV Bitola busbar fault	110	OHL 110 kV Kičevo - TEC Oslomej	12.49	151.23
2025	5	18	09:30	400 kV Bitola busbar fault	110	OHL 110 kV Kičevo - TEC Oslomej	17.07	150.15
2025	5	18	10:30	400 kV Bitola busbar fault	110	OHL 110 kV Bitola 1 - Sopotnica	14.31	150.15
2025	5	18	09:30	400 kV Bitola busbar fault	110	OHL 110 kV Kičevo - Sopotnica	17.09	149.97
2025	5	18	09:30	400 kV Bitola busbar fault	110	OHL 110 kV Bitola 1 - Sopotnica	17.48	149.95
2025	5	18	10:30	400 kV Bitola busbar fault	110	OHL 110 kV Kičevo - Sopotnica	13.79	149.95
2025	5	18	10:30	400 kV Bitola busbar fault	110	OHL 110 kV Kičevo - TEC Oslomej	13.18	149.45
2025	5	18	08:30	400 kV Bitola busbar fault	110	OHL 110 kV Bitola 1 - Sopotnica	20.34	148.74
2025	5	18	08:30	400 kV Bitola busbar fault	110	OHL 110 kV Kičevo - Sopotnica	19.90	148.57
2025	5	18	08:30	400 kV Bitola busbar fault	110	OHL 110 kV Kičevo - TEC Oslomej	19.37	148.11
2025	5	18	07:30	400 kV Bitola busbar fault	110	OHL 110 kV Bitola 1 - Sopotnica	25.55	147.67
2025	5	18	23:30	400 kV Bitola busbar fault	110	OHL 110 kV Bitola 1 - Sopotnica	27.25	147.28
2025	5	18	07:30	400 kV Bitola busbar fault	110	OHL 110 kV Kičevo - Sopotnica	24.60	146.77
2025	5	18	23:30	400 kV Bitola busbar fault	110	OHL 110 kV Kičevo - Sopotnica	24.87	144.96
2025	5	18	07:30	400 kV Bitola busbar fault	110	OHL 110 kV Kičevo - TEC Oslomej	21.87	143.97
2025	5	18	22:30	400 kV Bitola busbar fault	110	OHL 110 kV Bitola 1 - Sopotnica	27.90	141.17
2025	5	18	01:30	400 kV Bitola busbar fault	110	OHL 110 kV Bitola 1 - Sopotnica	31.52	139.68
2025	5	18	06:30	400 kV Bitola busbar fault	110	OHL 110 kV Bitola 1 - Sopotnica	24.80	139.17
2025	5	18	22:30	400 kV Bitola busbar fault	110	OHL 110 kV Kičevo - Sopotnica	24.85	138.23
2025	5	18	06:30	400 kV Bitola busbar fault	110	OHL 110 kV Kičevo - Sopotnica	23.63	138.05
2025	5	18	01:30	400 kV Bitola busbar fault	110	OHL 110 kV Kičevo - Sopotnica	29.80	137.94

N-X STATISTICS SORTED BY LOADING								
Year	Month	Day	Time stamp	CO Name	CB Unom	CB Name	Loading_BC [%]	Loading after outage [%]
2025	5	18	23:30	400 kV Bitola busbar fault	110	OHL 110 kV Kičevo - TEC Oslomej	17.07	137.44
2025	5	18	08:30	TIE 400 kV Peć 3 - Ribarevine & TIE 400 kV Tirana 2 - Podgorica 2	220	OHL 220 kV Vau Dejes - Koplik	67.48	136.72
2025	5	18	05:30	400 kV Bitola busbar fault	110	OHL 110 kV Bitola 1 - Sopotnica	27.58	135.10
2025	5	18	06:30	400 kV Bitola busbar fault	110	OHL 110 kV Kičevo - TEC Oslomej	20.13	134.50
2025	5	18	05:30	400 kV Bitola busbar fault	110	OHL 110 kV Kičevo - Sopotnica	26.13	133.66
2025	5	18	08:30	TIE 400 kV Peć 3 - Ribarevine & TIE 400 kV Tirana 2 - Podgorica 2	220	TIE 220 kV Podgorica 1 - Koplik (AL)	64.62	132.63
2025	5	18	01:30	400 kV Bitola busbar fault	110	OHL 110 kV Kičevo - TEC Oslomej	24.31	132.40
2025	5	18	02:30	400 kV Bitola busbar fault	110	OHL 110 kV Bitola 1 - Sopotnica	29.56	132.00
2025	5	18	21:30	400 kV Bitola busbar fault	110	OHL 110 kV Bitola 1 - Sopotnica	20.20	131.93
2025	5	18	03:30	400 kV Bitola busbar fault	110	OHL 110 kV Bitola 1 - Sopotnica	27.90	130.67
2025	5	18	02:30	400 kV Bitola busbar fault	110	OHL 110 kV Kičevo - Sopotnica	28.01	130.46
2025	5	18	04:30	400 kV Bitola busbar fault	110	OHL 110 kV Bitola 1 - Sopotnica	27.11	130.42
2025	5	18	03:30	400 kV Bitola busbar fault	110	OHL 110 kV Kičevo - Sopotnica	26.44	129.25
2025	5	18	21:30	400 kV Bitola busbar fault	110	OHL 110 kV Kičevo - Sopotnica	17.30	129.17
2025	5	18	05:30	400 kV Bitola busbar fault	110	OHL 110 kV Kičevo - TEC Oslomej	21.60	129.06
2025	5	18	04:30	400 kV Bitola busbar fault	110	OHL 110 kV Kičevo - Sopotnica	25.66	129.00
2025	5	18	22:30	400 kV Bitola busbar fault	110	OHL 110 kV Kičevo - TEC Oslomej	14.92	128.75
2025	5	18	02:30	400 kV Bitola busbar fault	110	OHL 110 kV Kičevo - TEC Oslomej	23.14	125.51
2025	5	18	03:30	400 kV Bitola busbar fault	110	OHL 110 kV Kičevo - TEC Oslomej	21.93	124.65
2025	5	18	04:30	400 kV Bitola busbar fault	110	OHL 110 kV Kičevo - TEC Oslomej	21.16	124.44
2025	5	18	21:30	400 kV Bitola busbar fault	110	OHL 110 kV Kičevo - TEC Oslomej	7.74	120.24
2025	5	18	08:30	TIE 400 kV Peć 3 - Ribarevine & TIE 400 kV Tirana 2 - Podgorica 2	220	TIE 220 kV Koplik - Podgorica 1 (ME)	57.62	119.01
2025	5	18	20:30	400 kV Bitola busbar fault	110	OHL 110 kV Bitola 1 - Sopotnica	18.36	109.51
2025	5	18	19:30	OHL 110 kV HEC Vrutok - Polog & OHL 110 kV HEC Vrutok - Skopje 1	110	OHL 110 kV HEC Vrutok - Gostivar	46.64	106.72
2025	5	18	23:30	400 kV Bitola busbar fault	110	OHL 110 kV HEC Vrutok - HEC Špilje	56.21	106.64
2025	5	18	20:30	400 kV Bitola busbar fault	110	OHL 110 kV Kičevo - Sopotnica	15.18	106.48
2025	5	18	18:30	TIE 400 kV Peć 3 - Ribarevine & TIE 400 kV Tirana 2 - Podgorica 2	220	TIE 220 kV Podgorica 1 - Koplik (AL)	48.09	105.60
2025	5	18	22:30	400 kV Skopje 4 busbar fault	110	OHL 110 kV Ovče Pole - Štip	30.15	104.50

N-X STATISTICS SORTED BY LOADING								
Year	Month	Day	Time stamp	CO Name	CB Unom	CB Name	Loading_BC [%]	Loading after outage [%]
2025	5	18	20:30	OHL 110 kV HEC Vrutok - Polog & OHL 110 kV HEC Vrutok - Skopje 1	110	OHL 110 kV HEC Vrutok - Gostivar	44.64	104.02
2025	5	18	18:30	TIE 400 kV Peć 3 - Ribarevine & TIE 400 kV Tirana 2 - Podgorica 2	220	OHL 220 kV Vau Dejes - Koplik	45.61	103.46
2025	5	18	22:30	400 kV Skopje 4 busbar fault	400/110	TR 400/110 kV Štip	50.69	103.25
2025	5	18	19:30	400 kV Skopje 4 busbar fault	400/110	TR 400/110 kV Štip	50.47	100.88
2025	5	18	01:30	400 kV Skopje 4 busbar fault	110	OHL 110 kV Ovče Pole - Štip	23.29	100.68
2025	5	18	19:30	TIE 400 kV Peć 3 - Ribarevine & TIE 400 kV Tirana 2 - Podgorica 2	220	TIE 220 kV Podgorica 1 - Koplik (AL)	43.61	100.60
2025	5	18	23:30	TIE 400 kV Peć 3 - Ribarevine & TIE 400 kV Tirana 2 - Podgorica 2	220	TIE 220 kV Podgorica 1 - Koplik (AL)	37.89	99.41
2025	5	18	22:30	400 kV Skopje 4 busbar fault	110	OHL 110 kV Kriva Reka - Kumanovo 1	15.51	98.71
2025	5	18	19:30	TIE 400 kV Peć 3 - Ribarevine & TIE 400 kV Tirana 2 - Podgorica 2	220	OHL 220 kV Vau Dejes - Koplik	41.55	98.42
2025	5	18	19:30	400 kV Skopje 4 busbar fault	110	OHL 110 kV Ovče Pole - Štip	27.23	98.38
2025	5	18	22:30	400 kV Bitola busbar fault	110	OHL 110 kV HEC Vrutok - HEC Špilje	50.14	98.25
2025	5	18	23:30	TIE 400 kV Peć 3 - Ribarevine & TIE 400 kV Tirana 2-Podgorica 2	220	OHL 220 kV Vau Dejes - Koplik	36.17	98.19
2025	5	18	22:30	400 kV Skopje 4 busbar fault	110	OHL 110 kV Veles - Ovče Pole	23.82	97.88
2025	5	18	21:30	400 kV Bitola busbar fault	110	OHL 110 kV HEC Vrutok - HEC Špilje	48.71	97.86
2025	5	18	01:30	400 kV Skopje 4 busbar fault	110	OHL 110 kV Veles - Ovče Pole	19.72	97.08
2025	5	18	08:30	TIE 400 kV Tirana 2 - Podgorica 2	220	OHL 220 kV Vau Dejes - Koplik	67.48	96.97
2025	5	18	20:30	400 kV Bitola busbar fault	110	OHL 110 kV Kičevo - TEC Oslomej	5.43	96.64
2025	5	18	01:30	400 kV Skopje 4 busbar fault	110	OHL 110 kV Kriva Reka - Kumanovo 1	8.79	95.51
2025	5	18	23:30	400 kV Skopje 4 busbar fault	110	OHL 110 kV Ovče Pole - Štip	28.68	94.99
2025	5	18	18:30	TIE 400 kV Peć 3 - Ribarevine & TIE 400 kV Tirana 2 - Podgorica 2	220	TIE 220 kV Koplik - Podgorica 1 (ME)	42.77	94.89
2025	5	18	22:30	TIE 400 kV Peć 3 - Ribarevine & TIE 400 kV Tirana 2 - Podgorica 2	220	TIE 220 kV Podgorica 1 - Koplik (AL)	40.04	94.54
2025	5	18	19:30	400 kV Bitola busbar fault	110	OHL 110 kV Bitola 1 - Sopotnica	15.66	93.96
2025	5	18	08:30	TIE 400 kV Tirana 2 - Podgorica 2	220	TIE 220 kV Podgorica 1 - Koplik (AL)	64.62	93.51
2025	5	18	22:30	TIE 400 kV Peć 3 - Ribarevine & TIE 400 kV Tirana 2 - Podgorica 2	220	OHL 220 kV Vau Dejes - Koplik	38.44	92.83
2025	5	18	23:30	400 kV Skopje 4 busbar fault	110	OHL 110 kV Kriva Reka - Kumanovo 1	17.97	92.77
2025	5	18	07:30	TIE 400 kV Peć 3 - Ribarevine & TIE 400 kV Tirana 2 - Podgorica 2	220	OHL 220 kV Vau Dejes - Koplik	47.03	92.68
2025	5	18	01:30	400 kV Skopje 4 busbar fault	110	OHL 110 kV Bitola 1 - Sopotnica	31.52	92.50
2025	5	18	19:30	400 kV Skopje 4 busbar fault	110	OHL 110 kV Veles - Ovče Pole	20.81	91.74

N-X STATISTICS SORTED BY LOADING								
Year	Month	Day	Time stamp	CO Name	CB Unom	CB Name	Loading_BC [%]	Loading after outage [%]
2025	5	18	19:30	400 kV Bitola busbar fault	110	OHL 110 kV Kičevo - Sopotnica	12.71	90.89
2025	5	18	01:30	400 kV Skopje 4 busbar fault	110	OHL 110 kV Kičevo - Sopotnica	29.80	90.62
2025	5	18	02:30	400 kV Skopje 4 busbar fault	110	OHL 110 kV Ovče Pole - Štip	21.88	90.62
2025	5	18	19:30	TIE 400 kV Peć 3 - Ribarevine & TIE 400 kV Tirana 2 - Podgorica 2	220	TIE 220 kV Koplik - Podgorica 1 (ME)	38.63	90.32
2025	5	18	18:30	400 kV Bitola busbar fault	110	OHL 110 kV HEC Vrutok - HEC Špilje	47.84	90.13

Table 2.13: SCC additional DACF security analysis results for MEPSO for 18 May 2025

The differences in DACF security analysis results between the original and additional processes are caused by the different topology status of OHL 110 kV Bitola 1–Prilep 1 in MEPSO IGMs (in subsequently created MEPSO DACF IGMs, this line is out of operation).

2.4 Market Conditions

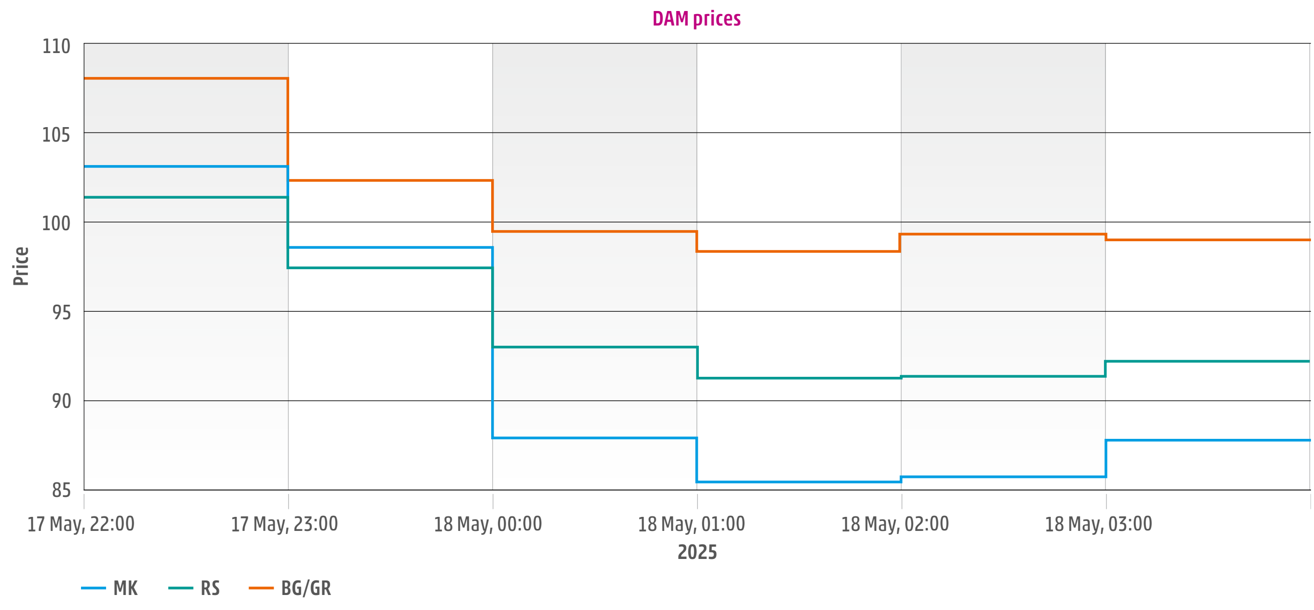


Figure 2.20: Day-ahead market (DAM) prices for 18 May 2025

Figure 2.20 shows the day-ahead market (DAM) prices for the bidding zones of North Macedonia (MK), Serbia (RS), and Bulgaria/Greece (BG/GR) for the period around 18 May 2025. The prices exhibit similar hourly trends across the three bidding zones, with slightly higher levels in the BG/GR area.

During the early morning hours of 18 May 2025, when the incident occurred, the prices remained stable and did not show any abrupt deviations, indicating that the market conditions were normal and that the event did not have an immediate impact on DAM prices.

3 SYSTEM CONDITIONS DURING THE INCIDENT

Chapter 3 is divided into an analysis of the dynamic behaviour (voltage, reactive and active power flows) of the system during the incident (Subchapter 3.1), an analysis of the behaviour of the protection system during the incident (Subchapter 3.2), the impact of the incident on the neighbouring TSOs (Subchapter 3.3) and a conclusion of the Chapter (Subchapter 3.4).

3.1 Dynamic Behaviour of the System During the Incident

In the morning hours of 18 May 2025, a series of voltage-related outages occurred, resulting in the disconnection of the 110 kV network from the 400 kV network. This ultimately led to a blackout in the 110 kV network (and consequently in the distribution system).

Subchapter 3.1 presents the dynamic behaviour of the system during the incident, covering:

- The evolution of the incident, including the chronology of outages and contingencies on 18 May 2025
- Disconnection of generation units and load on 18 May 2025
- Voltage behaviour
- Reactive and active power flows
- Phasor measurement unit (PMU) analysis

3.1.1 Evolution of the Incident

In the morning of 18 May 2025, between 02:26 and 02:58, high voltages[12] caused TR2 in Bitola and TR2 in Skopje 5 to disconnect from the grid. At 04:06, the voltage situation worsened, leading to the outage of the 400/110 kV transformer in Štip. To stabilise the situation, an attempt was made to connect the transformer in Skopje 5, and a request was made to synchronise two generators in HPP Vrutok and HPP Tikvesh.

However, due to the outage of the last remaining 400/110 kV transformer (TR2 in Skopje 4) at 04:59, the generators from the mentioned HPPs were not synchronised in time.

The main outages are listed in Table 3.1.

No.	Element	Disconnection	Connection	Event	Description
0	447 (OHL) SS Bitola 2 – SS Skopje 4 400 kV	16.05.2025 22:46	18.05.2025 08:48	Corrective measure	The OHL was disconnected as a precaution to reduce the injection of reactive power and keep system voltages lower.
1	TR2 SS Skopje 5 400/110 kV	18.05.2025 02:26	18.05.2025 02:50	Outage	High-voltage outage
2	TR2 SS Bitola 2 400/110 kV	18.05.2025 02:26	18.05.2025 02:49	Outage	High-voltage outage
3	TR2 SS Bitola 2 400/110 kV	18.05.2025 02:59	18.05.2025 06:27	Outage	High-voltage outage
4	TR1 SS Skopje 1, 5 400/110 kV	18.05.2025 03:35	18.05.2025 07:38	Outage	High-voltage outage
5	TR1 SS Štip 1 400/110 kV	18.05.2025 04:06	18.05.2025 07:47	Outage	High-voltage outage
6	TR2 SS Skopje 4 400/110 kV	18.05.2025 04:59	18.05.2025 06:49	Outage	High-voltage outage
7	172 (OHL) SS Kratovo – SS Palanka 110 kV	18.05.2025 04:59	18.05.2025 07:23	Outage	SS Palanka was energised, supplied by an island operation from the Bulgarian transmission grid side.
8	Block 1 – TPP Bitola, 110/15.7 kV	18.05.2025 04:59	18.05.2025 19:47	Outage	Outage at Block 1 in TPP Bitola due to generator protection
9	423 (OHL) SS Štip 1 – SS Vranje 4 400 kV	18.05.2025 06:05	18.05.2025 10:24	Corrective measure	Controlled disconnection for voltage stabilisation during restoration
10	420/1 SS Skopje 5 – SS Uroshevac 400 kV	18.05.2025 06:14	18.05.2025 07:37	Corrective measure	Controlled disconnection for voltage stabilisation during restoration
11	447 SS Bitola 2 – SS Skopje 4 400 kV	18.05.2025 22:00	19.05.2025 10:47	Corrective measure	Disconnection due to high voltages.

Table 3.1: Chronology of outages and contingencies on 18 May 2025

3.1.2 Voltage Behaviour on 18 May 2025

The voltage on all busbars is shown in Figure 3.1 for the period from 17 May 2025 12:00 to 18 May 2025 12:00. The time resolution of all plots within this sub-chapter is 10 minutes. Figure 3.2 shows the same measurements in a zoomed-in version. These plots show that the voltage limit of 420 kV was already exceeded around 01:30 and stayed above this limit consistently at all substations from 02:00 onwards.

The reason for the apparent zigzag behaviour (repetitive increases and decreases) of the 400 kV voltages remains unknown but may have been a result of additional switching actions (manual, automatic, or outages) that impacted voltage.

All busbars showed a steady increase in voltage, which ultimately led to the outage of all 400/110 kV transformers until 04:59 CEST. At this point, the entire 110 kV grid was connected only to Bulgaria via the Kriva Palanka–Skakavica line. The inability to maintain voltage in the 110 kV grid (overvoltage situation) resulted in the outage of all active generation units connected to the 110 kV grid during that period. The entire 110 kV grid remained without voltage until time of reconnection at 06:27; the delivery of electricity to all 110 kV nodes was interrupted, except for SS Kriva Palanka, which was powered via the 110 kV line SS Kriva Palanka – SS Skakavica.

12 Voltage values can be found in Subchapter 3.2. Further explanation on voltage control can be found in Chapter 7 on voltage control.

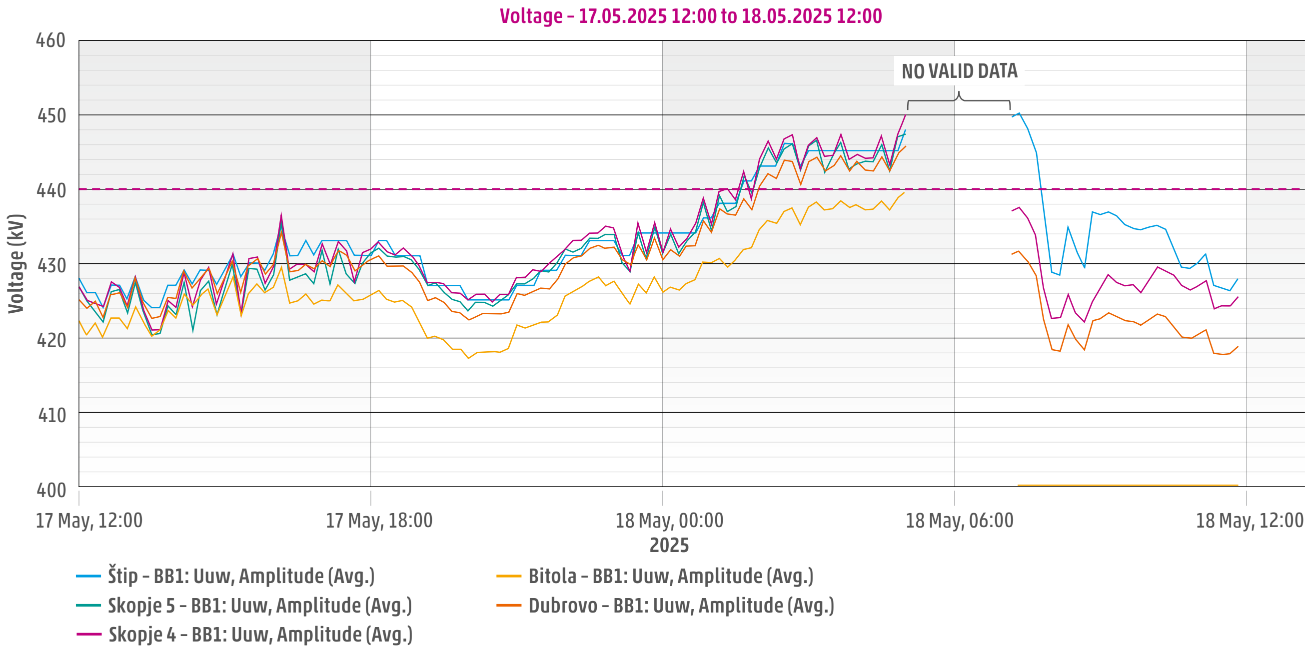


Figure 3.1: Voltage of 400 kV busbars over the course of 24 hours

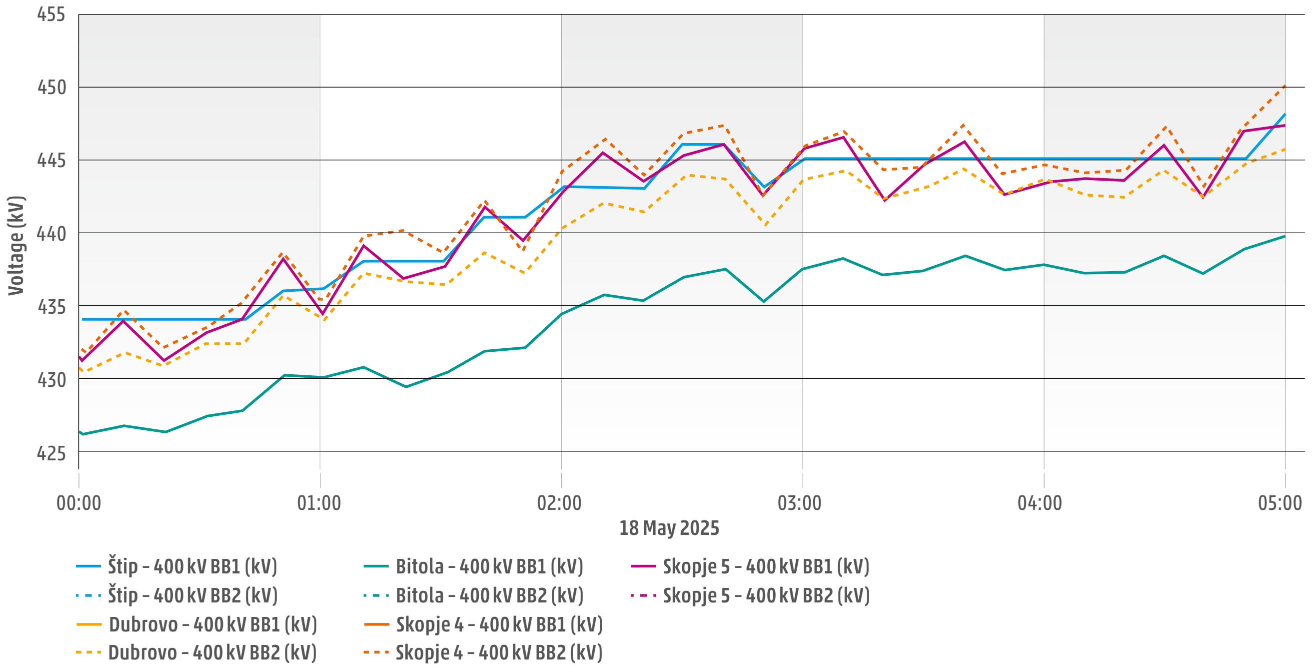


Figure 3.2: Voltage of 400 kV busbars over the course of five hours

3.1.3 Reactive and Active Power Flows on 18 May 2025

Whereas reactive power on the 400 kV lines stayed mostly unaffected (Figure 3.5) during the increase in voltages, the active power on the 400 kV lines decreased progressively (Figures 3.3, 3.4). After the tripping of all 400/110 kV transformers in the MEPSO transmission system at 04:59, all 400 kV OHLs remained in normal operating (on-load) condition, except for the internal 400 kV line Bitola 2–Skopje 4, which had been previously switched off as a preventive measure. This line is routinely switched off during nighttime hours to reduce voltage levels in the 400 kV network. Transit via the internal and interconnecting lines continued, and Block 3 of the Bitola power plant supplied power without interruption.

Generator	R+ (MVAr)	R– (MVAr)	Direction	Voltage Level (kV)
TPP Bitola, Block 3	0	6.6	Absorption	400
TPP Bitola, Block 1	0	2.2	Absorption	110
WPP Bogdanci	0.12	0	Injection	110
WPP Demir Kapija	3.3	0	Injection	110
HPP Špilje	0	0.25	Absorption	110

Table 3.2: Reactive power absorbed/injected prior to the blackout at 5:00 AM

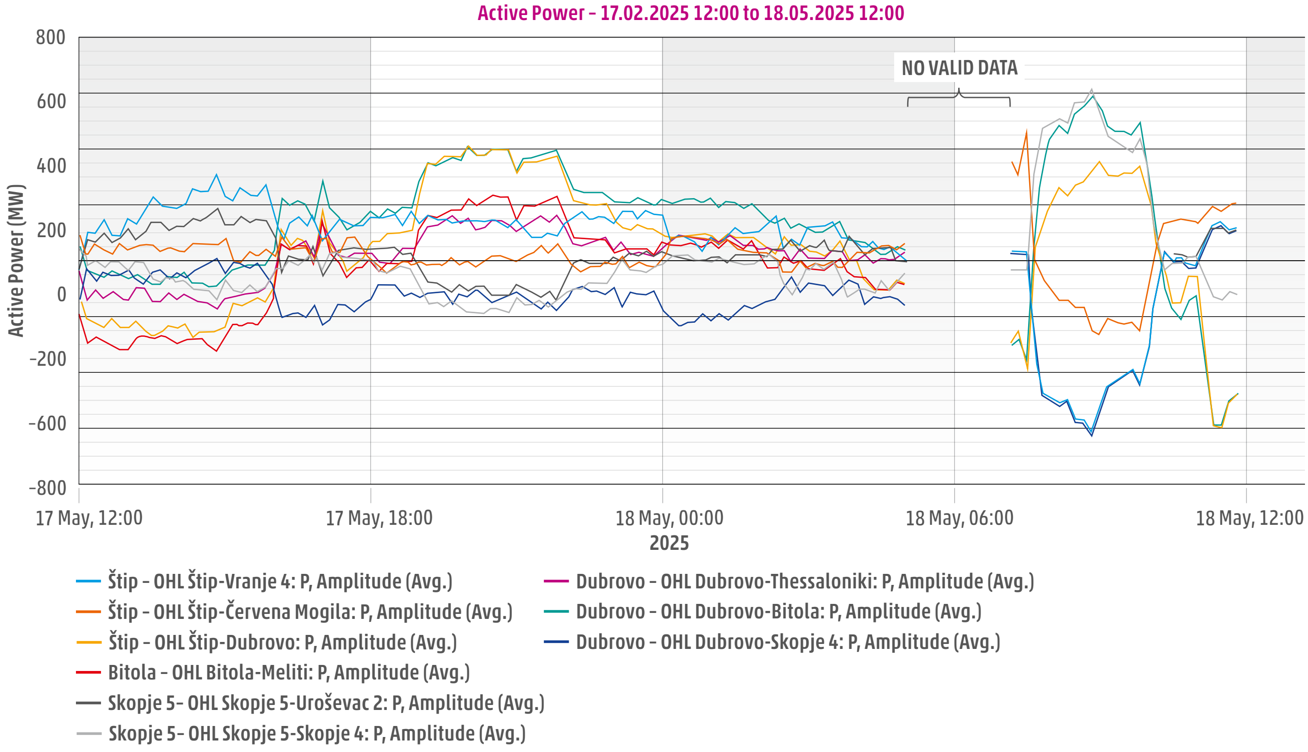


Figure 3.3: Active power of active 400 kV lines over the course of 24 hours

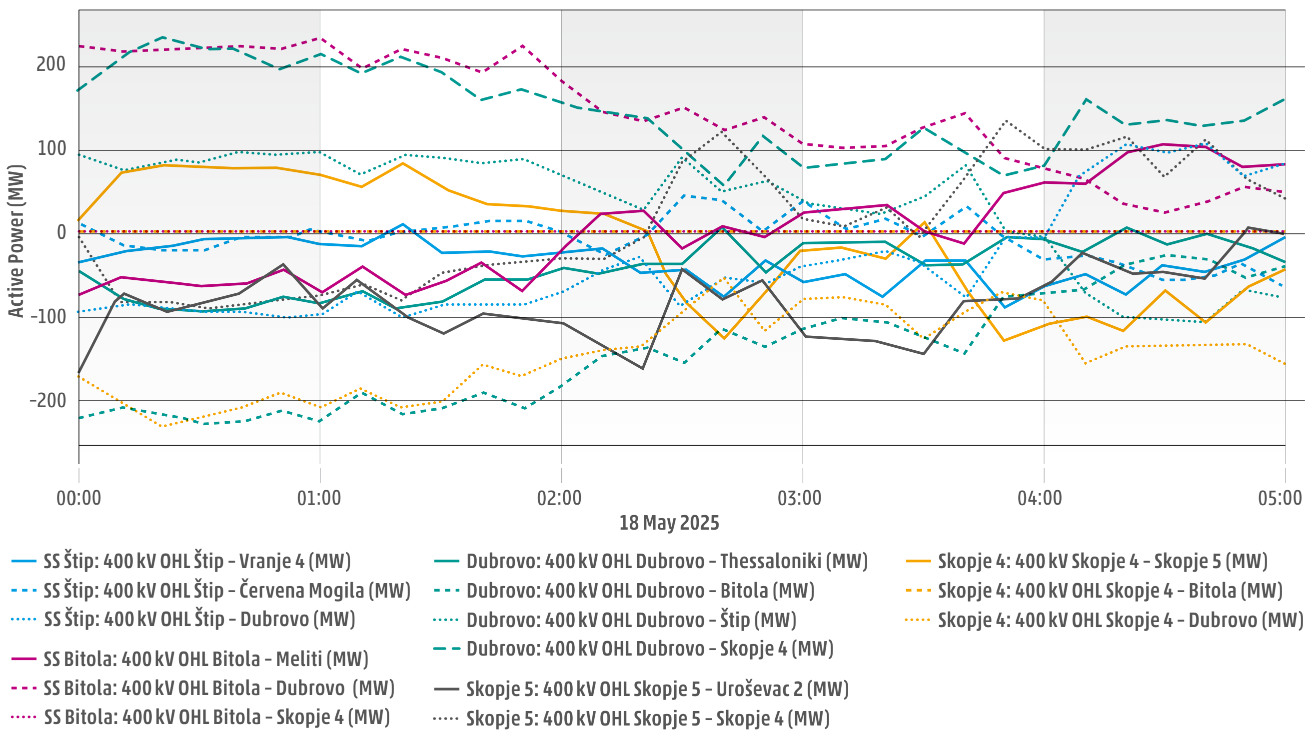


Figure 3.4: Active power of active 400 kV lines over the course of five hours

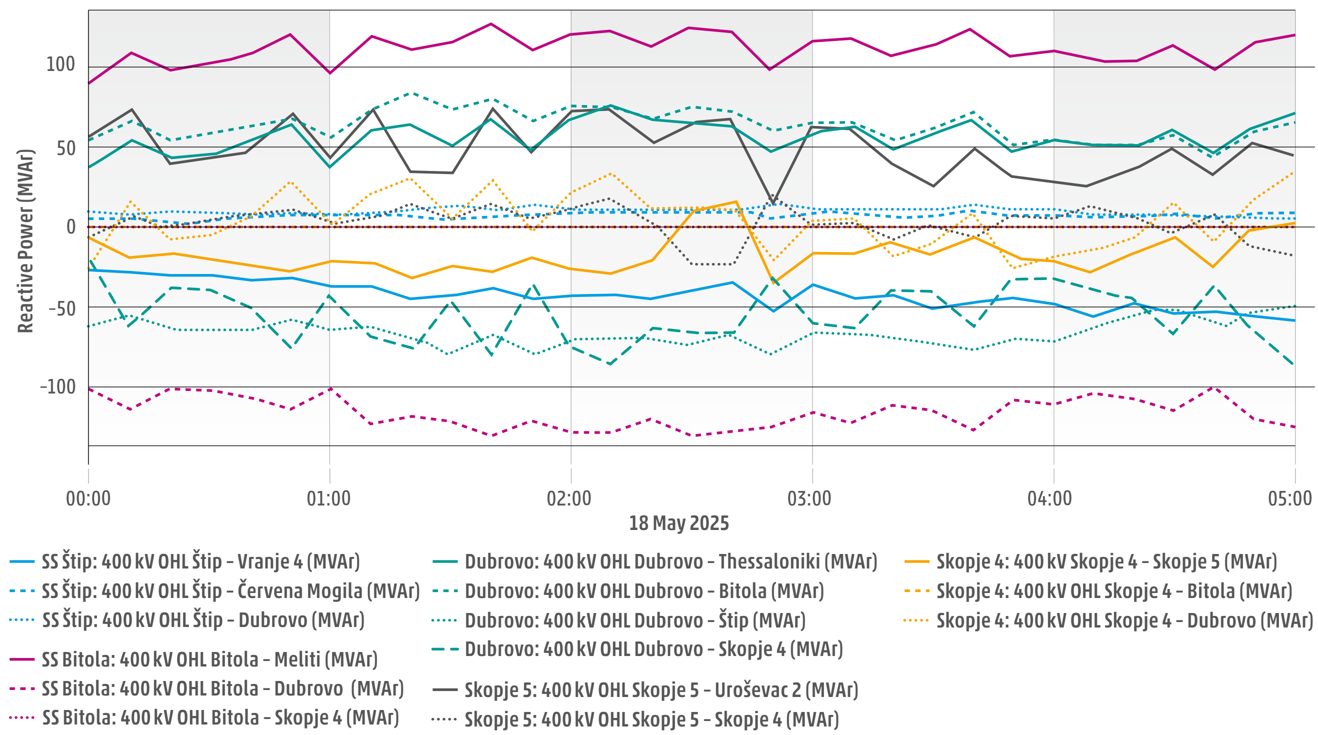


Figure 3.5: Reactive power of active 400 kV lines over the course of five hours

The following figures show the active and reactive power flows on the day of the incident at the interconnectors of MEPSO with each neighbouring TSO:

» R denotes reactive power; A denotes active power.

» "–" indicates export (output) and "+" indicates import (input).

» The magenta bars indicate the amount of reactive power exported from the system, while the green bars represent the power imported into the system.

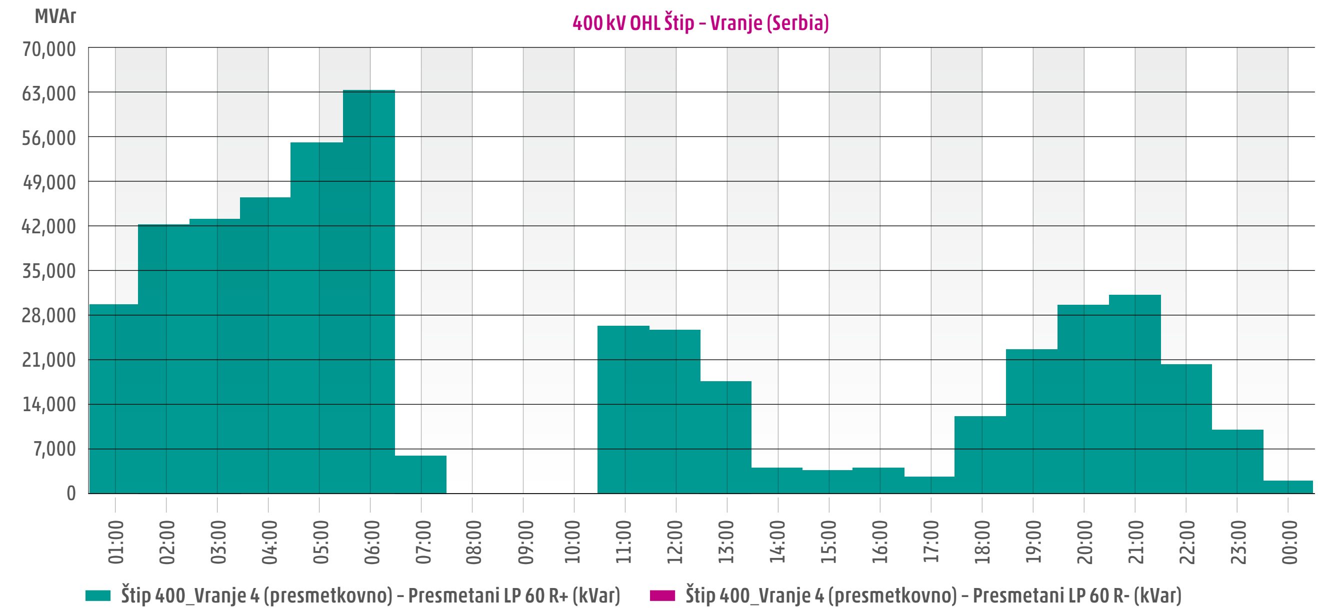


Figure 3.6: Hourly reactive power flow on the 400 kV OHL Štip-Vranje (EMS) (18 May 2025)

During 01:00–07:00, a reactive power flow R+ ≈ 60 MVAr on the 400 kV OHL Vranje–Štip was observed while active power was low.

This MVAr import at Štip contributed to a voltage increase at the Štip 400 kV bus (and along the corridor).

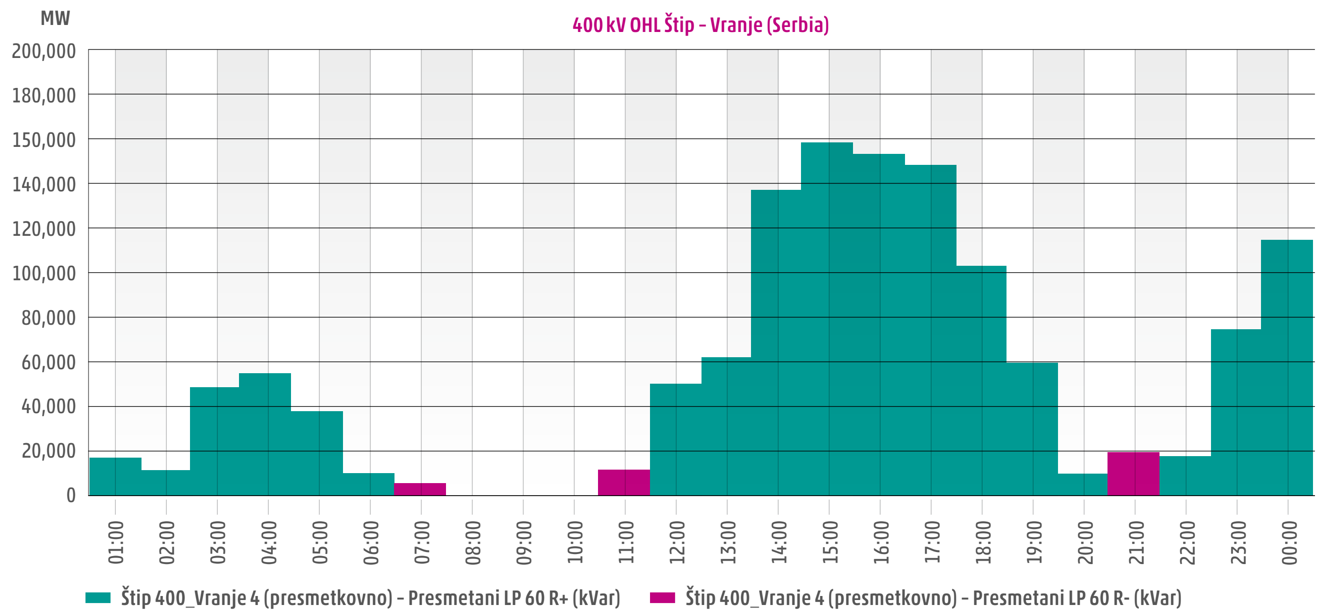


Figure 3.7: Hourly active power flow on the 400 kV OHL Štip-Vranje (EMS) (18 May 2025)

At around 05:00, when the incident occurred, the active power flow was near zero, indicating minimal exchange with EMS at that moment.

After the incident, a significant import from the power system of Serbia developed during the day, peaking in the afternoon.

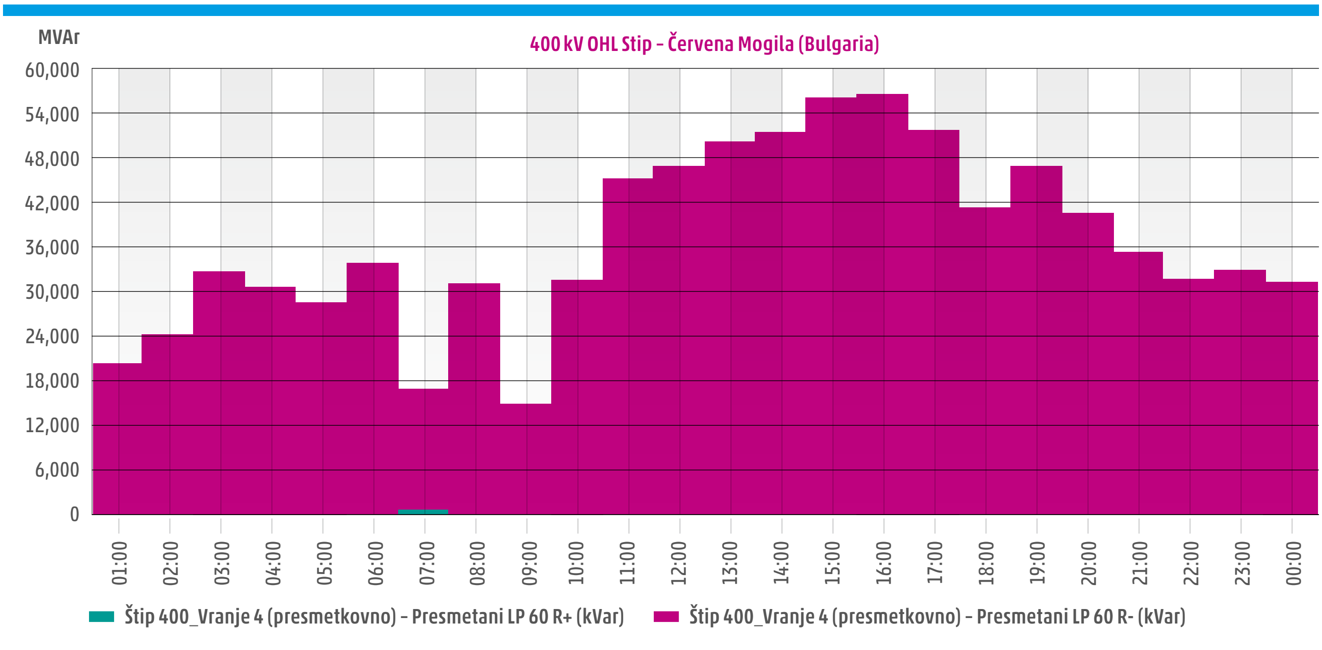


Figure 3.8: Hourly reactive power flow on the 400 kV OHL Štip-Červena Mogila (ESO) (18 May 2025)

During the night and early morning hours, dominant R– (reactive power export) caused a slight voltage decrease at the exporting side (mainly Štip), while at around 06:00, with P ≈ 0 and Q ≈ 0, a voltage rise was likely due to the line's capacitive charging.

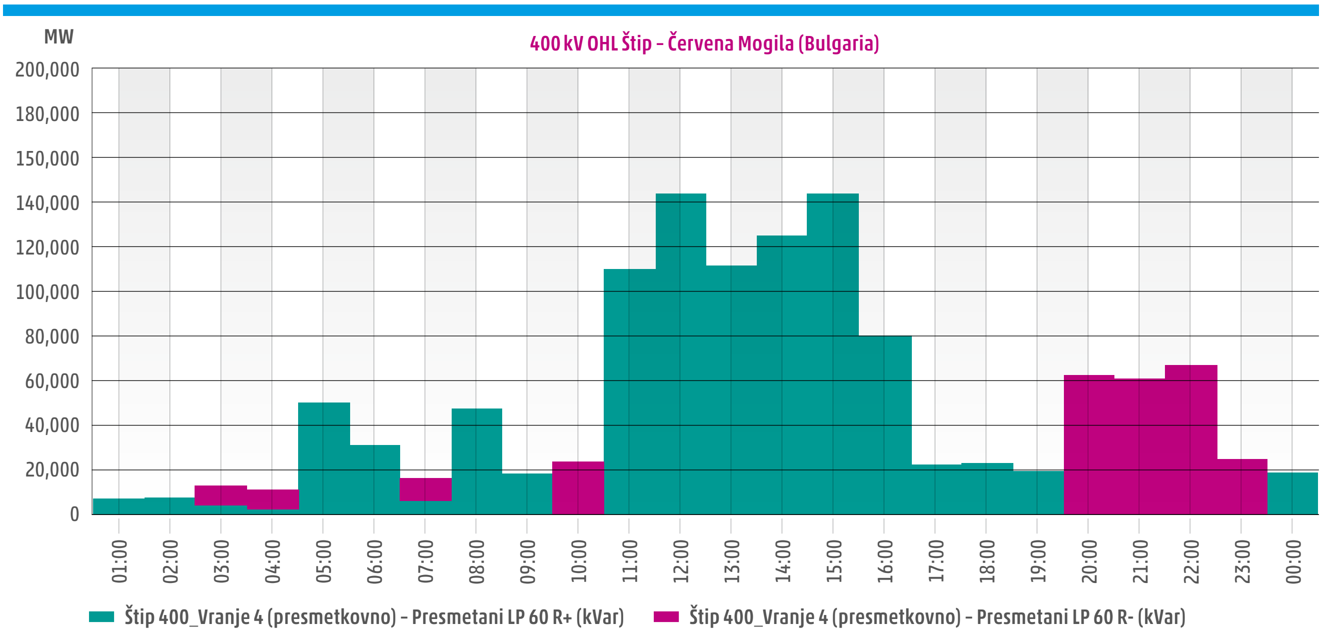


Figure 3.9: Hourly active power flow on the 400 kV OHL Štip-Červena Mogila (ESO) (18 May 2025)

Prior to and around 05:00, the exchange with ESO was negligible. Later that day, moderate imports to the power system of North Macedonia appeared, while limited exports to the power system of Bulgaria occurred in the evening, showing a stable but low interaction level on this line.

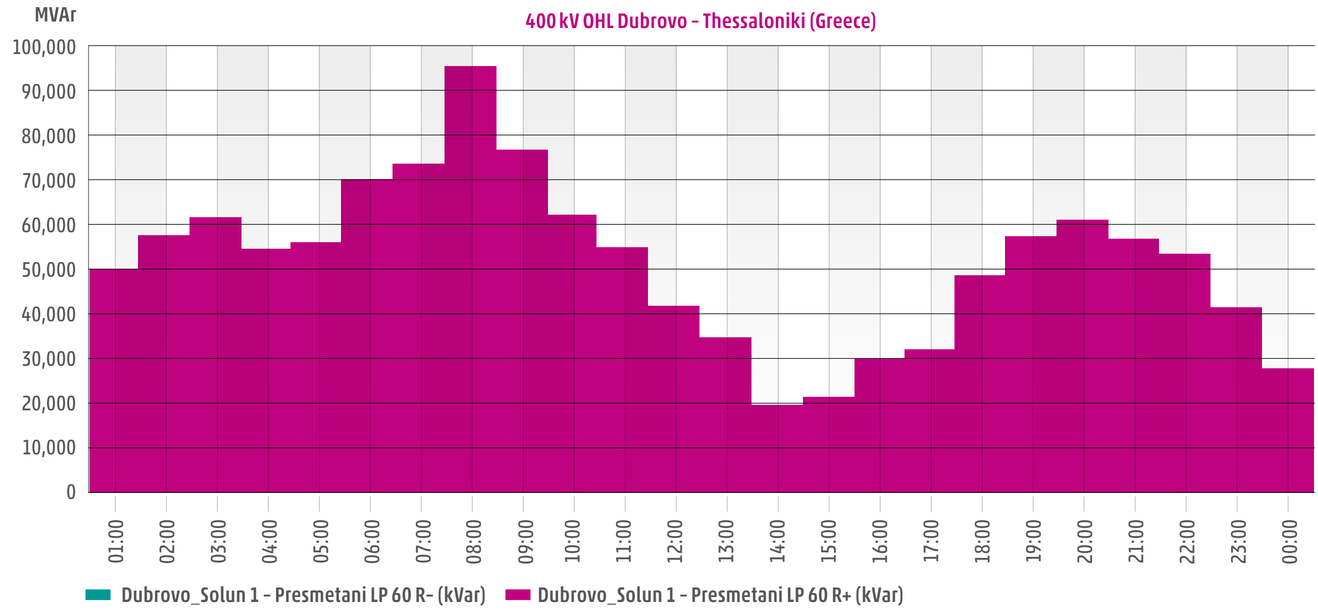


Figure 3.10: Hourly reactive power flow on the 400 kV OHL Dubrovo-Thessaloniki (IPTO) (18 May 2025)

During the night and early morning hours (01:00–07:00), there was low active power (P) and moderate reactive export (R− ≈ 40–70 MVAr). The continuous export of reactive power tends to reduce voltage on the North Macedonian (Dubrovo) side, leading to slightly higher voltages on the Greek side (in connection points close to the border with North Macedonia).

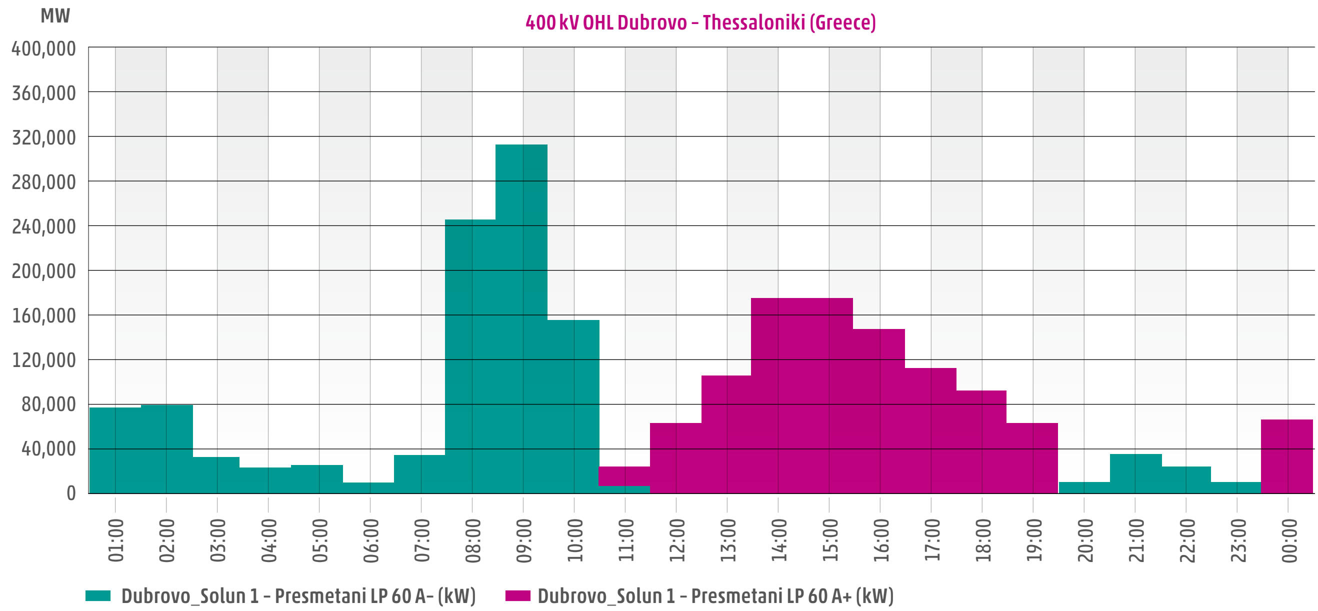


Figure 3.11: Hourly active power flow on the 400 kV OHL Dubrovo-Thessaloniki (IPTO) (18 May 2025)

During the early morning (around 05:00), the flow was low and directed towards the power system of Greece. Following the incident, exports increased sharply between 08:00 and 10:00, before reversing to imports later, illustrating dynamic regional adjustments.

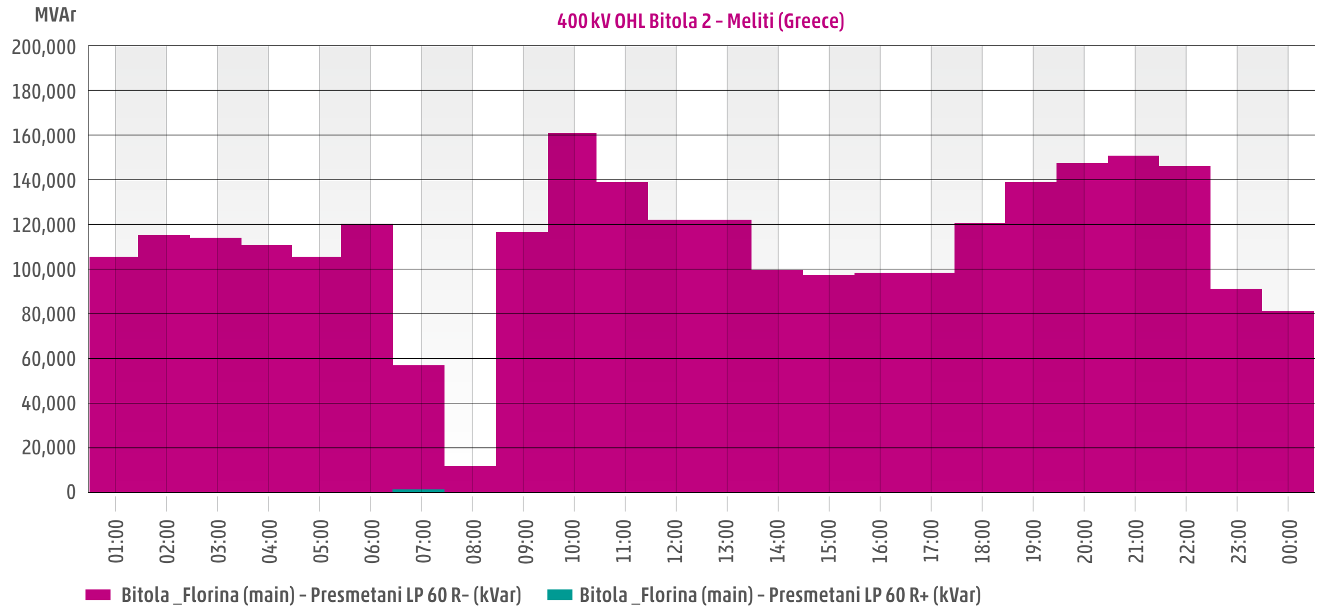


Figure 3.12: Hourly reactive power flow on the 400 kV OHL Bitola 2-Meliti (IPTO) (18 May 2025)

During the night and early morning hours (01:00–07:00), R- ≈100–120 MVAr was measured with low impact on active power.

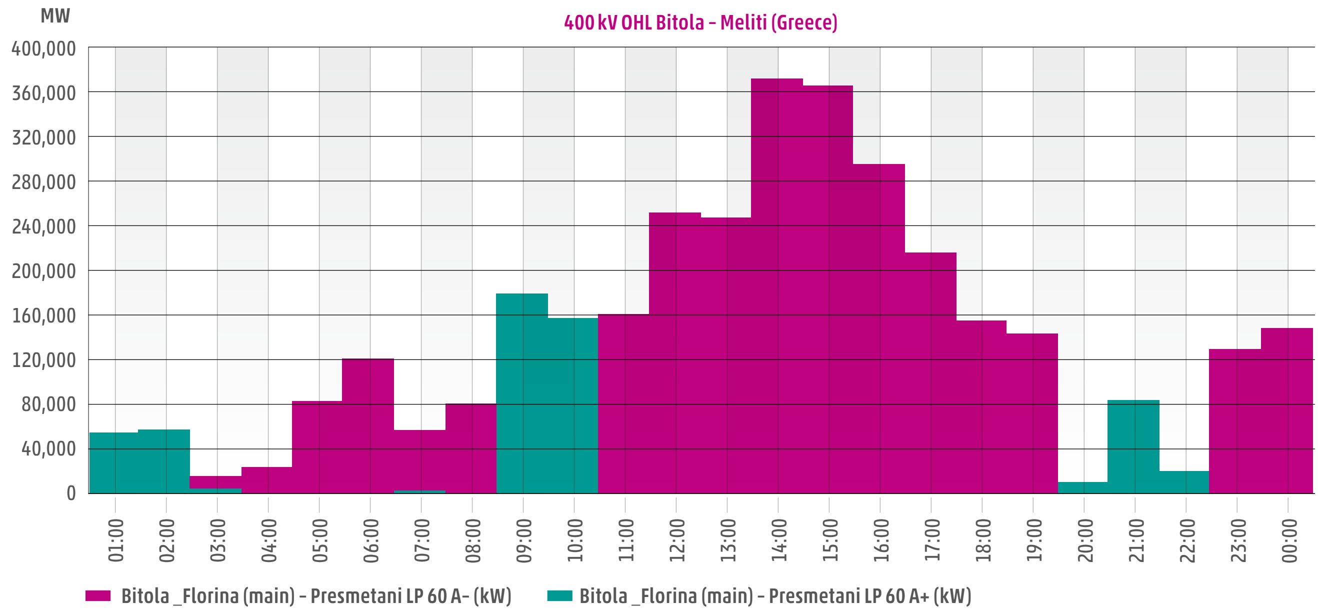


Figure 3.13: Hourly active power flow on the 400 kV OHL Bitola-Meliti (IPTO) (18 May 2025)

At the time of the incident (05:00), the flow decreased to close to zero.

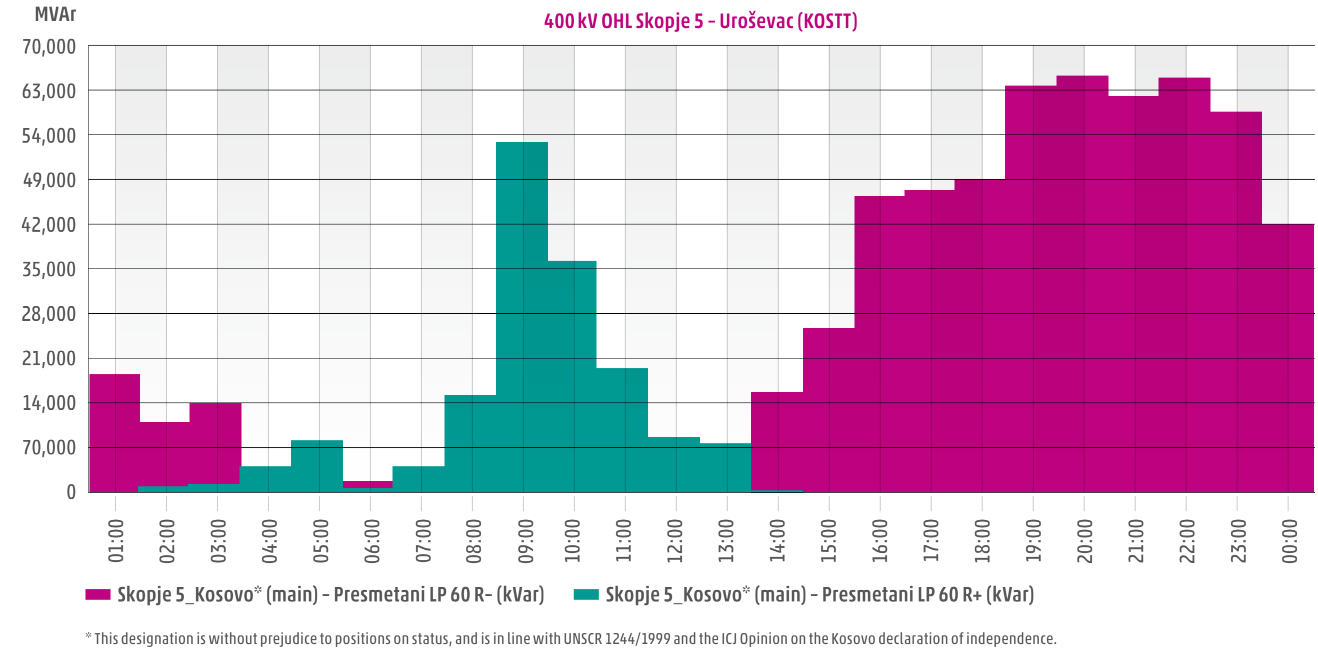


Figure 3.14: Hourly reactive power flow on the 400 kV OHL Skopje 5-Uroševac (KOSTT) (18 May 2025)

In the night and early morning hours (01:00–07:00), low power flows (below 15 Mvars, small R–) were measured.

Minor reactive exports from MK resulted in a slight voltage decrease at Skopje 5, with a neutral to slightly higher voltage value on the KOSTT side.

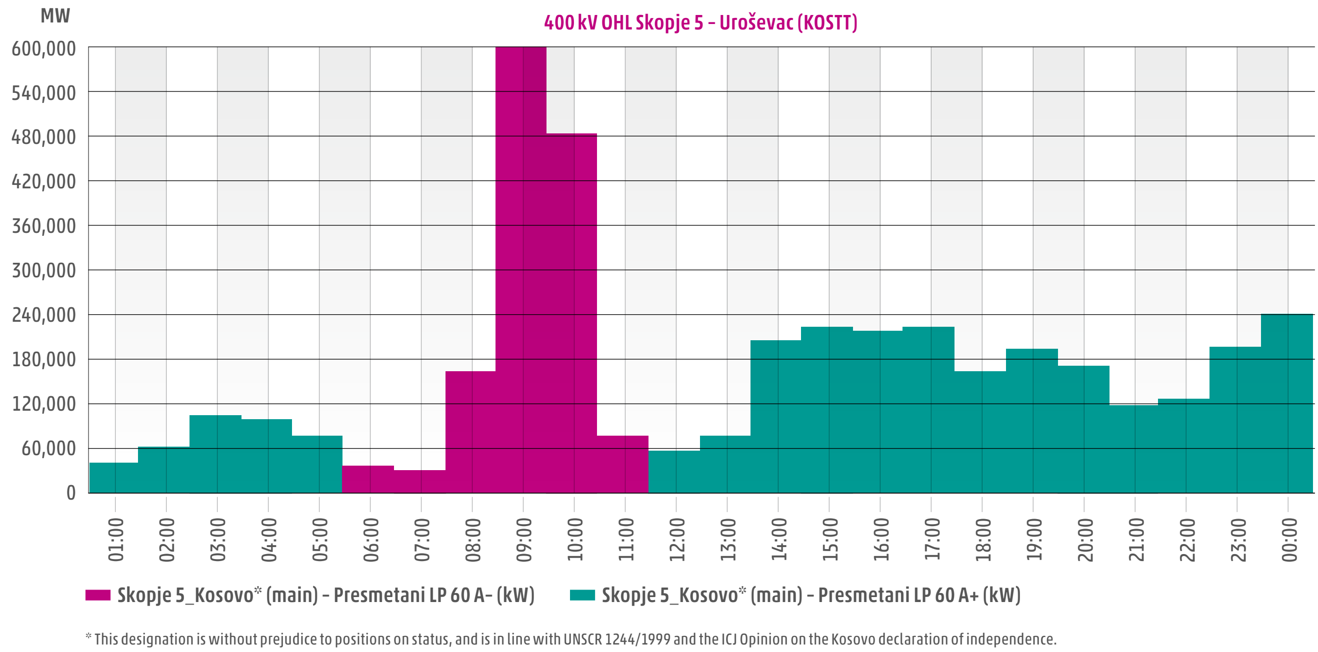


Figure 3.15: Hourly active power flow on the 400 kV OHL Skopje 5-Uroševac (KOSTT) (18 May 2025)

At around 05:00, the power flow was relatively stable, followed by a pronounced export peak around 09:00–10:00.

Later, imports prevailed, showing post-event stabilisation and gradual recovery of the balance of imports and exports in the region.

3.1.5 Disconnection of Generation Units and Loss of Load on 18 May 2025

At the time of the incident, the generation connected to the 110 kV network – including TPP Bitola Block 1 (140 MW), HPP Špilje (6 MW), WPP Bogdanci (25 MW), and WPP Dren (10 MW) (see Figure 3.16) – was disconnected due to the voltage collapse on the 110 kV system. 100 % of the load on the 110 kV (around 485 MW) was also disconnected.

On the 400 kV network, TPP Bitola Block 3 (132 MW) remained in operation and continuously supplied power throughout the incident, as the 400 kV transmission system maintained voltage and dynamic stability throughout the entire incident. A total of 313 MW (which is equal to 58 % of generation) was lost in the 400 kV network.

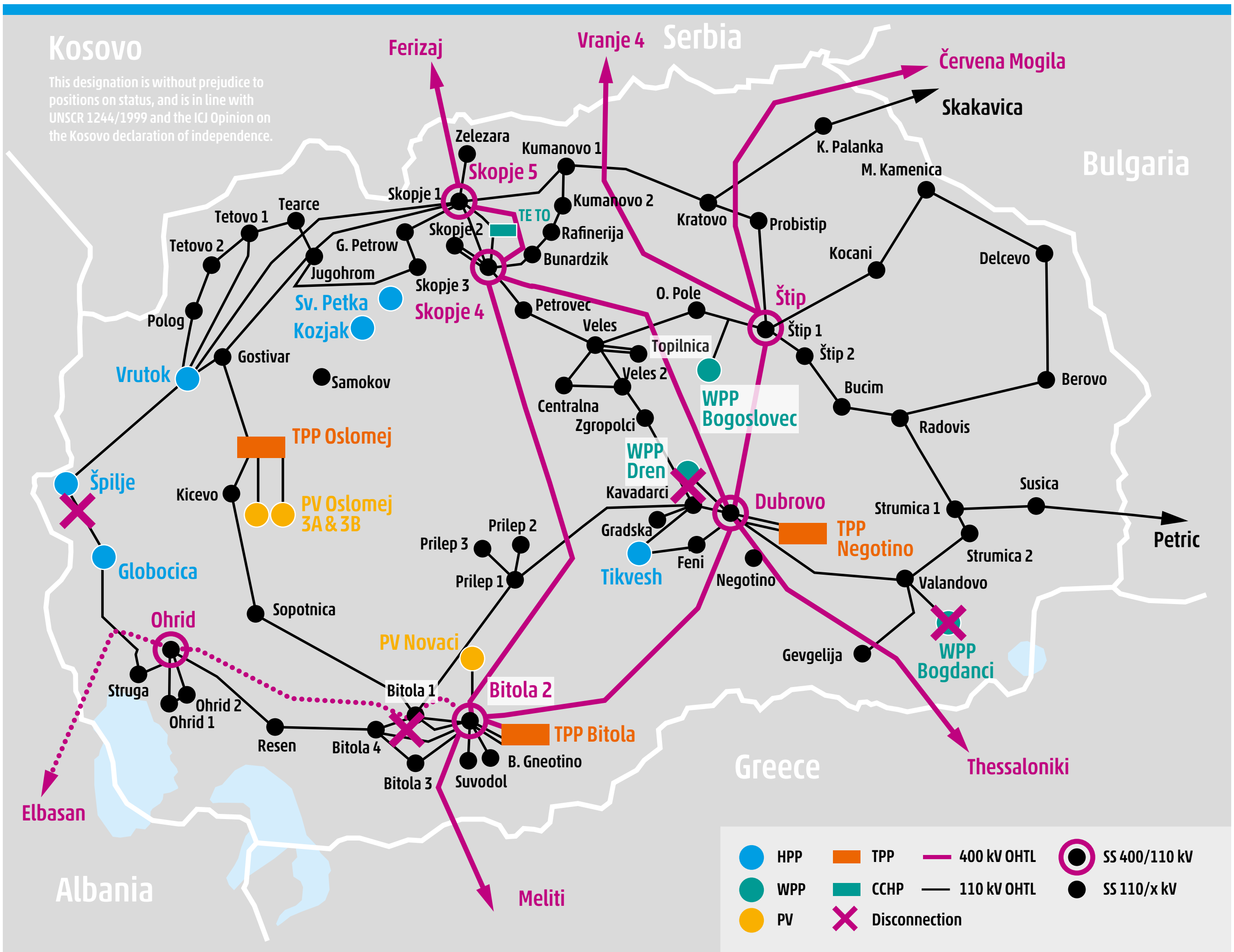


Figure 3.16: System topology and disconnections of generating units at the time of the incident

3.1.6 PMU Analysis on 18 May 2025

Disclaimer: *In order to describe the dynamic processes in the transmission system and evaluate their effects, high-resolution PMU measurements are necessary. The following analyses and diagrams are based on measurements taken by the Serbian TSO EMS at the Vranje substation in the field of the 400 kV Vranje 4–Štip line.*

The line was in operation until 06:05 and then disconnected as a corrective measure by MEPSO. The measurements after 06:05 with voltages above 455 kV do not represent the state of the transmission system of North Macedonia but result from the single-sided disconnection of the line. The line was finally disconnected on the Serbian side at 06:16.

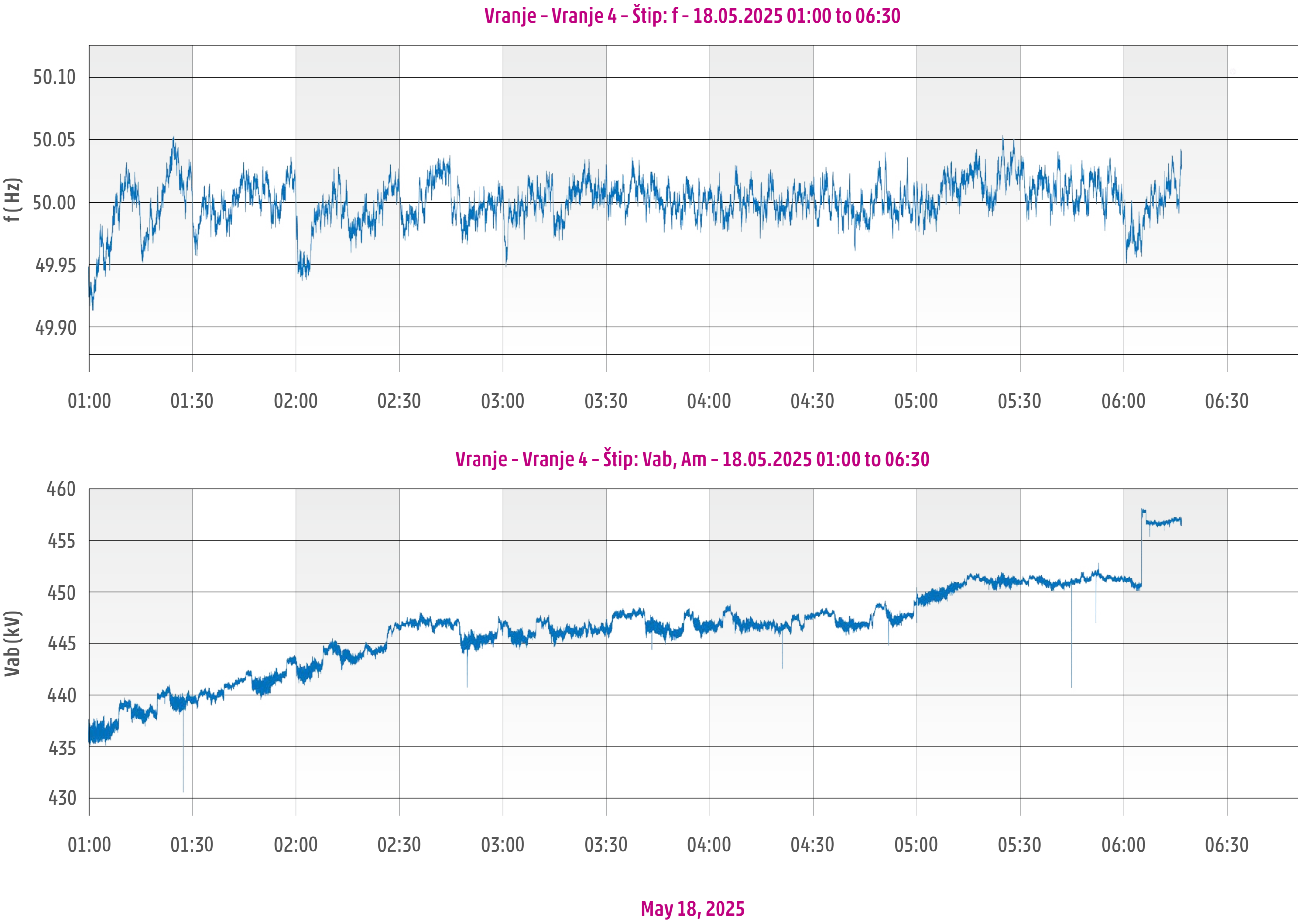


Figure 3.17: Voltage and frequency overview on 18 May 2025 based on PMU data

All asset outages between 01:00 and 06:30 whose effects are visible in the measurements and are related to events inside the transmission system of North Macedonia are highlighted in Figure 3.17 based on the numbering in Table 3.1 (Chronology of outages and contingencies on 18 May 2025).

3.1.6.1 Frequency Analysis

The frequency measurements recorded by the PMU show no significant anomalies. Throughout the entire period under investigation, the frequency remains mostly within a 50 mHz band around the nominal frequency of 50.0 Hz (Figure 3.18). Accordingly, the Expert Panel concluded that it is unlikely that the events in the transmission system of North Macedonia affected the frequency stability of the CE SA.

The significant frequency drops (Figure 3.17) at the hour change – for example, at 01:00, 02:00, 03:00, and 06:00 – are not related to events in the transmission system of North Macedonia. Rather, these are deterministic frequency deviations (DFD) that essentially result from the schedule change at the power plants and can be observed regularly throughout the CE SA.

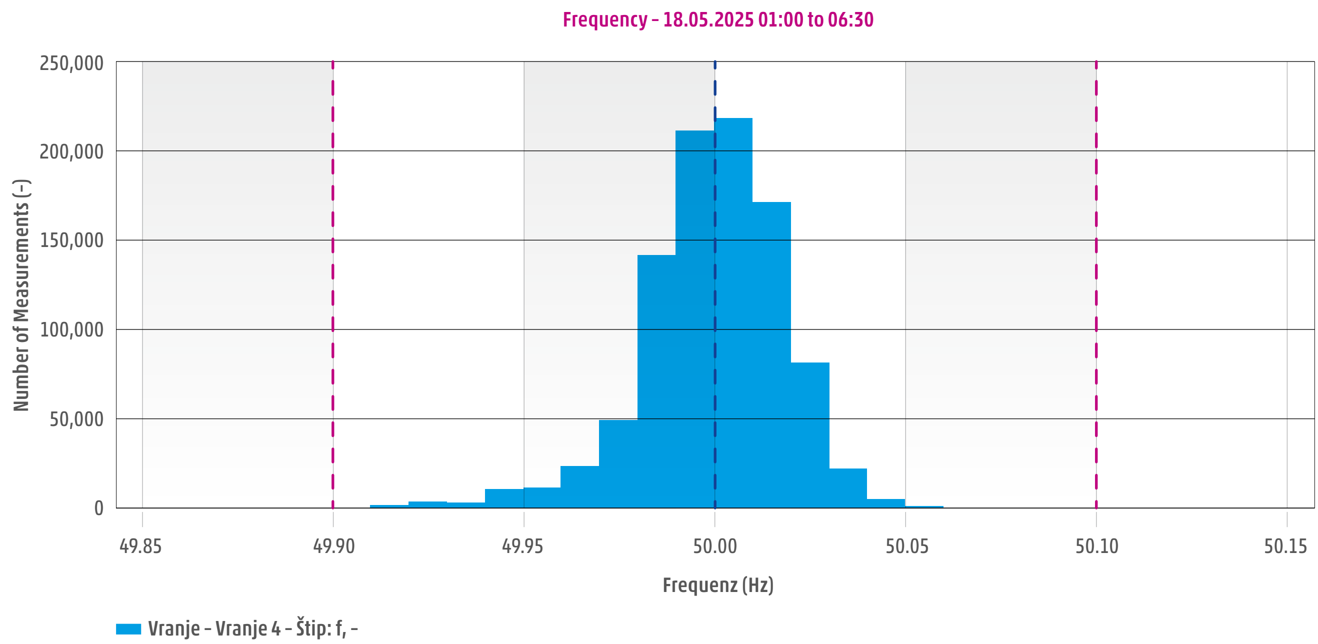


Figure 3.18: Histogram of frequency on 18 May 2025

3.1.6.2 Voltage Analysis

The voltage measurements on the Serbian side of the 400 kV Vranje 4–Štip line reveal a continuous increase in voltage during the night of 17 to 18 May 2025.

While the voltage was around 435 kV at 01:00, it rose continuously to over 445 kV by 02:30, then remained within a range of 445 to 448 kV until around 04:59. After outages No. 6, 7, and 8 at 04:59, the voltage exceeded 450 kV.

As described above, the measurements shown after 06:05 are not reliable, but result from the single-sided disconnection of the line Vranje 4–Štip (see outage No. 9).

The effects of all outages are described in detail below. According to the information available, all unmarked voltage drops are attributable to events outside the transmission system of North Macedonia and are not evaluated.

Outage of TR2 SS Skopje5 400/110 (No. 1), TR2 SS Bitola 2 400/110 (No. 2)

Outage No. 1 (Outage of TR2 SS Skopje 5 400/110) and No. 2 (Outage of TR2 SS Bitola 2 400/110) occurred at a voltage of 444.68 kV and resulted in a voltage increase of about 1 kV to 445.65 kV.

After this event, the voltage did not fall significantly below the 445 kV limit during the period under investigation until 06:30 on 18 May 2025.

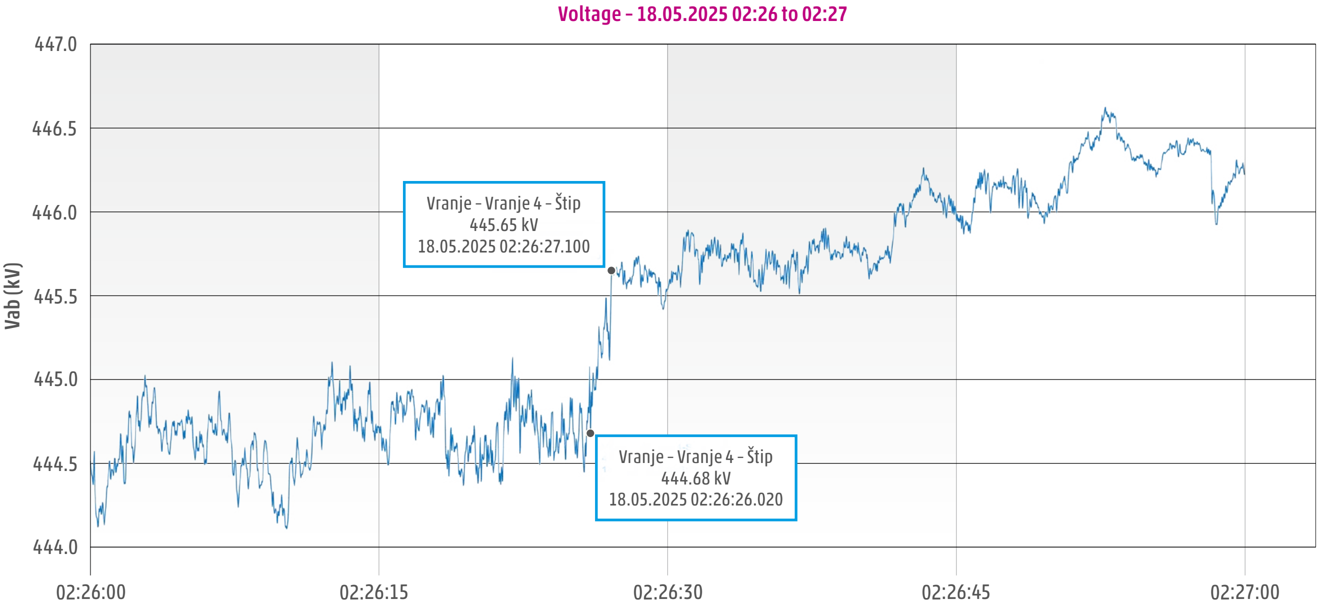


Figure 3.19: Outage of TR2 SS Skopje 5 400/110 (No. 1), TR2 SS Bitola 2 400/110 (Outage No. 2)

Reconnection of TR2 SS Bitola 2 400/110 (No. 2)

The reconnection of TR2 SS Bitola 2 400/110 (No. 2) at 04:49:37 resulted in a sudden voltage drop of around 5 kV, from 445.23 kV to 440.64 kV.

The voltage then stabilised at 444 kV before returning to its previous level of 445 kV at 04:50.

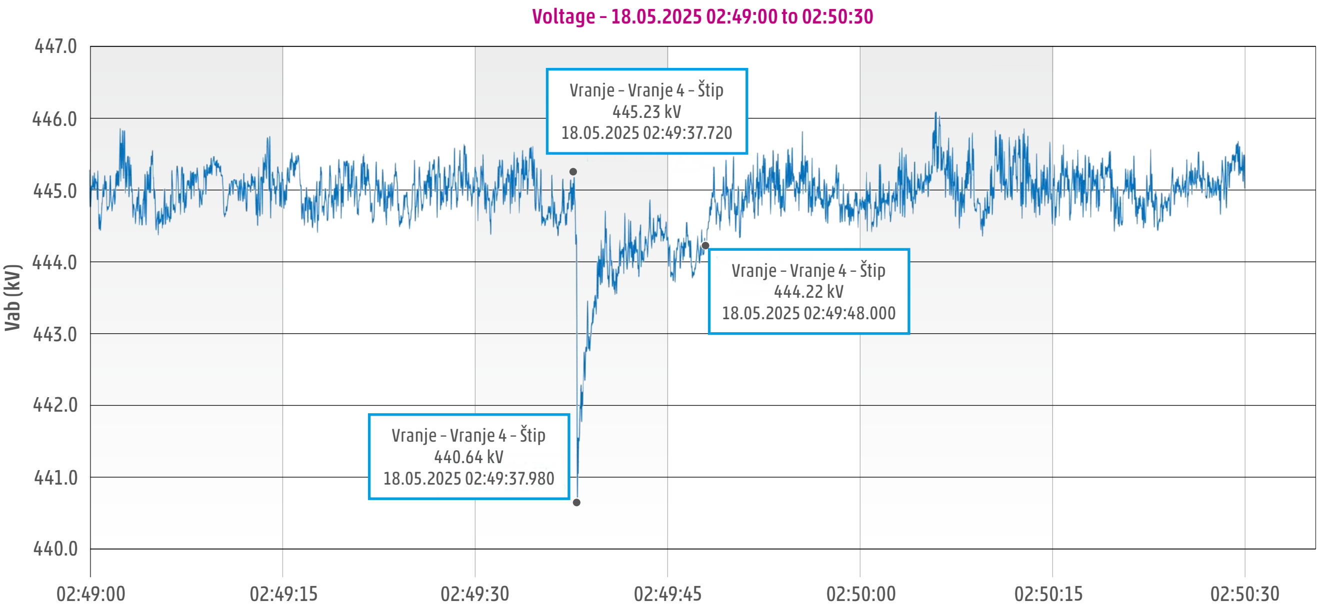


Figure 3.20: Reconnection of TR2 SS Bitola 2 400/110 (Outage No. 2)

Outage of TR1 SS Štip 1 400/110 (No. 5)

The Outage of TR1 SS Štip 1 400/110 (No. 5) led to a slight but insignificant drop in voltage. More important is the difference in the voltage before and after the outage. While the voltage was characterised by minor fluctuations before the outage, the voltage became noticeably more unstable after the event. This indicates that the 110 kV transmission system had a stabilising effect on the voltage.

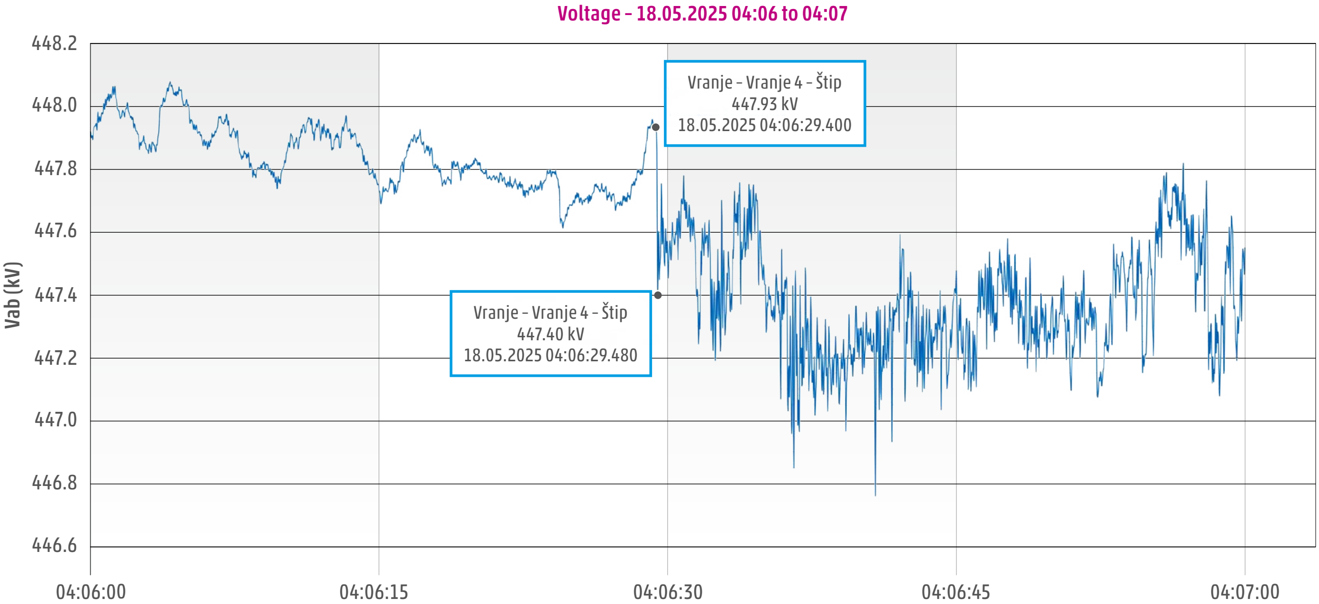


Figure 3.21: Outage of TR1 SS Štip 1 400/110 (Outage No. 5)

Outage of TR2 SS Skopje 4 400/110 (No. 6), 172 (OHL) SS Kratovo – SS Palanka 110 (No. 7) and Block 1, TPP Bitola, 110/15.7 (No. 8)

The final separation of the transmission system from the distribution system due to the outages of TR2 SS Skopje4 400/110 (No. 6), 172 (OHL) SS Kratovo–SS Palanka 110 (No. 7), and Block 1, TPP Bitola, 110/15.7 (No. 8) at first (04:58:58) resulted in a voltage increase of around 1 kV, from 448.08 kV to 449.10 kV. The consequences of the second event at 04:59:40 were much more limited, resulting in a voltage increase to 449.32 kV (+0.4 kV). The final outage at 04:59:45 was reflected in a significant voltage fluctuation. Subsequently, the voltage in the transmission system of North Macedonia rose significantly above the 450 kV limit (Figure 3.22).

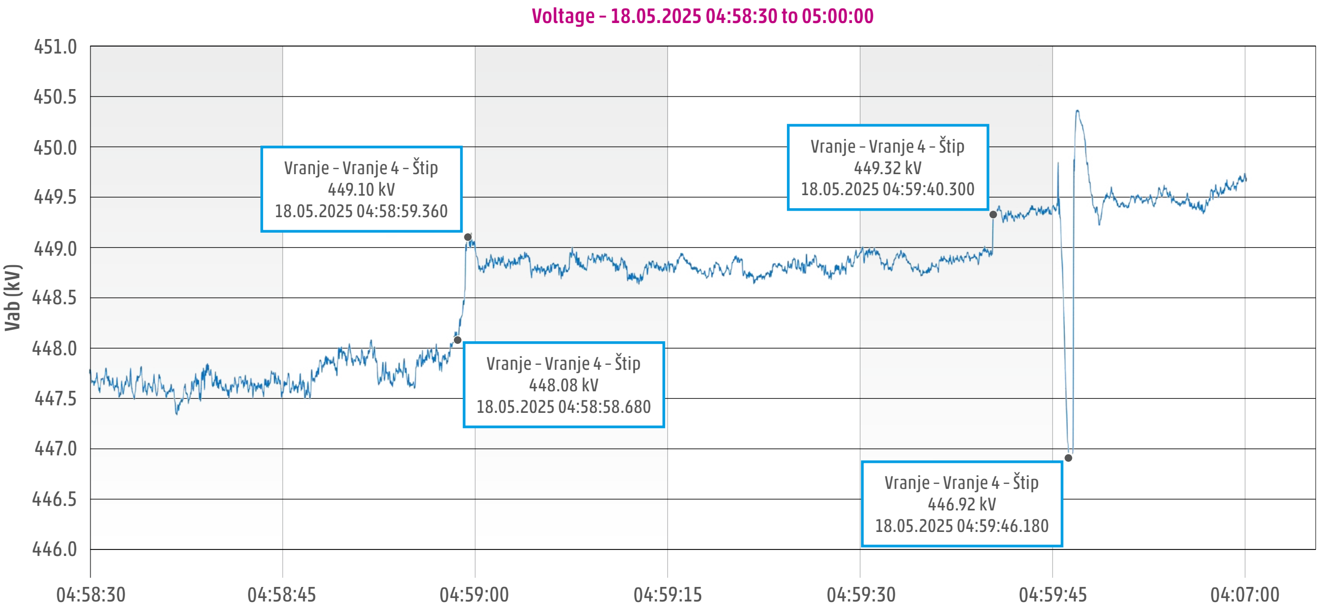


Figure 3.22: Outage of TR2 SS Skopje 4 400/110 (No. 6), 172 (OHL) SS Kratovo–SS Palanka 110 (No. 7) and Block 1, TPP Bitola, 110/15.7 (Outage No. 8)

3.1.6.3 Conclusion of PMU Analysis

The PMU analysis of the 400 kV line Vranje 4–Štip on 18 May 2025 shows that the frequency stayed stable and within a narrow band around 50 Hz. No effects on frequency stability in the CE SA werecould b detected. Observed drops at full hours are typical deterministic frequency deviations (DFDs) due to schedule changes and not related to the incident in the transmission system of North Macedonia.

In contrast, the voltage rose from about 435 kV to above 445 kV during the night and remained elevated. Outages of several 400/110 kV transformers (Skopje 5, Bitola 2, Štip 1) and the reconnection of TR2 SS Bitola 2 caused smaller voltage changes while also reducing the stabilising effect of the lower voltage level. The outages of TR2 Skopje 4, the 110 kV line Kratovo–Palanka and Block 1 of TPP Bitola finally separated the transmission system from the distribution system and led to further voltage increases, with voltages significantly above 450 kV.

3.2 Performance of the Protection System

3.2.1 MEPSO Protection Philosophy

During the night of 18 May 2025, high voltages occurred in the North Macedonian 400 kV transmission network. MEPSO's protection philosophy for the 400 kV to 110 kV power transformers includes overvoltage protection. It should be noted that overvoltage protection for power transformers is not a standard protection function in the protection philosophy of TSOs. The inclusion of overvoltage protection in the protection philosophy indicates the specific need to protect the assets and grid from high-voltage occurrences.

400 kV OHTL Bays

Two parallel protection systems are implemented on 400 kV OHTLs, providing functions such as distance protection, differential protection, overcurrent protection, earth fault protection, short-circuit fault protection (SOTF), current overload protection, and single-pole automatic reclosing. Additionally, on cross-border transmission lines, overfrequency and underfrequency protection are also activated.

110 kV OHTL Bays

On 110 kV OHTLs, one protection system is implemented, providing functions such as distance protection, differential protection (for short and radial lines), overcurrent protection, earth fault protection, SOTF, current overload protection, and single-pole automatic reclosing.

110 kV Coupler Bay

Overcurrent protection is implemented as one of the fundamental protection concepts applied in MEPSO's transmission system.

For 400 kV and 110 kV bus coupler bays, overcurrent protection is installed but not active in normal operation. The scheme is intended to be used only during system reconfiguration or transfer operations.

This arrangement ensures system flexibility while maintaining protection coverage in case the coupler bay becomes part of an operational circuit.

Busbar Protection

Busbar differential protection is implemented on all 400 kV and 110 kV substations operated by MEPSO. The protection continuously compares the currents entering and leaving the busbar section, enabling rapid detection and isolation of internal bus faults.

This selective and fast-acting scheme ensures high reliability and minimises the impact of faults on the remaining parts of the transmission system. Backup overcurrent and breaker failure protections are also applied to provide redundancy and operational security.

400/110 kV Power Transformer

The following protection and monitoring systems are implemented: transformer differential protection, distance protection on both the 400 kV and 110 kV sides, overcurrent and earth fault protection on both 400 kV and 110 kV, thermal overload, current overload, overvoltage protection, as well as Buchholz and contact thermometers for both windings and oil.

ID	Type Of Event	Substation	Local Time	Threshold[13] U> or I>	t [s]	U or I at the time of tripping
1	Trip	Bitola 2 TR2	18/05/2025 02:26:49	441.0 kV ±0,5 %	5	440.79 kV
2	Trip	Skopje 5 TR2	18/05/2025 02:26:58	449.6 kV ±0,5 %	5	449.16 kV
1→3	Manual_ON	Bitola 2 TR2	18/05/2025 02:49:37	Device was manually re-energised		
2→4	Manual_ON	Skopje 5 TR2	18/05/2025 02:51:55	Device was manually re-energised		
3	Trip	Bitola 2 TR2	18/05/2025 02:58:41	441.0 kV ±0,5 %	5	439.40 kV
4	Trip	Skopje 5 TR2	18/05/2025 03:34:52	449.6 kV ±0,5 %	5	448.77 kV
5	Trip	Štip TR1	18/05/2025 04:05:50	449.2 kV ±0,5 %	5	448.58 kV
6	Trip	Skopje 4 TR2	18/05/2025 04:59:45	449.6 kV ±0,5 %	5	449.04 kV
7	Trip	SS Kratova - SS Palangka	18/05/2025 05:00[14]	640 A	20	The exact value at the moment of tripping is unknown.
8	Trip	Bitola 1	18/05/2025 04:59:45	Protection settings are not available		The exact value at the moment of tripping is unknown.
→End	Manual_OFF	Štip 1 - Vranje 1 (Mepso-EMS)	18/05/2025 06:05	Line was manually switched off		
→ End	Manual_OFF	Skopje 5 - Uroshevac (Mepso - Kos)	18/05/2025 06:14	Line was manually switched off		
3 → End	Manual_ON	Bitola 2 TR2	18/05/2025 06:27	Device was manually re-energised		
6 → 9	Manual_ON	Skopje 4 TR2	18/05/2025 06:45:59	Device was manually re-energised		
9	Trip	Skopje 4 TR2	18/05/2025 06:51:31	449.6 kV ±0.5 %	5	448.477 kV
9 → End	Manual_ON	Skopje 4 TR2	18/05/2025 07:04:48	Device was manually re-energised		
7 → End	Manual_ON	SS Kratova - SS Palangka	18/05/2025 07:23	Device was manually re-energised		
4 → End	Manual_ON	Skopje 5 TR2	18/05/2025 07:37.58	Device was manually re-energised		
5 → End	Manual_ON	Štip TR1	18/05/2025 07:47	Device was manually re-energised		
8 → End	Manual_ON	Bitola 1	18/05/2025 19:47	Device was manually re-energised		

4:59:45 moment of complete separation between 400 kv and 110 kV grid

Table 3.3: Performance of the protection system in the sequence of events

13 The threshold refers to the RMS value of a line voltage or phase currents.

14 No information on the exact time of the OHL trip was available to the Expert Panel.

3.2.2 Outages During the Incident

General Remarks

- Table 3.1 shows a simplified view of the sequence of events viewed by the protection system. Not every trip is listed in Table 3.1. The details are described in the paragraphs below.
- This Subchapter is written with the collected information. Due to the limited number of fault registrations available, the Expert Panel combined data from different sources, such as Comtrade files, event logs, SCADA measurements, and measurements of energy transfer via transmission lines. Without detailed registration from the protection device, it is impossible to determine the actual electrical parameters at the moment the fault was detected or at the moment of tripping.
- The relay at Skopje 5 is set to trip if the root mean square (RMS) value of any one of the three line voltages exceeds the threshold for 5 seconds. The threshold is the same for all three line voltages. This is a common way to configure overvoltage/overcurrent protection functions.
- Electronic protection relays have a typical accuracy of ±0.5 % * $U_{>threshold}$. For a threshold of 449.6 kV/449.2 kV, this corresponds to a possible deviation of 2.248 kV/2.205 kV in the operation of the overvoltage protection. This means that if the threshold is 449.6 kV, the trip might occur anywhere between 447.35 kV and 451.84 kV.
- A fault recording has a pre-trigger recording that allows us to see the electrical parameters before the fault conditions. For a timing setting of 5 seconds, a pre-fault registration of >5 seconds is needed to see the electrical parameters before the fault. This was not the case for all the fault records available in this analysis.
- Voltage asymmetry occurs when the effective magnitudes of the three phases or the phase angles between them are uneven. This is common in power transmission systems and can be caused by factors such as the physical construction of the power system and the instantaneous load.

3.2.2.1 Outage ID 1 and Outage ID 3: 400/110 kV Transformer in TS Bitola 2

SS Bitola 2 has two 400 kV/110 kV transformers. TR1 was out of service, and only TR2 was in operation. TR2 is protected against overvoltage with an overvoltage relay, which was set to 441 kV for tripping the device. The 400 kV transmission line from Bitola 2 to Skopje 4 was disconnected at 22:46 on 17 May 2025. This line is regularly put out of service during periods of low load, e.g. nighttime, to prevent voltage from rising.

At 02:26:49, the voltage rose above the threshold, and TR2 was disconnected with the activation of the overvoltage relay (Outage ID 1). The recorded value was 440.79 kV, as shown in the SCADA extract.

#	Date	Time	Substation	Voltage level	Bay	Device	Signal Description
955	18-05-2025	02:26:44.078*	Bitola 2	400 kV	B03 TR2	F1 RET	Overvoltage protection START degree1
954*	18-05-2025	02:26:44.083*	Bitola 2	400 kV	B03 TR2	A1 REC	Main protection 1 – excitation
953*	18-05-2025	02:26:46.047*	Bitola 2	400 kV	B03 TR2	A1 REC	Voltage U12
952*	18-05-2025	02:26:49.079*	Bitola 2	400 kV	B03 TR2	F1 RET	Surge protection trip grade 1
951*	18-05-2025	02:26:49.081*	Bitola 2	400 kV	B03 TR2	F1 RET	General trip (general trip) LV
950*	18-05-2025	02:26:49.081*	Bitola 2	400 kV	B03 TR2	F1 RET	General trip (general trip) L1 LV
949*	18-05-2025	02:26:49.081*	Bitola 2	400 kV	B03 TR2	F1 RET	General trip L2 LV
948*	18-05-2025	02:26:49.081*	Bitola 2	400 kV	B03 TR2	F1 RET	General trip L3 LV
947*	18-05-2025	02:26:49.081*	Bitola 2	400 kV	B03 TR2	F1 RET	General trip
946*	18-05-2025	02:26:49.081*	Bitola 2	400 kV	B03 TR2	F1 RET	General trip L1
945*	18-05-2025	02:26:49.081*	Bitola 2	400 kV	B03 TR2	F1 RET	General trip L2
944*	18-05-2025	02:26:49.081*	Bitola 2	400 kV	B03 TR2	F1 RET	General trip L3
931*	18-05-2025	02:26:49.084*	Bitola 2	400 kV	B03 TR2	A1 REC	Main protection 1 – Trip
943*	18-05-2025	02:26:49.138*	Bitola 2	400 kV	B03 TR2	Q0	Status of the device

Table 3.4: Event logs for TS Bitola 2 at Outage ID 1

Event	Value	Logical Name	Index	Object text
Start		AA1C1Q03POV2PTOV1	10	Overvoltage protection pickup step1
Alarm		AA1C1Q03GS97	15	Protection main 1 start
Alarm	440.789	AA1C1Q03M02V1	16	Voltage U12
Start		AA1C1Q03POV2PTOV1	18	Overvoltage protection trip step1
Start		AA1C1Q03PSMPPTRC3	10	General trip LV
Start		AA1C1Q03PSMPPTRC3	11	General trip L1 LV
Start		AA1C1Q03PSMPPTRC3	12	General trip L2 LV
Start		AA1C1Q03PSMPPTRC3	13	General trip L3 LV
Start		AA1C1Q03PSMPPTRC1	10	General trip
Start		AA1C1Q03PSMPPTRC1	11	General trip L1
Start		AA1C1Q03PSMPPTRC1	12	General trip L2
Start		AA1C1Q03PSMPPTRC1	13	General trip L3
Alarm		AA1C1Q03GS97	16	Protection main 1 trip
Off		AA1C1Q03Q0	10	Position indication

Table 3.5: Information from the SCADA at Outage ID1

The protection relay recorded the electrical parameters at the exact moment of the trip (02:26:48.979). The values of the phase voltages are shown here.

	RMS U_{PhN} [kV]
L1	253.53
L2	253.69
L3	251.79

Table 3.6: U_{phN} voltages seen by the relay at the moment of Outage ID 1

The registered phase voltages, corresponding to line voltages of 439.40 kV, are consistent with the $U_{>threshold}$ of 441.0 kV ±0.5 %.

Shortly thereafter, voltage levels decreased, as shown in the SCADA extract, to a range of 435–439.7 kV. This allowed the reconnection of the transformer, which took place at 02:49:37.

#	Date	Time	Substation	Voltage level	Bay	Device	Signal Description
918	18-05-2025	02:47:46.368 *	Bitola 2	400 kV	B03 TR2	A1 REC	Voltage U12
917	18-05-2025	02:49:26.370 *	Bitola 2	400 kV	B03 TR2	A1 REC	Voltage U31
916	18-05-2025	02:49:35.696 *	Bitola 2	400 kV	B03 TR2	Q0	
915	18-05-2025	02:49:37.791 *	Bitola 2	400 kV	B03 TR2	Q0	
912*	18-05-2025	02:49:37.959 *	Bitola 2	400 kV	B03 TR2	A1 REC	Main protection 2 - excitation
913*	18-05-2025	02:49:37.962 *	Bitola 2	400 kV	B03 TR2	A1 REC	Main protection 1 - excitation
914	18-05-2025	02:49:37.964 *	Bitola 2	400 kV	B03 TR2	Q0	Status of the device
911*	18-05-2025	02:49:38.045 *	Bitola 2	400 kV	B03 TR2	Q0	Unwound spring
910	18-05-2025	02:49:40.254 *	Bitola 2	400 kV	B03 TR2	A1 REC	Main protection 1 - excitation
909	18-05-2025	02:49:40.265 *	Bitola 2	400 kV	B03 TR2	A1 REC	Main protection 2 - excitation

Table 3.7: Event logs for TS Bitola 2 at the moment of the first re-energisation

Event	Value	Locigal Name	Index	Object text
Warning	439.72	AA1C1Q03M02V1	16	Voltage U12
Normal	434.98	AA1C1Q03M02V1	18	Voltage U31
Selected		AA1C1Q03Q0	12	Breaker Q0 close select command
Executed		AA1C1Q03Q0	14	Breaker Q0 close execute command
Alarm		AA1C1Q03GS97	17	Protection main 2 start
Alarm		AA1C1Q03GS97	15	Protection main 1 start
On		AA1C1Q03Q0	10	Position indication
Alarm		AA1C1Q03GS95	26	Spring not charged
Normal		AA1C1Q03GS97	15	Protection main 1 start
Normal		AA1C1Q03GS97	17	Protection main 2 start

Table 3.8: Values from SCADA for TS Bitola 2 at the moment of the first re-energisation

However, rising voltage levels resulted in the activation of the overvoltage relay and another disconnection of the transformer at 02:58:41. The recorded voltage values are shown in the following SCADA extract. This time, the transformer remained disconnected, thereby isolating 400 kV and 110 kV at SS Bitola 2 for the rest of the incident until the final restoration.

The protection relay made a recording of the electrical parameters at the exact moment of the trip (02:58:41.333). The values of the phase voltages are shown in the following table.

	RMS U_{PhN} [kV]
L1	253.90
L2	254.23
L3	252.20

Table 3.9: U_{phN} voltages seen by the relay at the moment of Outage ID 3

During the given period, the voltage of SS Meliti in the transmission system of Greece, which is connected directly to Bitola 2 with a 400 kV transmission line, ranged between 428 kV and 431.8 kV.

#	Date	Time	Substation	Voltage level	Bay	Device	Signal Description
894	18-05-2025	02:58:36.426 *	Bitola 2	400 kV	B03 TR2	F1 RET	Overvoltage protection START degree1
893*	18-05-2025	02:58:36.433 *	Bitola 2	400 kV	B03 TR2	A1 REC	Main protection 1 – BUBUDA
892*	18-05-2025	02:58:36.779 *	Bitola 2	400 kV	B03 TR2	A1 REC	Voltage U12
891*	18-05-2025	02:58:41.433 *	Bitola 2	400 kV	B03 TR2	F1 RET	Surge protection trip grade 1
890*	18-05-2025	02:58:41.435 *	Bitola 2	400 kV	B03 TR2	F1 RET	General trip (general trip) LV
889*	18-05-2025	02:58:41.435 *	Bitola 2	400 kV	B03 TR2	F1 RET	General trip (general trip) L1 LV
888*	18-05-2025	02:58:41.435 *	Bitola 2	400 kV	B03 TR2	F1 RET	General trip L2 LV
887*	18-05-2025	02:58:41.435 *	Bitola 2	400 kV	B03 TR2	F1 RET	General trip L3 LV
886*	18-05-2025	02:58:41.435 *	Bitola 2	400 kV	B03 TR2	F1 RET	General trip
885*	18-05-2025	02:58:41.435 *	Bitola 2	400 kV	B03 TR2	F1 RET	General trip L1
884*	18-05-2025	02:58:41.435 *	Bitola 2	400 kV	B03 TR2	F1 RET	General trip L2
883*	18-05-2025	02:58:41.435 *	Bitola 2	400 kV	B03 TR2	F1 RET	General trip L3
870*	18-05-2025	02:58:41.440 *	Bitola 2	400 kV	B03 TR2	A1 REC	Chapter 1 – EXCLUSION
880*	18-05-2025	02:58:41.492 *	Bitola 2	400 kV	B03 TR2	Q0	Status of the device
882	18-05-2025	02:58:41.497 *	Bitola 2	400 kV	B03 TR2	F1 RET	Overvoltage protection START degree1

Table 3.10: Event logs for TS Bitola 2 at Outage ID 3

Event	Value	Locigal Name	Index	Object text
Alarm	440.120	AA1C1Q03M02V1	16	Voltage U12
Warning	439.915	AA1C1Q03M02V1	16	Voltage U12
Alarm	440.231	AA1C1Q03M02V1	16	Voltage U12
Warning	439.803	AA1C1Q03M02V1	16	Voltage U12
Alarm	440.653	AA1C1Q03M02V1	16	Voltage U12
Warning	439.391	AA1C1Q03M02V1	16	Voltage U12
Alarm	440.631	AA1C1Q03M02V1	16	Voltage U12
Warning	439.781	AA1C1Q03M02V1	16	Voltage U12
Alarm	440.598	AA1C1Q03M02V1	16	Voltage U12
Warning	439.819	AA1C1Q03M02V1	16	Voltage U12
Alarm	440.382	AA1C1Q03M02V1	16	Voltage U12
Warning	439.911	AA1C1Q03M02V1	16	Voltage U12
Alarm	440.108	AA1C1Q03M02V1	16	Voltage U12
Warning	439.931	AA1C1Q03M02V1	16	Voltage U12

Table 3.11: SCADA values for TS Bitola 2 at Outage ID 3

Voltage at SS Bitola 2 dropped to around 429 kV at 06:26 (shown in the following SCADA extract). The 400 kV/110 kV TR2 of Bitola 2 was reconnected successfully at 06:27:35. Bitola 2 was the first substation to be reconnected to the 110 kV network, facilitating the electric power supply and ending the blackout.

#	Date	Time	Substation	Voltage level	Bay	Device	Signal Description	Event	Value
672*	18-05-2025	06:27:25.864 *	Bitola 2	110 kV	A15 TR2	A1 REC	Voltage difference - outside permissible limits	Alarm	
673*	18-05-2025	06:27:25.864 *	Bitola 2	110 kV	A15 TR2	A1 REC	Voltage difference - outside permissible limits	Alarm	
674	18-05-2025	06:27:25.714 *	Bitola 2	400 kV	B03 TR2	Q0		Executed	
675	18-05-2025	06:27:24.262 *	Bitola 2	400 kV	B03 TR2	Q0		Selecter	
676	18-05-2025	06:26:36.360 *	Bitola 2	400 kV	B07 DUBROVO	F1 REL	SDDRFUF1 General start of function	Reset	
677	18-05-2025	06:26:37.078 *	Bitola 2	400 kV	B08 MELITI	A1 REC	Voltage U31	Normal	429.178

Table 3.12: Event logs for TS Bitola 2 at the moment of the finale re-energisation

The voltages remained high – close to 430 kV but below the threshold – as shown in the following SCADA extract, which presents recordings in the first couple of minutes immediately after the reconnection.

#	Date	Time	Substation	Voltage level	Bay	Device	Signal Description	Event	Value
634	18-05-2025	06:36:49.986 *	Bitola 2	400 kV	B08 MELITI A1	REC	Voltage U31	Warning	430.502
635	18-05-2025	06:36:39.886 *	Bitola 2	400 kV	B08 MELITI A1	REC	Voltage U31	Normal	428.464
636	18-05-2025	06:35:56.000 *	Bitola 2	400 kV	B04 TPP Block 3	A1 REC	Voltage U31	Warning	430.698
637	18-05-2025	06:35:45.999 *	Bitola 2	400 kV	B04 TPP Block 3	A1 REC	Voltage U31	Normal	429.895
638	18-05-2025	06:34:33.584 *	Bitola 2	400 kV	B08 MELITI A1	REC	Voltage U23	Normal	429.672
639	18-05-2025	06:34:23.584 *	Bitola 2	400 kV	B08 MELITI A1	REC	Voltage U23	Warning	430.093

Table 3.13: Event logs for TS Bitola 2 a couple of minutes after the finale re-energisation

3.2.2.2 Outage ID 2 and Outage ID 4: 400/110 kV TR2 in TS Skopje 5

At 02:26:58 local time, TR2 in TS Skopje 5 was tripped (Outage ID 2) by the overvoltage protection function, which was set at a value of 449.6 kV.

At the moment of the trip, the following phase voltages were recorded by the protection device.

	RMS U_{PhN} [kV]
L1	258.14
L2	259.32
L3	258.13

Table 3.14: U_{phN} voltages seen by the relay at the moment of Outage ID 2

The registered phase voltages, corresponding to line voltages of 449.16 kV, are consistent with the $U_{>threshold}$ of 449.6 kV when accounting for the relay's ±0.5 % inaccuracy.

ID	Date	Time	Substation	Voltage level	Bay	Bay Desc	Device	Signal Description
9876027	18-05-2025	02:26:47	TS Skopje 5	400 kV	A05	1TA 400 kV	RET2	400 kV switching by overvoltage U>
9876028	18-05-2025	02:26:51	TS Skopje 5	400 kV	A05	1TA 400 kV	RET1	400 kV switching by overvoltage U>
9876029	18-05-2025	02:26:58	TS Skopje 5	400 kV	A06	2TA 400 kV	RET1	400 kV switching by overvoltage U>

Table 3.15: Event logs for TS Skopje 5 at Outage 2

At 02:51:55, TR2 was switched back on at the primary side, and at 02:52:19 at the secondary side.

ID	Date	Time	Substation	Voltage level	Bay	Bay Desc	Device	Signal Description
9876169	18-05-2025	02:26:47	TS Skopje 5	400 kV	A06	Q0	Switch	Closed

Table 3.16: Event logs for TS Skoplje 5 at the moment of first re-energisation

At 03:34:52, TR2 tripped once again (Outage ID 4) due to overvoltage protection. At the moment of the trip, the following phase voltages were recorded by the protection device.

	RMS U_{PhN} [kV]
L1	257.73
L2	259.10
L3	257.65

Table 3.17: U_{phN} voltages seen by the relay at the moment of Outage ID 4

The registered phase voltage corresponds to a line voltage of 448.77 kV. This is consistent with the $U_{>threshold}$ of 449.6 kV, when accounting for the relay's ±0.5 % inaccuracy.

TR2 was energised on the primary side four times between 06:07:16 and 6:32:31. At 07:02:11, the circuit breaker on the secondary side was closed manually, and TR2 tripped again at 07:05:43 due to overvoltage.

TR2 was closed five more times – at 07:05:43, 07:08:15, 07:26:01, 07:29:27, and 07:30:41 – and tripped each time due to overvoltage. The event logs show that the trip occurred 5 seconds after the secondary circuit breaker was switched on.

TR2 in SS Skopje 5 was re-energised at 07:37.58.

In SS Skopje 5, the overvoltage protection of TR1 also detected overvoltages at 04:04:40, 04:31:58, 04:47:57, 05:44:48, 06:11:32, 06:16:12, 06:21:56, 06:21:57, 06:26:24, 06:07:21, 06:21:05, 06:21:57, and 06:26:24. At 06:32:12, the primary circuit breaker was manually closed. At 06:32:17, the overvoltage protection of TR1 detected an overvoltage. At 07:07:01, the primary circuit breaker of TR1 was closed, and at 07:07:21, the secondary circuit breaker of TR1 was closed.

3.2.2.3 Outage ID 5: 400/110 kV Transformer in TS Štip

At 04:05:45 CET, overvoltage protection of the 400/110 kV transformer in TS Štip registered a violation of the overvoltage criteria as the voltage reached 448.58 kV. At the same time, the voltage in TS Vranje 4 in the transmission system of EMS was 448.2 kV.

This caused the overvoltage protection to trip, which led to the disconnection of the power transformer by opening both the 400 and 110 kV circuit breakers Q0. Table 3.18 shows the event list referring to this relay activity.

Number	Date	Time	Location	Message text	Condition
10022098	18-05-2025	4:05:45	Štip\400 kV\TR_400-110 kV\CP1_F11	Surge protection U> - excitation	Active
10022090	18-05-2025	4:05:45	Štip\400 kV\TR_400-110 kV\CP1_F11	Protection - Excitement	Active
10022150	18-05-2025	4:05:50	Štip\400 kV\TR_400-110 kV\CP1_F11	Protection/Total. OFF	Active
10022151	18-05-2025	4:05:50	Štip\400 kV\TR_400-110 kV\CP1_F11	Volt U> Surge Protection - Shutdown	Active
10016378	18-05-2025	4:05:50	Štip\110 kV\TR_400-110 kV\CC1_F11	Command_Switch Q0	Off
10016873	18-05-2025	4:05:50	Štip\400 kV\TR_400-110 kV\CC1_F11	Command_Switch Q0	Off
10016378	18-05-2025	4:05:50	Štip\110 kV\TR_400-110 kV\CC1_F11	Command_Switch Q0	[2105] Off
10016873	18-05-2025	4:05:50	Štip\400 kV\TR_400-110 kV\CC1_F11	Command_Switch Q0	[2105] Off

Table 3.18: Event logs for 400/110 kV transformer in TS Štip

Later, at 06:32:09, the protection device once again detected overvoltage conditions, but at that moment, the transformer was already out of service.

The transformer stayed out of service until 07:47:34, when it was successfully re-energised.

Number	Date	Time	Location	Message text	Condition
10022098	18-05-2025	4:05:45	Štip\400 kV\TR_400-110 kV\CP1_F11	Surge protection U> - excitation	Active
10022090	18-05-2025	4:05:45	Štip\400 kV\TR_400-110 kV\CP1_F11	Protection - Excitement	Active
10022150	18-05-2025	4:05:50	Štip\400 kV\TR_400-110 kV\CP1_F11	Protection/Total. OFF	Active
10022151	18-05-2025	4:05:50	Štip\400 kV\TR_400-110 kV\CP1_F11	Volt U> Surge Protection - Shutdown	Active

Table 3.19: Recording from the list of events marking the second crossing of overvoltage seen by the relay

3.2.2.4 Outage ID 6 and Outage ID 9: 400/110 kV Transformer in TS Skopje 4

On 18 May 2025, between 04:00:04 and the time of disconnection, high-voltage alarms were activated. At 04:20:54, thermal protection was activated for TR2. At 04:25:43, a cooling group of TR2 was activated.

At 04:59:45, the 400/110 kV transformer in TS Skopje 4 tripped due to overvoltage protection (Outage ID 6) at a value of 449.042 kV for U_{12} and 448.740 kV for U_{23}. This value is consistent with the $U_{>threshold}$ of 449.6 kV ±0.5 %. The trip occurred at 04:59:45, which is 5 seconds later than the detection of the overvoltage alarm at 04:59:40.

Type name	Time	Station desc	Substation desc	Bay	Bay desc	Type name	Object ID	Event	Value
U23	18-05-2025 4:59	SS Skopje 4	400	C04	Transformer 2TA	U23		HIHI (448)	448.739750
U12	18-05-2025 4:59	SS Skopje 4	400	C04	Transformer 2TA	U12		HIHI (448)	449.042063
U12	18-05-2025 4:59	SS Skopje 4	400	C04	Transformer 2TA	U12		LOLO (360)	683.661133
U23	18-05-2025 4:59	SS Skopje 4	400	C04	Transformer 2TA	U23		LOLO (360)	451.956201
U31	18-05-2025 4:59	SS Skopje 4	400	C04	Transformer 2TA	U31		LOLO (360)	5.311780
OFF from overvoltage U>	18-05-2025 4:59	SS Skopje 4	400	C04	Transformer 2TA	OFF from overvoltage U>	T60_1_400 kV	ARRIVED	1
GROUP 2 COOLING ON	18-05-2025 4:59	SS Skopje 4	400	C04	Transformer 2TA	Group 2 cooling on		DEPARTED	0

Table 3.20: Event log for TS Skopje 4 at Outage ID 6

This was the last 400/110 kV transformer in service in the transmission system of MEPSO. After the trip, the 400 kV and 110 kV networks were completely separated.

At 06:45:59, TR2 was manually switched on, but overvoltage caused it to trip again at 06:51:31.

3.2.2.5 Outage ID 7: 110 kV OHL Kratovo–Kriva Palanka

The 110 kV network of MEPSO is connected to the transmission system of ESO via two 110 kV lines. On the day of the incident, only one was in service.

Due to the separation between the 400 kV and 110 kV networks, at 05:00 local time, a current transferred through the 110 kV OHL Kratovo–Kriva Palanka reached the settings of the electromechanical protection relay (overcurrent) installed in SS Kriva Palanka, tripping the 110 kV transmission line SS Kriva Palanka–SS Kratovo. The entire 110 kV network, with the exception of SS Kriva Palanka, was switched to island mode. SS Kriva Palanka remained energised due to its interconnection with the power system of Bulgaria.

Data from energy meters on the interconnection line give an indication of the load on this line during the period.

Figure 3.23 shows energy transfer over the affected 110 kV line.

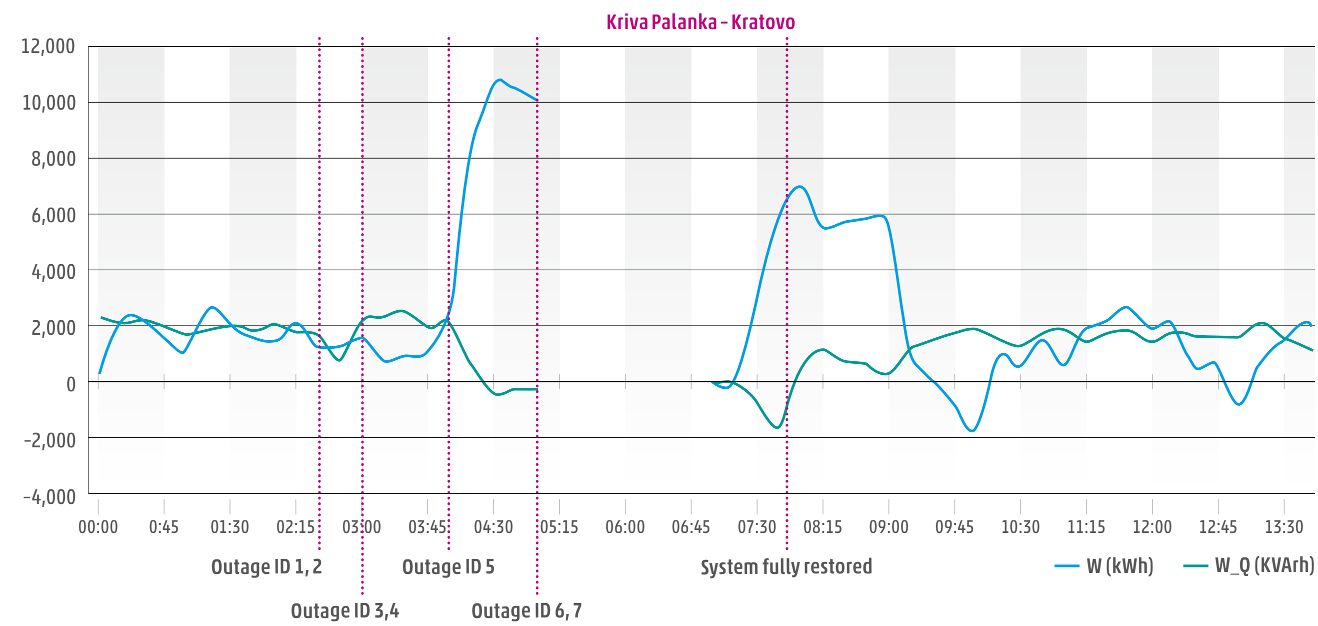


Figure 3.23: Transfer of energy measured during the 15 minute-period over the affected line on 18 May 2025

3.2.2.6 Outage ID 8: TE Bitola 1–110/15.7 kV

At 04:59, the power transformer 110/15.7 kV connecting the power plant Bitola 1 with the 110 kV grid was switched off due to low voltage. At this moment, the 400 kV and 110 kV grids were completely separated.

Date	Time	Type	Name	Designation	Value	Quality
18-05-2025	04:59:46.876	I&C	1IGBIAL_1 IQ.AL	Quality Alarm	Error	GOD
18-05-2025	04:59:46.876	I&C	1IGCIAL1 IQ.AL	Quality Alarm	Error	GOD
18-05-2025	04:59:46.892	I&C	1 PKON02.AA00711ALARM	General alarm indicator, see diagnostic data	Error	GOD
18-05-2025	04:59:46.892	I&C	1 K1 03llAl_21Q_AL	Quality Alarm	Error	GOD
18-05-2025	04:59:46.992	I&C	1K10411Al_21Q_AL	Quality Alarm	Error	GOD
18-05-2025	04:59:47.092	I&C	1K102UPRI32371 IQ_AL	Quality Alarm	Error	GOD
18-05-2025	04:59:47.092	I&C	1K101 UPRIAl_21Q_AL	Quality Alarm	Error	GOD
18-05-2025	04:59:47.149	w	1 MAY1 ODS501 llXC01	LIMIT FREQUENCY RELAY	OPERATED	GOD
18-05-2025	04:59:47.149	T	1 MAY1 ODS501 llXH51	LIMIT FREQUENCY RELAY	FREQUENCY	GOD
18-05-2025	04:59:47.176	A	1 EX1161115CE	Excitement-Restriction	Limit	GOD
18-05-2025	04:59:47.315	A	1 BUY01EZ3011116451112CEL	General Alarm UPS1	present	GOD
18-05-2025	04:59:47.315	A	1 BUY02EZ301l116456112CEL	General Alarm UPS2	present	GOD
18-05-2025	04:59:47.450	I&C	1MKA10CEO0111XM26	GEN ACTIVE POWER (FIG. 1)	FAULT	GOD
18-05-2025	04:59:47.476	A	156STll15CE	Stator signal overload	Active	GOD
18-05-2025	04:59:47.599	w	1 MAY1 ODU901 IT ABIEIXTO4	ADMISSION SETPOINT FORMATION	CTRLSIG	GOD
18-05-2025	04:59:47.676	I&C	1IGBIAL_1 IQ_AL	Quality Alarm	Error	GOD
18-05-2025	04:59:47.699	w	1 MYA01 DU090110UT	CTRLLGC	FAULT	GOD
18-05-2025	04:59:47.699	I&C	1 MYA01 DU09011XM04	They: MASTER	UNCRITICAL	GOD
18-05-2025	04:59:47.699	I&C	1 MYA01 DU09011XM05	TC:SLAVE	UNCRITICAL	GOD
18-05-2025	04:59:47.815	I&C	1 PKON02.BA00711ALARM	General alarm indicator, see diagnostic data	Error	GOD
18-05-2025	04:59:47.815	I&C	1 PP118111248	Mill Fan No.6	Error	GOD
18-05-2025	04:59:47.815	I&C	1 PP116111248	Mill Fan No.4	Error	GOD
18-05-2025	04:59:47.815	I&C	1 PP115111248	Mill Fan No. Z	Error	GOD
18-05-2025	04:59:47.815	I&C	1 PP113111248	Mill fan no. 1	Error	GOD
18-05-2025	04:59:47.850	I&C	1 MKA10CEO0211XM26	GEN ACTIVE POWER (FIG. 2)	FAULT	GOD
18-05-2025	04:59:47.876	I&C	1 PKON02.AC01 OllALARM	General alarm indicator, see diagnostic data	Error	GOD
18-05-2025	04:59:47.876	I&C	RA 1-1RA-CI1341 30IQ.AL	Quality Alarm	Error	GOD
18-05-2025	04:59:47.896	A	1 MYA01 DU091 C11XK45	TURBINE CONTROLLER TRIP	TRIP	GOD
18-05-2025	04:59:47.976	I&C	1IGAIAL_1 IQ_AL	Quality Alarm	Error	GOD
18-05-2025	04:59:47.976	I&C	1IGBIAL_1 IQ_AL	Quality Alarm	Error	GOD
18-05-2025	04:59:47.976	I&C	1IGCIAL_1 IQ_AL	Quality Alarm	Error	GOD
18-05-2025	04:59:47.987	A	1MAY01EZ00111XK61	I&C Turbine Trip	TRIP	GOD

Table 3.21: Event log for Outage ID 8

3.2.3 Conclusion Regarding Protection Equipment Performance on 18 May 2025

During the night of 18 May 2025, high voltage occurred in the 400 kV transmission grid of North Macedonia. MEPSO's protection philosophy for the 400 kV to 110 kV power transformers includes overvoltage protection. It should be noted that overvoltage protection for power transformers is not a standard protection function in the protection philosophy of TSOs. The inclusion of overvoltage protection in the protection philosophy indicates the specific need to protect the assets and grid from high-voltage occurrences in the affected area.

At the start of the incident, one transformer was in service in the affected substations. The overvoltage thresholds at the moment of the incident were confirmed to be set at the following values:

- **Skopje 5:** Maximum 449.6 kV during 5 seconds for TR1 and TR2
- **Skopje 4:** Maximum 449.6 kV during 5 seconds for TR2 and 441 kV for TR1
- **Štip:** Maximum 449.2 kV during 5 seconds for TR1
- **Bitola 2:** Maximum 441.0 kV during 5 seconds for TR2

Based on the available information, the Expert Panel conclude that the protection system behaved as intended. The protection system in SS Skopje 5 and SS Bitola 2 made a detailed fault recording during the incident. A fault recording is a registration of the electrical values (voltages and currents) and internal logs of the device during a predefined period.

Once a protection relay detects an event, it automatically saves the registration of the event, including a predefined pre- and post-fault period. The pre-fault period in the relays is set at 100 milliseconds, while the waiting time for the overvoltage protection is set at 5 seconds. Therefore, it is not possible to determine the time between the detection of the overvoltage event and the moment the protection tripped. The event log of the local SS HMI in Skopje 5 shows that the overvoltage protection tripped 5 seconds after the transformer's secondary circuit breaker was switched on.

Based on the event logs of the local HMI of the substation, it can be concluded that the overvoltage protection in SS Skopje 4 and SS Štip operated as expected. The power transformer at Skopje 4 was the last transformer supplying the 110 kV grid from the 400 kV grid. The protection system for the 110 kV OHL Kratovo–Kriva Palanka is a combination of overcurrent and distance protection. The protection for this line tripped due to overcurrent. The behaviour of this relay cannot be verified, as no event log is available. However, metering data shows a clear increasing trend in energy transfer over this OHL up to the moment of the trip. Simultaneously, the transformer at Bitola 1, which connects a generator unit to the 110 kV grid, tripped due to low voltage.

3.3 Impact of the Incident on Neighbouring Systems

As part of the incident investigation, the Expert Panel contacted neighbouring TSOs to determine whether their system conditions had shifted from normal to an alert or emergency state on the day of the incident (see TSO responses in Table 3.22).

Among them, only the ESO control area transmission system experienced an alert state, which lasted for eight hours due to elevated voltage levels in the western part of its system.

CGES	In CGES, there was no violation or change in system state triggered by the incident in North Macedonia.
EMS	EMS had issues with high voltages, but their system remained in secure and stable conditions
ESO	ESO's transmission system control area was in normal state. However, ESO declared an alert state in the EAS system, due to the high voltages. A Scale 1 OV1 incident in accordance with the ICS Methodology was declared with a maximum voltage violation from 441 kV.
IPTO	There was no violation to trigger a change of system state. IPTOs control area was in normal state.
KOSTT	Despite extremely high voltage values at the 400 kV level on May 18, 2025, KOSTT has not switched from the normal or alert state to the emergency state. (EAS system is not implemented in KOSTT control room)
OST	There was no violation or trigger to change system state caused due to incident in N. Macedonia

Table 3.22: Neighbouring TSOs' responses to "Did your system move from normal or alert state to emergency state during 18 May 2025?"

However, voltage levels above 420 kV were observed in the transmission systems of all neighbouring TSOs on the day of the incident (see Chapter 7). These high voltage levels were not a consequence of the incident, but rather reflected the prevailing system conditions in the SEE region. Voltage levels above 420 kV are an operational reality in the region, particularly during spring. ENTSO-E created the Project Group on Voltage Control in the SEE Region to better understand the situation in the region and commonly define measures for improving voltage control in the short- and mid-term perspective. More information is provided in Chapter 8.

3.4 Conclusion

The 18 May 2025 incident in the power system of North Macedonia involved multiple outages of power transformers across all substations at the 400 kV voltage level, primarily resulting in the separation of the 400 kV and 110 kV grid. In the first event, two simultaneous trips occurred on the TR2–SS Bitola 2 400/100 kV and TR2–SS Skopje 5 400/110 kV at 02:26. Both power transformers were put back into operation at 02:49 and 02:51, respectively. Shortly after, the TR2–SS Bitola 2 tripped again at 02:59, with an unsuccessful second reconnection attempt. At 03:35, the second TR2–SS Skopje 1.5 400/110 kV tripped, followed by an unsuccessful attempt for reconnection. At 04:05, an outage was recorded on TR2–SS Skopje 4 and another was recorded at 04:59 CET TR2–SS Skopje 4, leading to a complete separation of the 400 kV and 110 kV grid, immediately followed by a disconnection at 05:00 of 110 kV OHL SS Kratovo–SS Palanka. Based on the information collected and analysed by the Expert Panel, the relay protection systems of each affected high-voltage element operated according to its parameter settings.

The sequence of events indicates a cascading effect, which was initiated by overvoltage conditions in the 400 kV network. These elevated voltage levels caused the transformer overvoltage protection to activate, resulting in successive transformer disconnections. Therefore, it can be concluded that the blackout was not caused by an isolated failure or trip, but rather by a sequence of transformer trips triggered by sustained overvoltage conditions and the corresponding responses of the protection system.

Disclaimer: *To achieve a comprehensive understanding of the incident and proper contextualisation, it is necessary to consider the voltage conditions and reactive power flows across the entire SEE. This report primarily focuses on the transmission system of MEPSO since only one neighbouring transmission system moved to an alert state during the incident. However, Chapter 8 will include recommendations for the entire SEE region to enhance voltage control and coordination.*

4 RE-ENERGISATION AND MARKET RESTORATION PROCESS

Following the incident in North Macedonia on 18 May 2025, MEPSO activated its restoration plan in accordance with the NC ER (Commission Regulation (EU) 2017/2196 of 24 November 2017) and national operational procedures. Coordination was maintained with regional partners, where applicable. The procedure implemented to achieve system restoration on 18 May 2025 is described below.

4.1 Re-energisation Process

4.1.1 Preconditions and Strategies for the Restoration Process

MEPSO's System Defence Plan (in line with the NC ER requirements transposed into the North Macedonian Grid Code), defines two re-energisation strategies: the **bottom-up** and the **top-down** approach.

The bottom-up strategy refers to the re-energisation of parts of the transmission system without external assistance, starting from local generation and gradually energising higher voltage levels.

The top-down strategy, on the other hand, requires assistance from neighbouring TSOs to re-energise parts of MEPSO's network, from the interconnected 400 kV system downward.

The incident resulted in the trip of all 400/110 kV transformers within the national transmission network, causing an outage of the 110 kV system that required gradual restoration through the top-down re-energisation process.

The 400 kV transmission network, including both interconnections and internal lines, remained in service. Therefore, the top-down approach was applied, even though neighbouring TSOs were not needed to re-energise the 110 kV network.

Communication with neighbouring TSOs was established to verify the condition of interconnecting transmission lines, while contact with TPP Bitola confirmed the status of Block 1 and Block 3. At the same time, the national control center mobilised part of the dispatching team via mobile telephone to compensate for the failure of telecommunication and IT equipment. Finally, coordination with the dispatching centre of the distribution network operator provided information on the status of all 110 kV substations. These assessments and organisational measures created the necessary conditions to begin system restoration.

4.1.2 Restoration Sequences

Due to high voltages at the 400 kV level, remedial actions were initiated, including the disconnection of interconnections with EMS at 06:05 CEST and KOSTT at 06:14 CEST, to reduce voltages and enable safe synchronisation of 400/110 kV transformers.

At the beginning of the restoration process, the system operated in a top-down re-energisation mode, as defined in MEPSO's Defence Plan, utilising support from the 400 kV SS Bitola 2 to re-energise the 110 kV system.

The restoration sequences started at 06:05 CEST and ended at 07:47 CEST. Events are listed in Table 4.1 and depicted in Figure 4.1, including both automatic and manual actions performed by the NCC and SS operators to gradually restore transformation capacity and voltage stability in the Macedonian transmission network.

Restoration Process 18.05.2025

	Time (CEST)	Element	Action	Remark
	06:05	TIE Štip (MEPSO) – Vranje (EMS)	Disconnection of TIE	Action to decrease the voltage in the 400 kV network and enable synchronisation of 400/110 kV TRs
	06:14	TIE Skopje 5 (MEPSO) – Ferizaj (KOSTT)	Disconnection of TIE	Action to decrease the voltage in the 400 kV network and enable synchronisation of the 400/110 kV TRs
	06:07	TR2 Skopje 5	Attempt to connect – unsuccessful	Overvoltage
	06:15	TR2 Skopje 5	Attempt to connect – unsuccessful	Overvoltage
1	06:27	TR2 Bitola 2	Successful connection, which restored transformation between the 400 kV and 110 kV networks	At voltage level 425.332
2	06:50	TR2 Skopje 4	Successful connection	At voltage level 445
3	07:29	TR2 Skopje 5	Successful connection	
4	07:47	TR Štip	Successful connection	

Table 4.1: Restoration process and transformer energisation sequence (18 May 2025)

Following the energisation of TR2 Bitola 2, voltage and transformation capacity were restored between the 400 kV and 110 kV levels.

Within a short period, supply to major 110 kV substations in the western part of the country, as well as to the HPPs in Vrutok, Špilje, and Globochica, also located in the west, was restored, enabling synchronisation of the generating units.

By approximately 07:00, voltage was re-established across all 110 kV nodes of the transmission network, and normal operational conditions were gradually recovered.

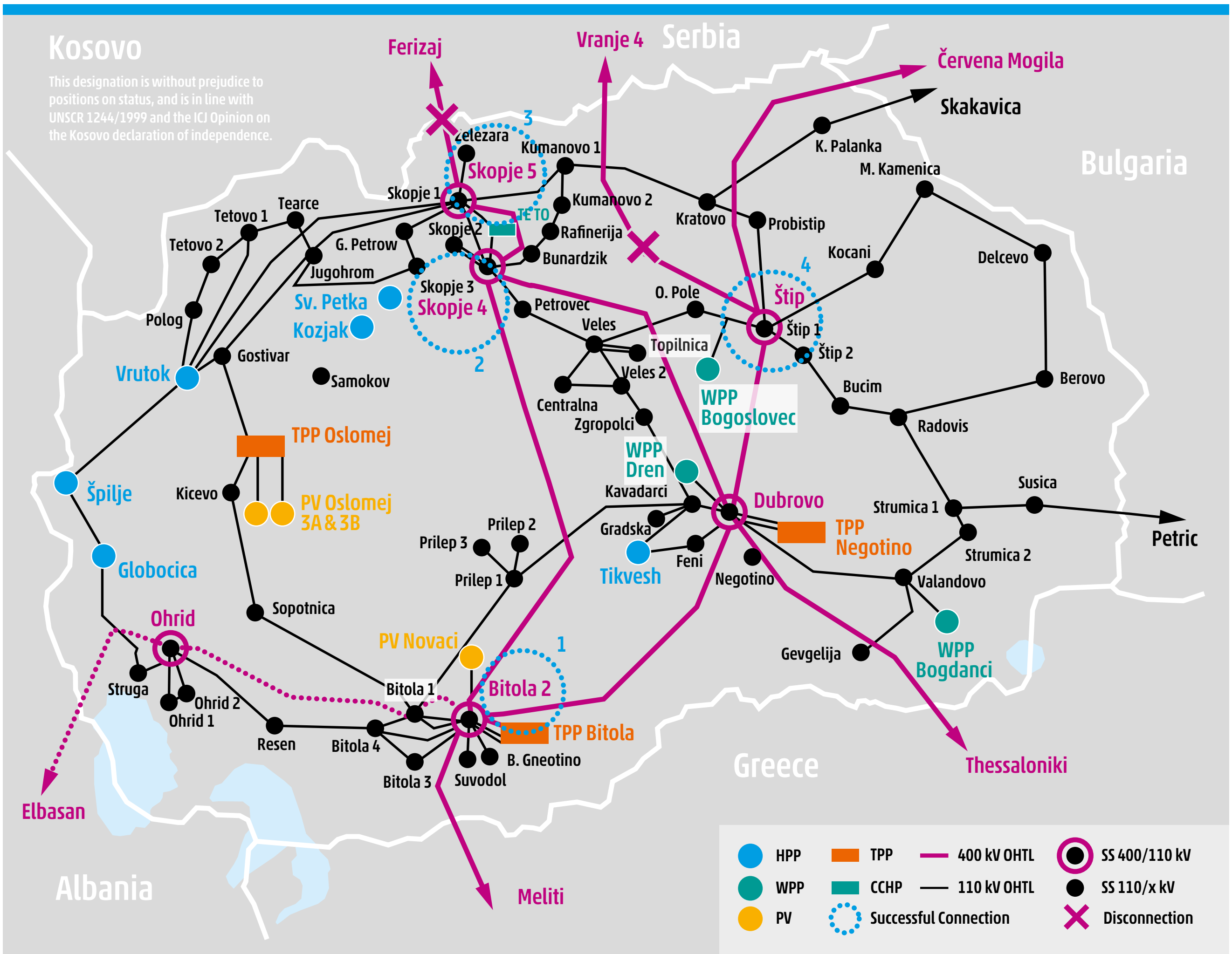


Figure 4.1: Restoration process and transformer energisation sequence (18 May 2025)

4.1.3 Generation and Load Recovery

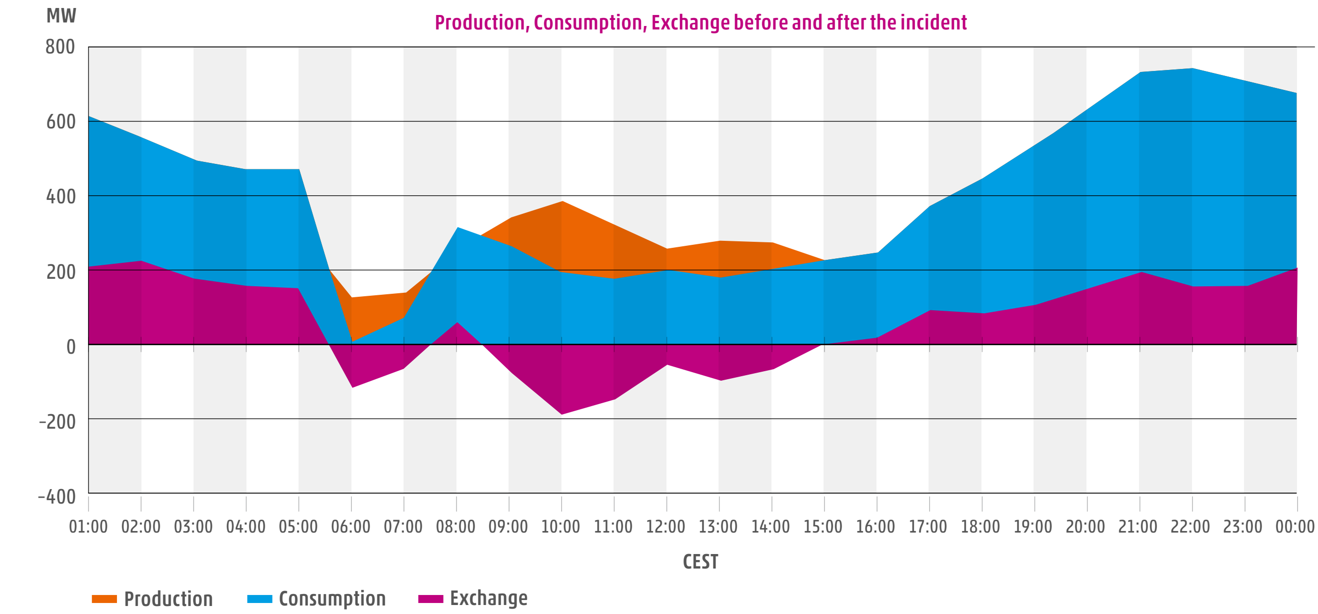


Figure 4.2: Production, consumption, exchange on 18 May 2025

Figure 4.2 illustrates the evolution of production, consumption, and cross-border exchange throughout the day of the incident. A sharp drop in generation and consumption is observed around 05:00 , followed by gradual recovery and normalisation of exchanges during the restoration process.

4.1.4 Steps After System Restoration

Starting the day after the incident, consultations and analyses were conducted in collaboration with SCC. In addition, knowledge was shared with neighbouring TSOs regarding their experience in managing the risk of cascading outages caused by high voltages and the settings of the overvoltage relay protection for 400/110 kV power transformers.

In coordination with EMS and SCC, it was agreed to disconnect the 400 kV OHL SS Štip–SS Vranje interconnection between 01:00 and 06:00 on 25 and 26 May 2025 as a mitigating measure to reduce voltages, if deemed necessary.

Furthermore, MEPSO reviewed the incident that occurred on 18 May 2025 and conducted internal analyses, implementing intermediate solutions to prevent a reoccurrence. The analyses showed that operating the transformers at their maximum technical limits can only be sustained for a short period. Nevertheless, the equipment is not expected to be operated at its highest possible limits throughout its life cycle – a conclusion confirmed by the manufacturers.

In the work week after the incident (from 20 to 23 May 2025) all 400/110 kV TRs were re-adjusted on the following overvoltage limits, as shown in Table 4.2.

Substation	Transformer	Type of transformer	Relay type	Set voltage value	Set disconnection time
SS Skopje 5	TP1 400/110 kV	SIEMENS	RET 670, ABB	456 kV	5 seconds
SS Skopje 5	TP2 400/110 kV	SIEMENS	RET 670, ABB	456 kV	5 seconds
SS Skopje 4	TP1 400/110 kV	KONCAR 1977	T60, GE	441.2 kV	5 seconds
SS Skopje 4	TP2 400/110 kV	SIEMENS 2002	T60, GE	449.6 kV	5 seconds
SS Štip	TP400/110 kV	SIEMENS	7UT, SIEMENS	455.6 kV	5 seconds
SS Bitola 2	TP2 400/110 kV	ASTOR 2024	RET 670, ABB	456 kV	5 seconds

Table 4.2: Adjustments made to all 400/110 kV TRs on overvoltage limits in the week after the incident

4.2 Market Restoration Process

As required by Article 36 (1) of the NC ER, each TSO shall develop a proposal for rules concerning the suspension and restoration of market activities. This proposal shall be subject to consultation with relevant stakeholders and approval by the regulatory authority.

According to MEPSO's System Defence Plan, MEPSO may suspend the following market activities if:

1/ The MEPSO transmission system is in a blackout state in accordance with the classification of system states set out in Article 120 (4) of the North Macedonian Grid Code and Article 18 (4) of the SO GL Regulation (EU) 2017/1485 of 2 August 2017;

2/ MEPSO has exhausted all options provided by the market and the continuation of market activities under the emergency state would deteriorate one or more of the conditions referred to in Article 120 (3) of the North Macedonian Grid Code and Article 18 (3) of the SO GL; or

3/ The continuation of market activities would significantly decrease the effectiveness of the restoration process to the normal or alert state; or

4/ Tools and communication methods necessary for MEPSO to facilitate market activities are not available.

4.2.1 Market Operations During System Blackout

The balancing mechanism was suspended from 05:00 to 07:00 during the incident. Between 05:00 and 06:00, the total imbalance in the transmission system amounted to 250 MWh remaining in the grid, while between 06:00 and 07:00, the imbalance was 140 MWh within the 400 kV network. The load plan summary for all balance responsible parties was 490 MWh between 05:00 and 06:00 and 423 MWh between 06:00 and 07:00.

4.2.2 Gradual Market Re-entry

Considering the size of the transmission system and the overall consumption at the time of the blackout early Sunday morning, supply was restored in a very short time. This was achieved by first putting into operation a single 400/110 kV transformer, followed by the rapid energisation of the 110 kV network.

The outage of elements in the 110 kV grid affected only one generator at TPP Bitola 1 and one turbine at HPP Špilje.

Before 08:00 all market participants had returned to their scheduled energy plans, except for Block 1, a thermal generator at TPP Bitola. Due to the technology of the lignite fuel power plant, it was not possible to synchronise the generator (state of cold start) before 19:47 on the day of the incident.

4.3 Conclusion

The disturbance occurred on 18 May 2025, and the restoration process demonstrated the operational behaviour of MEPSO transmission grid under high-voltage conditions. The restoration process was carried out through a top-down re-energisation strategy in accordance with NC ER and MEPSO's System Defence Plan.

Voltage management at the 400 kV level was a critical factor during system restoration. The disconnection of targeted interconnectors reduced overvoltage and enabled the synchronisation of 400/100 kV transformers. This approach allowed the re-energisation of substations, the recovery of generation units, and the stabilisation of system operating conditions within a limited time window.

In parallel, the restoration of market operations was closely coordinated with the physical restoration of the transmission grid, ensuring that the balancing and scheduling procedures were restored only after a stable grid had been ensured.

5 COMMUNICATION AND COORDINATION DURING THE INCIDENT

This chapter lists the exchanges between the involved parties at the time of the incident, including the communication between the MEPSO National Control Centre (NCC) and the local substations, DSOs, generation companies, and neighbouring TSOs.

5.1 Communication During the Incident

The communication and coordination during the incident are listed in chronological order in Table 5.1 to illustrate the timeline of events, focusing on the actions and calls made to communicate with relevant parties. This may differ from the actual time at which actions (recorded in assets) were executed.

The ENTSO-E Awareness System (EAS) was not used to inform European TSOs, but the MEPSO NCC contacted neighbouring TSOs via mobile phone. Communication with the RCC SCC Belgrade was not established during the time of the incident. There was no detected frequency deviation within the MEPSO transmission system; therefore, there was no established communication with the synchronous area monitor (SAM).

#	Time (CEST)	Party contacted by NCC MEPSO	Notification/Message/Information
1	2:27	SS Bitola 2 400/110 kV	Based on the internal procedure for communication between the NCC and substation personnel, the outage of TR2-SS Bitola 2 400/110 kV was reported and confirmed by local substation personnel due to the overvoltage protection trip.
2	2:27	SS Skopje 5 400/110 kV	There was a phone call between the NCC and substation personnel. The outage of TR2-SS Skopje 5 400/110 kV was reported and confirmed by local substation personnel to the NCC due to the overvoltage protection trip.
3	2:49	SS Bitola 2 400/110 kV	Shortly after the tripping of TR2-SS Bitola 2 400/110 kV, the NCC submitted a request to local substation personnel to manually switch on TR2-SS Bitola 2 400/110 kV, where the power transformer was put into operation.
4	2:51	SS Skopje 5 400/110 kV	The NCC submitted a request to local substation personnel to manually switch on TR2-SS Skopje 5 400/110 kV, where the power transformer was put into operation.
5	2:59	SS Bitola 2 400/110 kV	After a brief period, TR2-SS Bitola 2 400/110 kV tripped again. The NCC received a notification from local substation personnel about the tripping of the power transformer due to overvoltage protection.
6	3:29	SS Bitola 2 400/110 kV	The NCC requested substation personnel to switch on TR2-SS at Bitola 2 400/110 kV once again, but the attempt was unsuccessful. The power transformer remained out of operation until 06:27.
7	3:35	SS Skopje 5 400/110 kV	Local substation personnel notified the NCC via phone call about the tripping of the second transformer, TR1-SS Skopje 5 400/110 kV, due to overvoltage protection.
8	4:07	SS Štip 400/110 kV	In a phone call, local substation personnel alerted the NCC to a trip of TR1-SS Štip 400/110 kV due to overvoltage protection.
9	4:22	SS Bitola 2 400/110 kV	The NCC requested substation personnel to switch on TR2-SS Bitola 2 400/110 kV for the second time, but the attempt was unsuccessful. The transformer remained out of operation.
10	4:38	SS Skopje 5 400/110 kV	The NCC requested substation personnel to switch on TR1-SS Skopje 5 400/110 kV, which was unsuccessful. The transformer remained out of operation.
11	4:51	Power Plants of North Macedonia (ESM) CC	The NCC requested, via phone call to the ESM CC, the synchronisation of two generators in HPP Vrutok and two generators in HPP Tikvesh at 110 kV, with a total generation of 120 MW; however, they failed to synchronise on time.
12	4:59		Outage of 400/110 kV TR in Skopje 4 and Block 1 of TPP Bitola 2, connected on 110 kV
	04:59	Loss of 110 kV network	
13	5:01	SS Skopje 4 400/110 kV	The NCC received notification from local substation personnel that TR2-SS Skopje 4 400/110 kV had tripped, and provided information on the voltage state on a 110 kV busbar.

#	Time (CEST)	Party contacted by NCC MEPSO	Notification/Message/Information
14	5:02	SS Skopje 5 400/110 kV	Shortly thereafter, the NCC requested local substation personnel to switch on TR2-SS Skopje 5 400/110 kV. The attempt was unsuccessful, and the transformer remained out of operation.
15	5:04	SS Bitola 2 400/110 kV	The NCC requested local substation personnel to switch on TR2-SS Bitola 2 400/110 kV. The attempt was unsuccessful, and the transformer remained out of operation.
16	5:10	DSO CC	The NCC, via phone call, notified the DSO CC about the network state.
17	5:12	TPP Bitola	The NCC received notification from TPP Bitola about the tripping of generating unit BT1 at 05:00, which was connected to the 110 kV busbar in SS Bitola 2, as well as the status of generating unit BT3, connected to the 400 kV busbar in SS Bitola 2.
18	5:13	SS Skopje 5 400/110 kV	The NCC requested local substation personnel to disconnect all lines on the 110 kV busbar in SS Skopje 5.
19	5:15	SS Bitola 2 400/110 kV	The NCC requested local substation personnel to switch on TR2-SS Bitola 2 400/110 kV, which was unsuccessful. The transformer remained out of operation until 06:27.
20	5:20	NCC IPTO	The MEPSO NCC requested the IPTO NCC to provide information about the parameters of both TIEs between MEPSO and IPTO, i.e. TIE 400 kV Bitola 2 (MEPSO)-Meliti (IPTO) and 400 kV Dubrovo (MEPSO)-Thessaloniki (IPTO).
21	5:32	NCC IPTO	NCC Athens responded to a previous call from IPTO regarding the parameters of both TIEs between MEPSO and IPTO.
22	5:37	NCC ESO	The NCC requested information on the parameters of TIE 400 kV Štip 1 (MEPSO)-Cr.Mogila (ESO) and TIE 110 kV K. Palanka (MEPSO)-Susica (ESO).
23	5:40	NCC IPTO	The MEPSO NCC informed the Athens NCC on the status of the MEPSO network.
24	5:41	SS Dubrovo 400/110 kV	The NCC requested information on the state of all 400 kV transmission lines from local substation personnel.
25	5:43	SS Štip 400/110 kV	The NCC requested local substation personnel to switch on TR1-SS Štip 400/110 kV, which was unsuccessful. The transformer remained out of operation until 07:47.
26	06:00	NCC EMS	The MEPSO NCC requested information about the parameters of TIE 400 kV Štip (MEPSO)-Vranje (EMS) from the EMS NCC and requested its disconnection. TIE 400 kV Štip (MEPSO-Vranje (EMS) was disconnected at 06:05.
27	06:10	SS Skopje 5 400/110 kV	The NCC requested local substation personnel to switch on TR2-SS Skopje 5 400/110 kV, which was unsuccessful. The power transformer remained out of operation.
28	06:11	NCC KOSTT	The MEPSO NCC requested information about the parameters of TIE 400 kV Skopje 5 (MEPSO)-Ferizaj (KOSTT) from the KOSTT NCC and requested its disconnection. TIE 400 kV Skopje 5 (MEPSO)-Ferizaj (KOSTT) was disconnected at 06:14.
29	6:25	SS Bitola 2 400/110 kV	The NCC requested local substation personnel to switch on TR2-SS Bitola 2 400/110 kV, which was successful. The power transformer resumed operation at 06:27.
30	6:30	TPP Bitola	The NCC contacted TPP Bitola to verify the operational status of Block 3, which is connected to the 400 kV busbar at SS Bitola 2 and remained in operation throughout the entire incident. The NCC also enquired about the possibility and expected time for the reconnection of Block 1, which is connected to the 110 kV side of SS Bitola 2 and had tripped at 04:59. The generating unit Block 1 in TPP Bitola was successfully synchronised in operation at 19:47.
31	6:30	DSO CC	From 6:30 to 06:47, the NCC coordinated with the DSO CC regarding the reconnection of the 110 kV network.
32	6:49	SS Skopje 4 400/110 kV	The NCC requested local substation personnel to switch on TR2-SS Skopje 4 400/110 kV, which was successful. The power transformer remained in operation.
33	6:52	Power Plants of North Macedonia (ESM) CC	The NCC requested the ESM CC to synchronise its generating units in line with the previously established production plan, where the planned generating units were synchronised on the transmission network.
34	7:35	NDC KOSTT	The MEPSO NCC coordinated with the KOSTT NCC to reconnect the TIE 400 kV Skopje 1.5 (MEPSO)-Ferizaj (KOSTT). The TIE resumed operation at 07:37.
35	7:37	SS Skopje 5 400/110 kV	The NCC requested substation personnel to switch on TR1-SS Skopje 5 400/110 kV, which was successful. The power transformer resumed operation at 07:38.
36	7:45	SS Štip 400/110 kV	The NCC requested substation personnel to switch on the power on the transformer, which was successful. The power transformer resumed operation at 07:47.
37	10:22	NDC EMS	The MEPSO NCC coordinated with the EMS NCC to reconnect the TIE 400 kV Štip (MEPSO)-Vranje (EMS), which resumed operation at 10:24.

Table 5.1: Communication during the incident

5.2 Conclusion

Communication during the incident and subsequent restoration process was effective but could be further strengthened. Neighbouring TSOs were informed of the disturbance via telephone. The EAS usage procedure covers not only the use of the EAS system by TSOs to communicate system states in the context of the SO GL, but also sets out specific criteria regarding when and how the tool should be used. However, the EAS and its corresponding usage procedure were not used to raise awareness among European TSOs.

6 CLASSIFICATION OF THE INCIDENT BASED ON THE ICS METHODOLOGY

The ICS methodology was originally developed in accordance with Regulation (EC) No 714/2009 of the European Parliament and of the Council of 13 July 2009, which was subsequently repealed by Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity (recast). It was later updated to meet the objectives and security indicator requirements set out in Article 15 of Commission Regulation (EU) 2017/1485 of 02 August 2017 (SO GL). The definitions and concepts in this methodology are in line with Articles 15 and 18 of the SO GL and further extended to describe the real-time situation of the TSO's system.

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 6.1: Incident classification scale

Figure 6.1 shows the criteria from the methodology and the corresponding scale. The criteria are ordered by priority, with #1 representing the highest priority and #27 the lowest. An incident may consist of multiple events that each meet the threshold of ICS criteria. In such cases, the overall scale of the incident is determined by the highest-priority criterion.

For scale 2 and scale 3 incidents, the Expert Panel conducts an investigation following the investigation procedure for scale 2 and scale 3 incidents outlined in the ICS methodology. While only the highest-priority criterion is relevant for determining the scale, the other criteria are also assessed.

This section describes the incident in line with the ICS methodology, taking into account all events connected to the incident that meet the threshold of ICS criteria.

Scale of the Incident

The highest ICS criterion for the incident outlined in this report is the blackout (OB3) criterion. This criterion is defined in accordance with Article 18 (4) of the SO GL and is met if more than 50 % of demand in the TSO's control area is lost, or if there is a total absence of voltage for at least three minutes in the TSO's control area, triggering restoration plans.

In this case, the threshold for OB3 was met, as almost all of the load in the MEPSO control area (around 485 MW) was disconnected from the transmission network.

RCC Investigation Threshold

The RCC post-operation and post-disturbances analysis and reporting (RIAR) methodology was developed to define the respective RCC task in accordance with Article 37 (1)(i) of Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity. This methodology provides for an RCC investigation, in addition to the work of the Expert Panel, if both of the following criteria are met:

1/ A TSO has moved from a normal or alert system state to an emergency system state as a result of actions taken by another TSO in an emergency, blackout, or restoration system state.

2/ The incident has been confirmed as at least a scale 2 incident as defined by the ICS methodology.

In this case, post-analysis confirmed that no other TSO moved to an emergency system state as a result of the incident, and the RCC threshold for investigation was not met.

Scale of All Events Linked to the Incident

The first ICS criterion that was violated was loss of tools, means, and facilities (LT0). The scale 0 threshold of this criterion was reached due to a failure of the primary UPS and the subsequent outage of SCADA systems on 19 April.

The OV1 criteria threshold was exceeded at 2:26 CEST at SS Bitola due to voltage levels above 1.1 pu being present for longer than 30 seconds. This was followed by a series of disconnections, beginning with the 400/110 kV transformers TR2 at SS Bitola 2 and TR2 in SS Skopje 5, which occurred at 2:26. Subsequent disconnections of 400/110 kV transformers took place at 3:00 (SS Bitola 2), 3:20 (SS Skopje 5), and 3:30 (SS Štip). These are classified as T2 events according to the ICS methodology, as they required activation of the System Defence Plan.

The last 400/110 kV transformer in the MEPSO grid disconnected at 04:59 CEST after reaching a voltage level of 449 kV. This tripping resulted in the separation of the 400 kV and 110 kV networks and the subsequent loss of load and generation. The amount of lost load was 100 % of the pre-incident load in North Macedonia. Therefore, the incident is classified as OB3 according to the ICS methodology.

In addition to the events observed in the MEPSO control area, the OV1 criterion was met in both the control area of EMS due to voltages of 448.42 kV at SS Vranje 4 and the control area of ESO, where voltage levels of 441 kV were reached.

Criterion	Scale	MEPSO	EMS	ESO EAD
OB	3	×		
L	2	×		
	1			
	0			
F	2	Not Violated		
	1			
	0			
	BS			
T	2	×		
	1	×		
	0			
G	2			
	1			
	0			
	BS	×		
ON	2	Not Violated		
	1			
RS	2	Not Violated		
	1			
	0			
OV	2	×		
	1		×	×
	0			
	BS			
RRC	2	Not Violated		
	1			
	0			
LT	2			
	1			
	0	×		

Table 6.1: ICS criteria violations by TSO
Note: Each violated ICS criterion has an X in the cell. The scales shown are 0-3 and below scale (BS). There was no violation of the ICS F, ON, RS, RRC criteria.

7 VOLTAGE CONTROL

7.1 Introduction

Voltage control is a fundamental aspect of secure and reliable power system operation, ensuring that voltage levels across the transmission system remain within predefined operational limits under all system conditions. This chapter provides an overview of the voltage control framework within the MEPSO transmission system, including applicable technical and regulatory requirements, observed voltage conditions, and the implementation of applied voltage management measures. Special attention is given to the evolving system conditions in the SEE region, characterised by periods of low demand and high reactive power generation, which contribute to increased voltage levels.

The chapter also assesses the adequacy of the available operational tools, system defence mechanisms, and coordination practices, and identifies key challenges and areas for improvement to ensure effective voltage control under both normal and unstable operating conditions.

7.2 Technical and Regulatory Requirements Currently Applicable in North Macedonia

The North Macedonian Transmission Code integrates system operation guidelines, connection network codes, and network code on emergency and restoration requirements. In accordance with the North Macedonian Grid Code, MEPSO is responsible for maintaining voltage levels within the prescribed operational limits at both the 400 kV and 110 kV network levels by applying appropriate corrective measures.

7.2.1 Voltage and Reactive Power Requirements at the Transmission System Level

The requirements for voltage and reactive power control at the transmission system level are defined in the North Macedonian Grid Code, primarily through Articles 122, 126, and 195, which together establish the operational, technical, and organisational framework for maintaining voltage within secure limits.

Article 122 defines the concept and application of corrective measures in system operation. It outlines the range of actions available to MEPSO to maintain operational security, including network topology changes, transformer tap adjustments, activation of reactive power devices, redispatching, and coordination with system users and neighbouring TSOs.

In the context of voltage control, this article is particularly relevant as it provides the operational toolbox for real-time management of voltage and reactive power, ensuring that appropriate measures can be prepared and activated based on system conditions and contingency analyses.

Article 126 specifies the permissible voltage ranges at transmission levels (400 kV and 110 kV) under normal and unstable operating conditions. It defines the target voltage limits, as well as the extended ranges allowed for limited periods, and establishes the obligation of MEPSO to restore voltages within acceptable limits using available reactive power resources.

Furthermore, it emphasises the need for sufficient reactive power reserves and coordinated voltage control with neighbouring TSOs, as well as the utilisation of all available reactive power resources within the transmission system, including coordination with DSOs.

Article 195 addresses the procurement, availability, and utilisation of system services for voltage control. It defines MEPSO's responsibility to ensure adequate reactive power reserves through system service providers, monitor their availability and location, and use economically efficient mechanisms for their activation. In addition, it highlights the importance of regional coordination to minimise cross-border reactive power flows and ensures that voltage control is supported through both market-based and operational mechanisms.

Together, these three articles form a comprehensive framework that combines operational measures, technical requirements, and system service provision, enabling effective voltage and reactive power management in the transmission system.

7.2.2 Requirements for Generators on Voltage Stability and Reactive Power Control

Voltage stability and reactive power control are essential functions for both synchronous generation units and power park modules to ensure secure system operation and maintain voltage profiles within permissible limits under varying grid conditions. As stated in Section 7.2.1, Article 126 of the North Macedonian Transmission Code specifies the permissible voltage deviation ranges applicable during normal operating conditions and following contingency events. These voltage ranges are applicable to all power-generating modules (PGMs) and are aligned with RfG.

Voltage Level	Voltage Intervals Under Normal Conditions [kV]	Short-Term Intervals of Extremely Low Voltages in Disturbance Regimes [kV]	Short-Term Intervals of Extremely High Voltages in Disturbance Regimes [kV]
	Unlimited	60 minutes	60 minutes
110	99.0-123.0	93.5-99.0	123.0-126.5
400	360.0-420.0	340.0-360.0	420.0-440.0

Table 7.1: Allowed voltage intervals in the transmission system according to Article 126 of the North Macedonian Grid Code

XIII.2.4 and XIII.3.2 in Appendix 3 of the North Macedonian Grid Code address voltage stability and reactive power control, respectively, for synchronous generators and power park modules. MEPSO defines the reactive power capability profile (U-Q/P_{max}) that synchronous power generating modules (SPGMs) must follow at maximum capacity, taking into account economic and technical factors. Power transformers must be equipped with tap changers compatible with the generator's regulation range and step size.

SPGMs must operate anywhere within their P-Q/P_{max} diagram in response to MEPSO's reactive power control commands. New online reactive power setpoints issued by MEPSO must be implemented at the connection point within one minute. Each generating unit must fulfil a minimum reactive power capability at the connection point, as specified by MEPSO (Figure 7.1), with flexibility for additional requirements, if needed. Generators must have the technical capability to support voltage setpoints at specified network points as determined by MEPSO. Even when operating below maximum active power, synchronous units must maintain reactive power capabilities according to their P-Q capability curve, considering auxiliary loads and transformer losses. MEPSO may define control based on:

- Power factor (cos φ)
- Reactive power injection (Q in Mvar)
- Voltage range (U in kV)

Reactive power setpoints can be contractually defined or specified online, depending on network needs. Generating modules must remain connected and operational within the defined voltage ranges at the point of connection (expressed in p.u.), in accordance with the specified time frames. Automatic disconnection due to voltage deviations is prohibited within the permissible voltage range and duration as defined. MEPSO may impose shorter voltage ride-through times when there is a combination of voltage and frequency deviations (e.g. undervoltage + overfrequency).

Both Q/P_{max} and voltage deviation ranges are in compliance with RfG requirements.

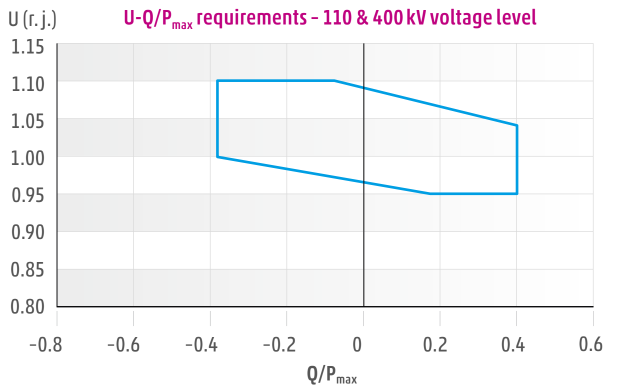


Figure 7.1: Requirement for reactive power control U = f (Q/P_{max} for 400 kV and 110 kV)

As for the requirements applicable to power plant modules (PPMs), these are specified in the following: Proposed U-Q/P_{max} characteristic of an energy park module connected to 110 kV.

Both Q/P_{max} and voltage deviation ranges are in compliance with RfG requirements. Regarding the requirements for reactive power when active power capacity is below its maximum value, the applicable provisions are specified in Appendix 3, Section XIII.3.2. This requirement aligns with RfG requirements.

PPMs must be capable of operating in one of the following modes:

» Voltage control
» Reactive power control
» Power factor control

The slope range is between 2 % and 7 %, with step adjustments of up to 0.5 %. Reactive power output is zero when the grid voltage matches the setpoint.

The voltage setpoint can be adjusted with or without a dead band. The dead band can be set between 0 % and ±5 % of the reference voltage (1 p.u.) in steps not exceeding 0.5 %.

After a step change in voltage, the module must reach 90 % of the reactive power change within five seconds. It must stabilise within 60 seconds, with a steady-state tolerance of ±5 % of maximum reactive power.

The energy park module can regulate the voltage at the connection point by exchanging reactive power with the grid. The set voltage range is 0.95 to 1.05 p.u., with steps not exceeding 0.01 p.u.

The module must allow reactive power to be set anywhere within its range. Adjustment steps should not exceed 5 MVAr or 5 % of total reactive power, whichever is smaller.

Reactive power accuracy at the connection point must be within ±5 MVAr or ±5 % of total reactive power, whichever is smaller.

MEPSO defines target power factor, tolerance, and response time following active power changes. MEPSO and the PPM owner must agree on which of the three control modes will be applied and what additional equipment is needed for remote control. MEPSO specifies whether active or reactive power contribution takes priority during fault ride-through scenarios. If active power has priority, this must be implemented within 150 milliseconds of fault initiation.

If required by MEPSO, the PPM must contribute to power oscillation damping. Voltage and reactive power control systems shall not negatively impact the damping function.

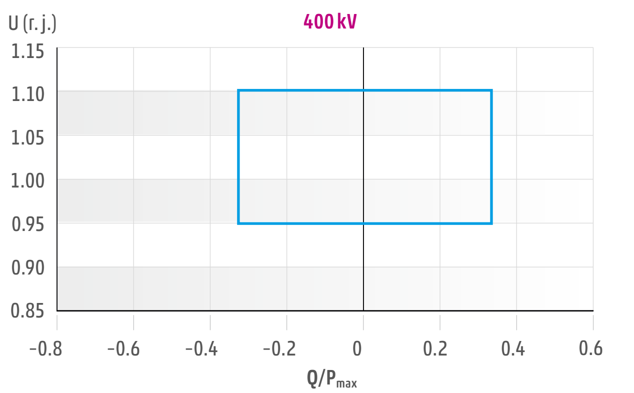


Figure 7.2: Proposed U-Q/P_{max} characteristic of an energy park module connected to 110 kV and 400 kV

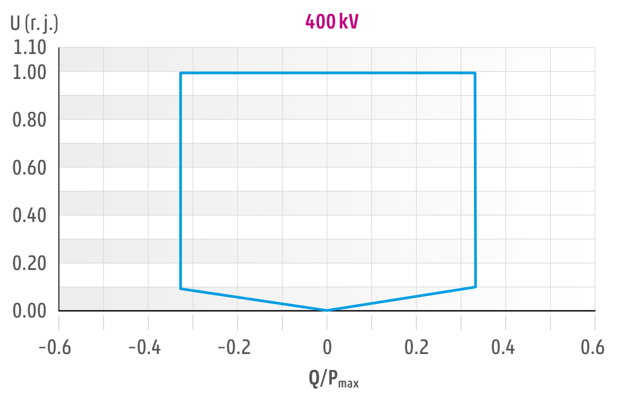


Figure 7.3: Reactive power capability below maximum power applicable to PPMs

Outlook

Currently, the North Macedonian Grid Code is being updated in line with the new North Macedonian Energy Law adopted in 2025. Within this process, MEPSO is aligning the requirements with the ENTSO-E RfG, particularly regarding the P–Q/P_{max} characteristic of power park modules (Figure 7.4). The implementation of this characteristic will bring several key benefits:

- Full and symmetrical reactive power capability across the entire active power range, ensuring consistent system support under all operating conditions
- Capability to provide reactive power even at low or zero active power output, which is especially important during periods of high renewable energy source (RES) generation and low demand
- Enhanced voltage control and overall system stability, particularly in scenarios with high RES penetration
- Clearly defined and enforceable technical requirements, improving transparency and compliance for power park module operators

Overall, this approach will significantly strengthen the operational flexibility and reliability of generation units, while enabling more secure integration of large-scale RES into the transmission system.

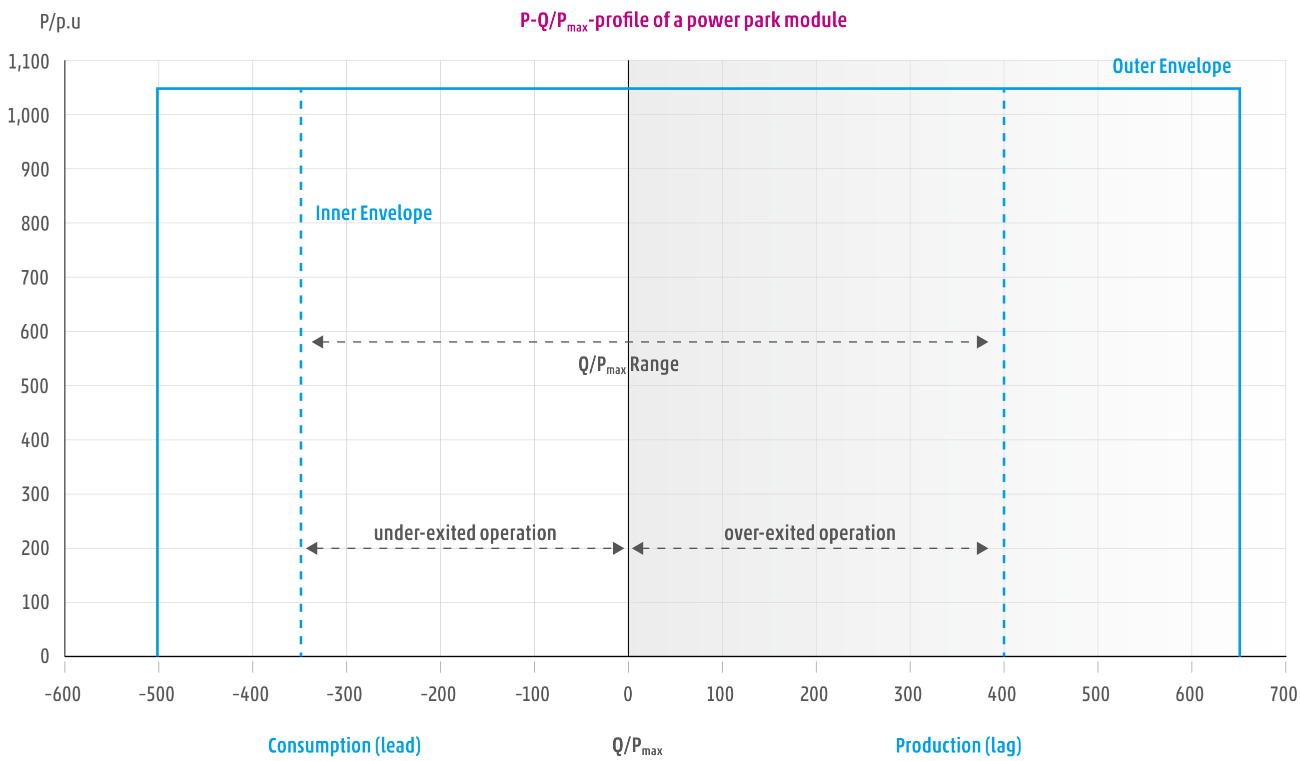


Figure 7.4: Update of reactive power capability below maximum power applicable to PPMs

7.2.3 Requirements of the System Defence Plan (Including Load Shedding)

MEPSO has created and implemented a System Defence Plan that describes manual and automatic measures used to prevent system blackouts, limit the spread of disturbances, and stabilise the grid as quickly as possible with minimal impact on grid users pursuant to the provisions of NC ER.

The MEPSO System Defence Plan specifies:

- A procedure for selection and awareness of system states (normal, alert, emergency, blackout, and restoration)
- The observability area for the system of North Macedonia
- A procedure for the implementation of preventive and curative measures to address the most serious system disturbances (voltage management, overload, and large active power imbalance)
- Technical and organisational measures for automatic system protection schemes in case of system stability issues

In relation to voltage deviations, Title 9 of the MEPSO System Defence Plan, the Voltage Deviation Procedure, states the following:

"The measures of the voltage deviation management procedure set out in the MEPSO System Defence Plan is developed in accordance with NC ER Article 19. This procedure is intended to return the voltage to normal operational limits. The voltage deviation management procedure is activated manually by MEPSO in case when the voltage deviates from the operational limits specified in the North Macedonian Grid Code:

- 0.9 p.u. – 1.05 p.u. for 400 kV connection points
- 0.9 p.u. – 1.118 p.u. for 110 kV connection points

During these events, MEPSO may use all available reactive power control devices (tap changers, reactors, capacitor banks, SVCs, etc.) in coordination with DSOs or request additional voltage/reactive power support from generating units, where applicable. If the above measures are not sufficient, MEPSO may decide to activate the manual demand disconnection procedure."

The current System Defence Plan is based on operational experience of the MEPSO power transmission system, taking into account all major disturbances to the normal state. Before 2023, MEPSO did not have problems with high voltages in the 400 kV transmission system, but rather with low voltages (below 0.9 p.u.) in the 110 kV transmission system. Therefore, the System Defence Plan does not specify a scenario for high voltages above 1.1 p.u. Of the measures outlined in the MEPSO System Defence Plan, the only operational measure available during the incident was the disconnection of the internal 400 kV TIE, which was carried out by the dispatchers. Other assets for voltage regulation, such as reactors, capacitor banks, etc., have not yet been implemented in the MEPSO transmission system.

7.2.4 Load Shedding

In accordance with the System Defence Plan, MEPSO can perform manual load shedding only in coordination with the DSO. Manually controlled load shedding takes longer than automatic load shedding.

However, on the day of the incident, manually controlled load shedding in coordination between TSO and DSO dispatchers was not performed.

7.3 Voltage Situation

7.3.1 Voltage Situation in the SEE Region

Figures 7.5–7.7[15] show that average voltage levels in the SEE region during the weekend night hours (22:00–06:00) were similar during the nights of 17 and 18 March, as well as throughout the broader spring period (March to May). Elevated voltages above 420 kV are observed not only in the MEPSO transmission system but also across all neighbouring systems.

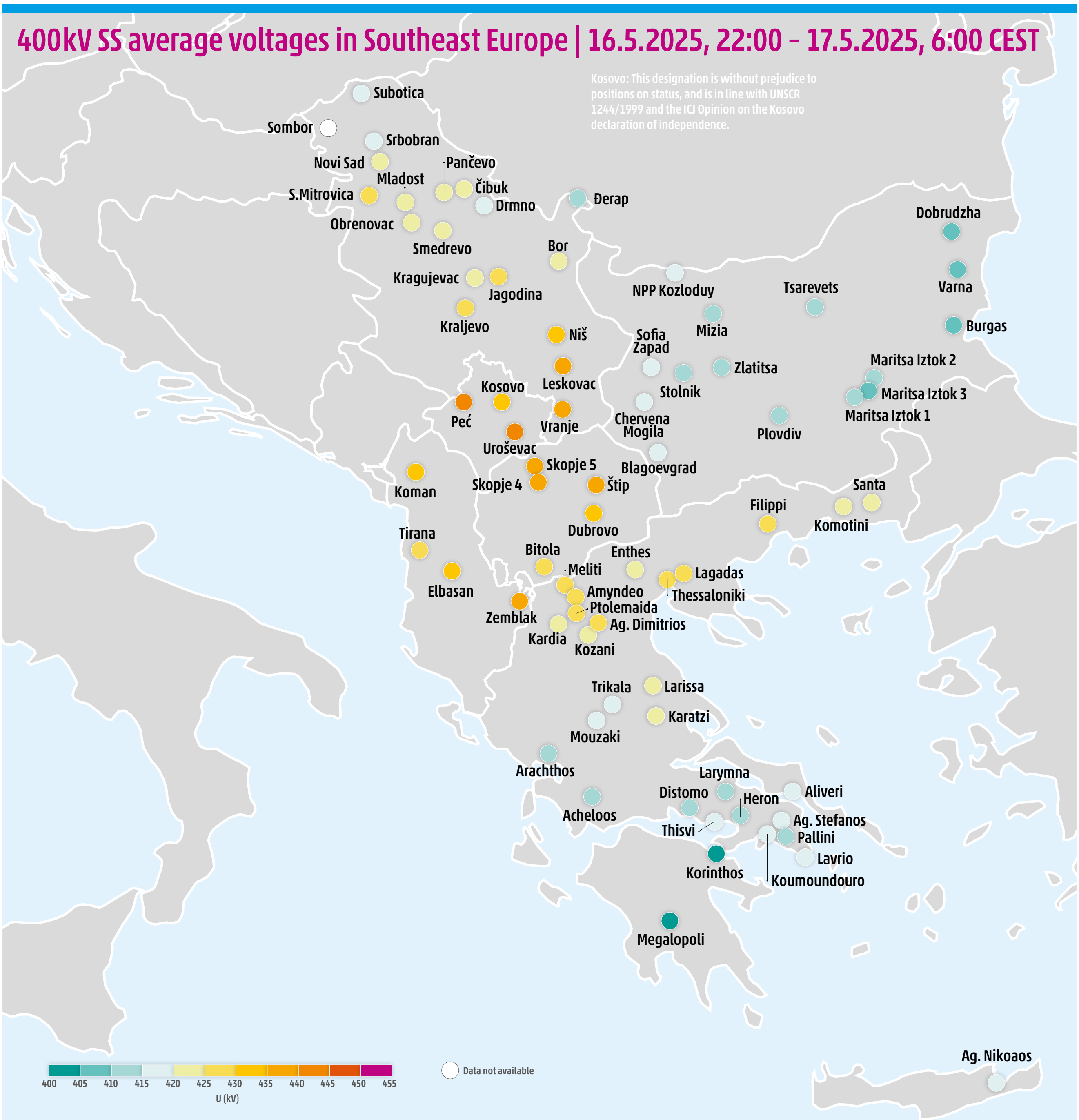


Figure 7.5: Average voltage levels in SEE during the night of 16–17 May 2025

15 Data represented in Figures 7.5–7.7, based on data collected from neighboring TSOs of MEPSO.

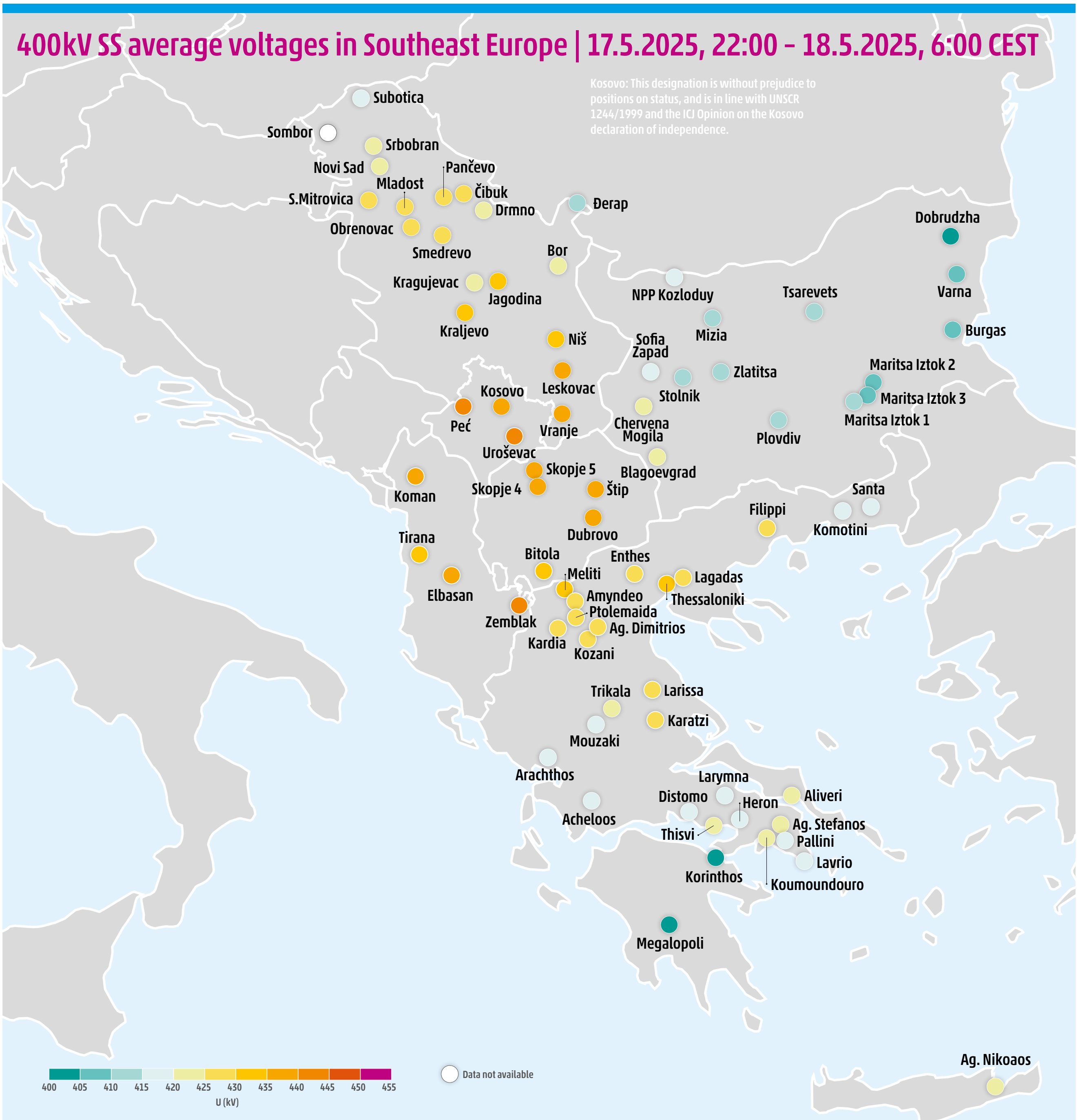


Figure 7.6: Average voltage levels in SEE during the night of 17–18 May 2025

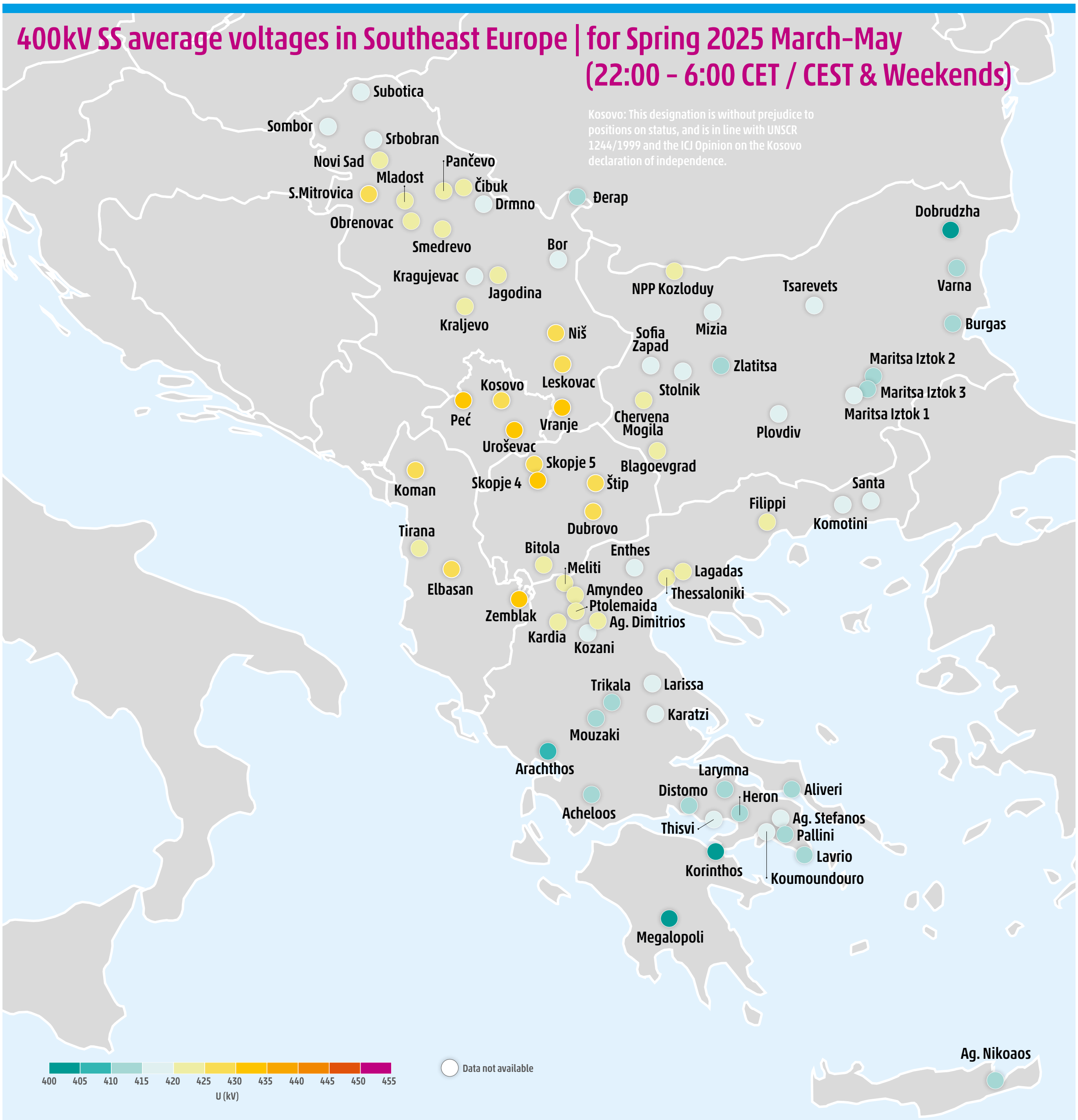
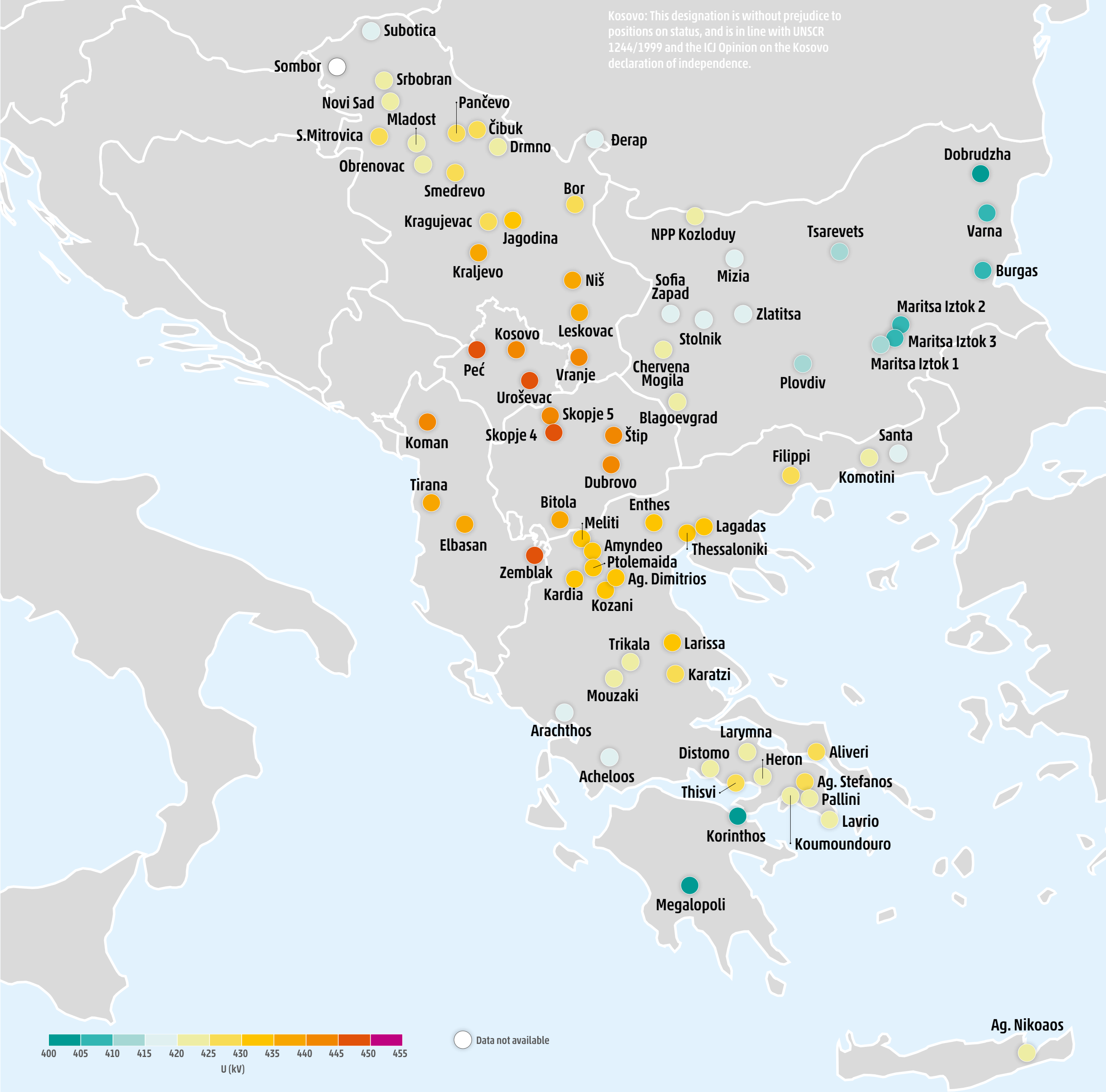


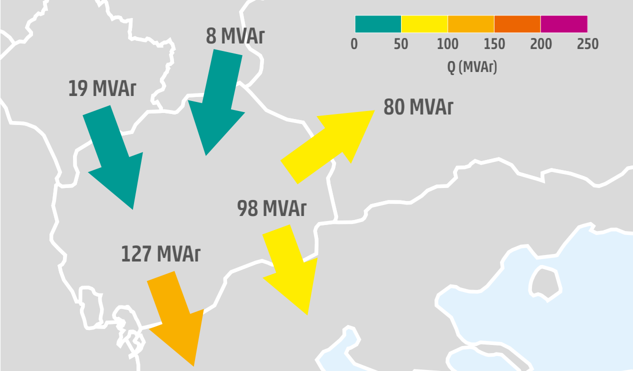
Figure 7.7: Averaged voltage in SEE in spring 2025 (March-May) during nighttime on weekends

However, analysing the average hourly voltage values at substations on the night of the incident reveals that voltage values increased most in the MEPSO transmission system during the incident, as well as in the KOSTT and EMS transmission systems (see Figure 7.8 on the following pages).

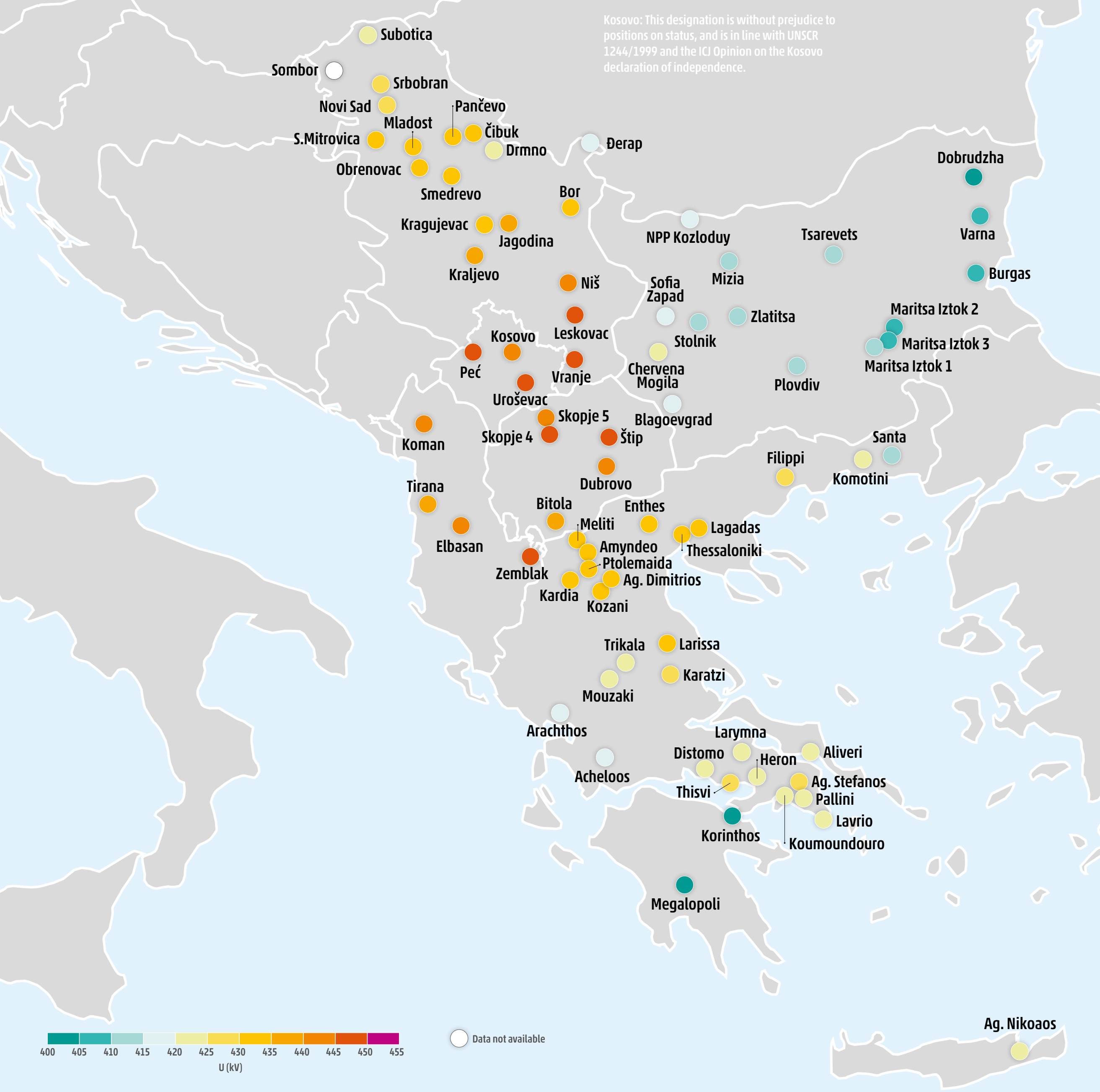
400kV SS average voltages in Southeast Europe | 18.5.2025, 2:00 – 3:00 CEST



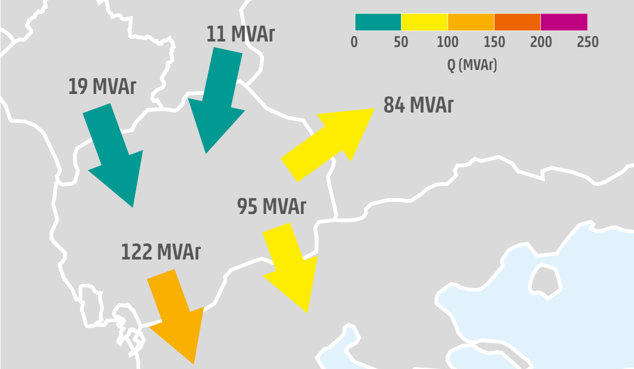
Average border reactive power flow in Southeast Europe 18.5.2025 2:00 – 3:00 CEST



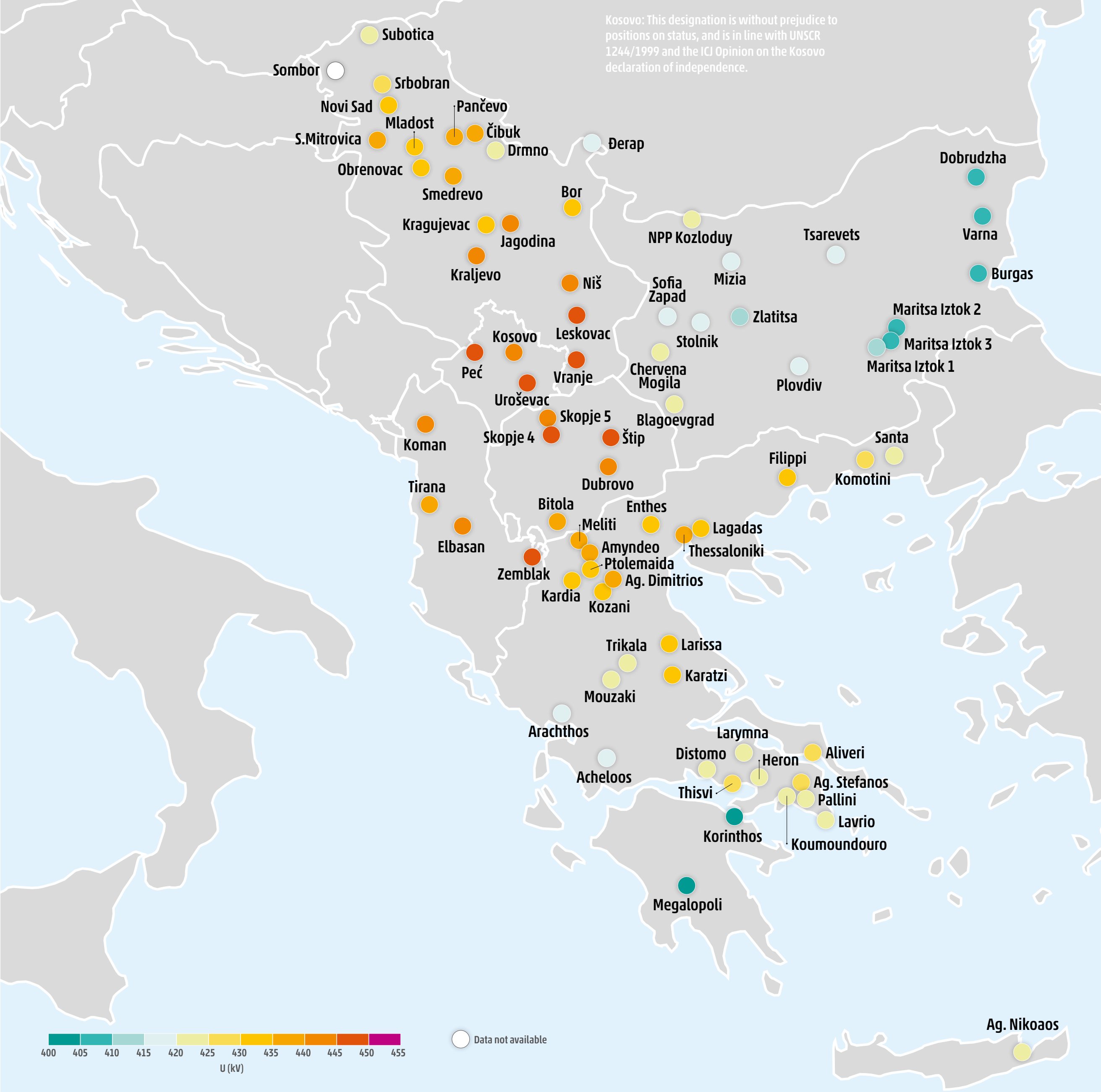
400kV SS average voltages in Southeast Europe | 18.5.2025, 3:00 – 4:00 CEST



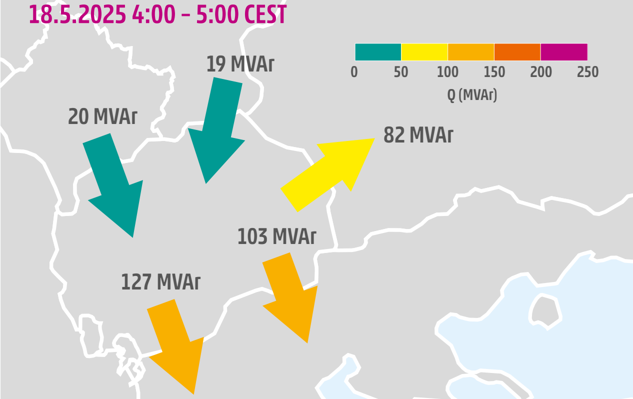
Average border reactive power flow in Southeast Europe 18.5.2025 3:00 – 4:00 CEST



400kV SS average voltages in Southeast Europe | 18.5.2025, 4:00 – 5:00 CEST

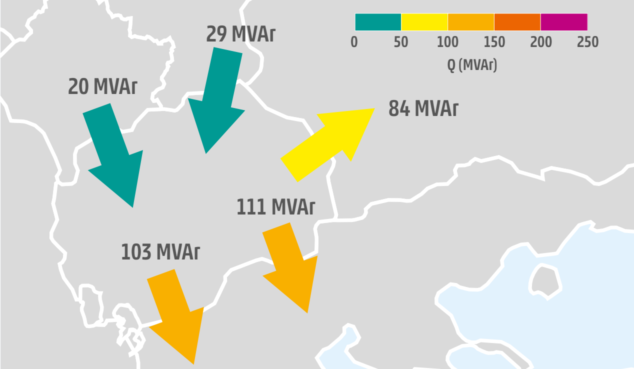


Average border reactive power flow in Southeast Europe 18.5.2025 4:00 – 5:00 CEST



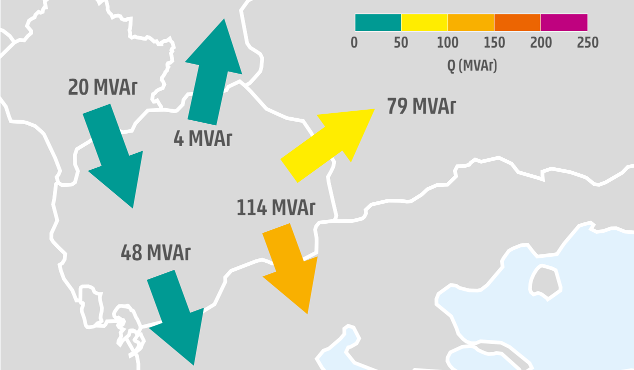
400kV SS average voltages in Southeast Europe | 18.5.2025, 5:00 – 6:00 CEST

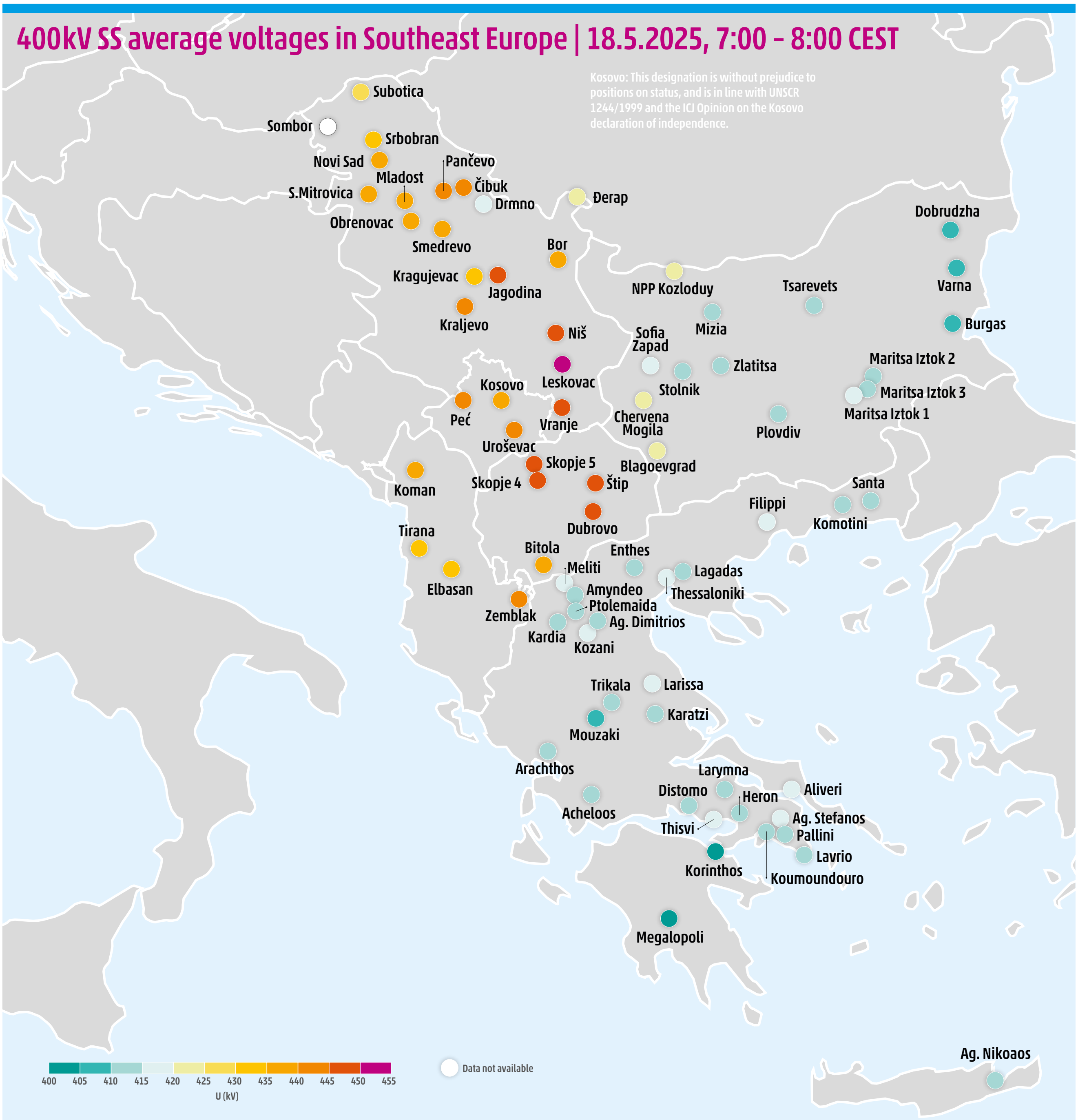
Average border reactive power flow in Southeast Europe 18.5.2025 5:00 - 6:00 CEST



400kV SS average voltages in Southeast Europe | 18.5.2025, 6:00 – 7:00 CEST

Average border reactive power flow in Southeast Europe
18.5.2025 6:00 – 7:00 CEST





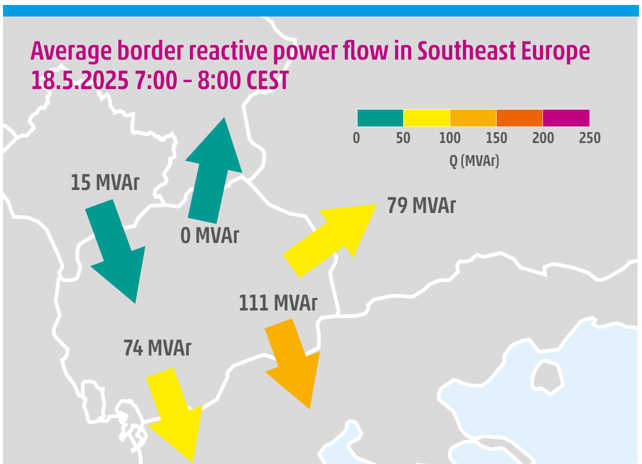


Figure 7.8: Evolution of hourly average voltage levels and reactive power flows on 18 May 2025 (02:00–08:00) in the SEE region

Comparing the average hourly reactive power flows during the night of the incident with the average reactive power flows for nighttime hours during spring 2025 (see Figure 7.9) shows that reactive power flows towards IPTO were higher during the incident. Additionally, the reactive power flow toward EMS changed: during the incident, reactive power flowed from EMS to MEPSO. The observed reactive power flow pattern can be explained by the voltage differences between the transmission systems. During the incident, voltage levels in EMS and KOSTT were higher than in MEPSO, while voltage levels in the IPTO transmission system were comparatively lower.

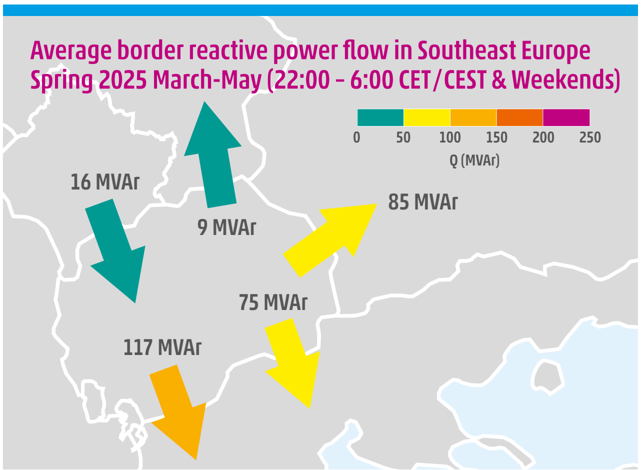


Figure 7.9: Average border reactive power flows in SEE for spring 2025 (March–May) – 22:00–6:00 CET, weekends

7.3.2 Voltage Situation Three Months Prior to the Incident at all MEPSO Substations

The following figures illustrate the development of the voltage situation at all MEPSO substations over the last three months. For improved visualisation and clarity, only one voltage per substation is represented. If two busbars were active simultaneously, only the higher voltage is displayed.

Figure 7.10 shows that voltages grew constantly from February to May 2025, while consumption declined steadily due to rising temperatures over the course of the year. The actual voltage limits exceeded the permanent limit of 420 kV throughout the entire period. From mid-April onwards, the 440 kV limit was exceeded almost daily, with measured voltages up to 450 kV.

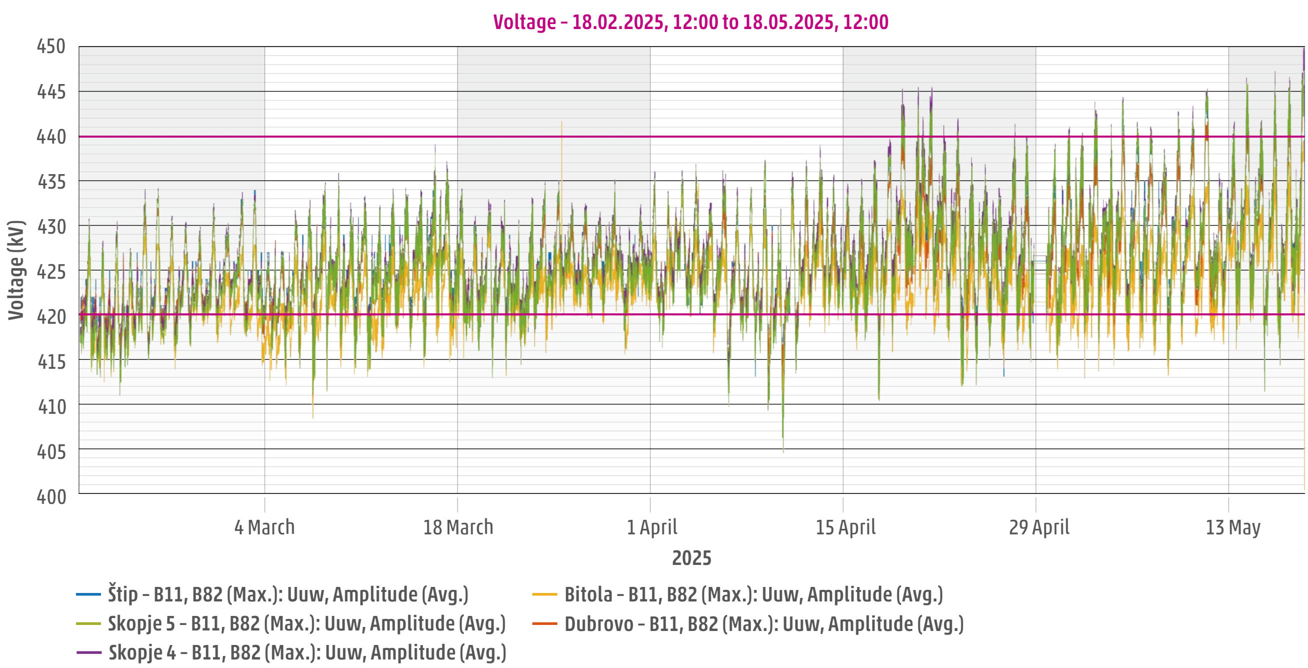


Figure 7.10: Voltage values in 400 kV busbars in North Macedonia from February through 18 May 2025

Figure 7.11 shows that not all busbars and stations were equally affected by this phenomenon. SS Bitola, due to its proximity to generation units, experienced comparatively low voltages and only isolated voltage limit violations (relative to the 440 kV limit). SS Skopje 4 and SS Skopje 5 had the most voltage exceedances and the highest average voltages in the North Macedonian grid. Significant voltage volatility was particularly apparent at these stations.

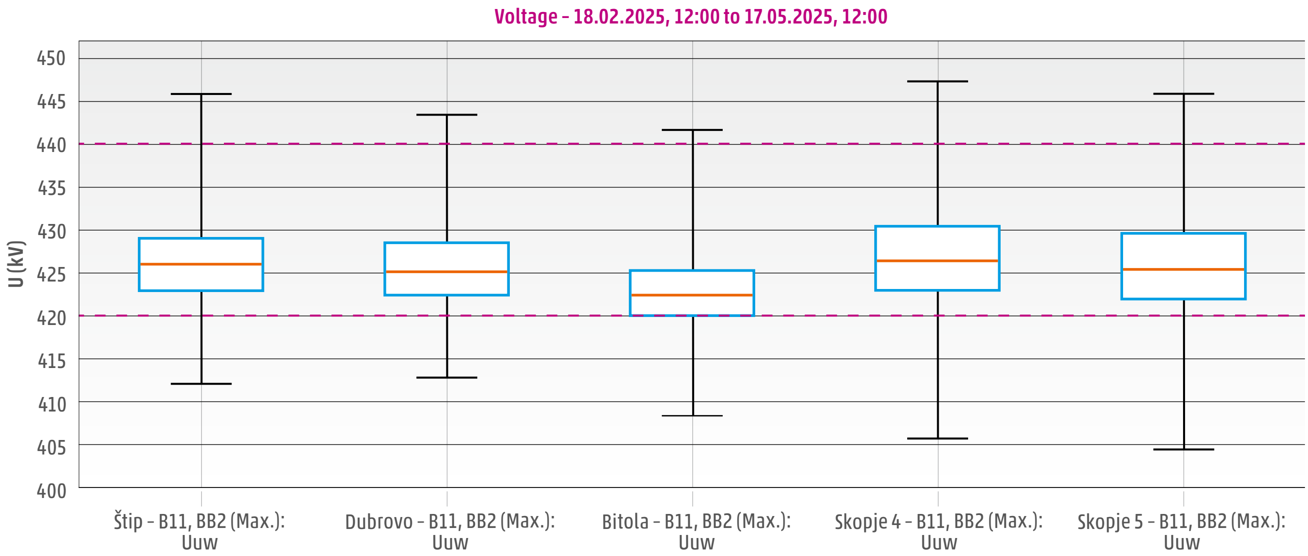


Figure 7.11: Box plots of voltage values in MEPSO SS

Figure 7.12 shows the voltage of SS Skopje 4 over the course of the day. Each box plot represents the voltage in the substation in a specific hour. It is clear that voltage volatility is strongly related to the time of day. The highest voltages always occur in the early hours of the day, between 02:00 and 08:00 CEST. This is mainly because the surrounding 400 kV lines and the heavily expanded distribution networks are only slightly used during the night and have a high reactive power production. During the day and at the beginning of the night, when consumer loads are higher and the grids are loaded more heavily, the voltages at SS Skopje 4 drop significantly.

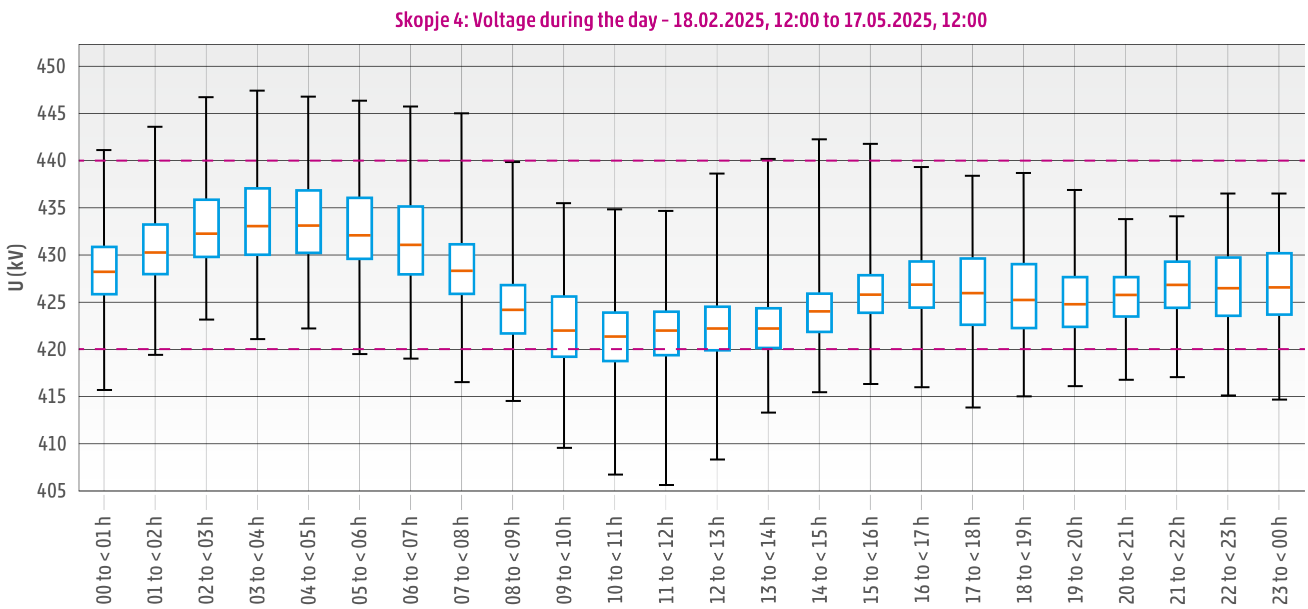


Figure 7.12: Box plots of voltage values during the day in SS Skopje 4

Figure 7.13 shows that voltages increased constantly during the three-month period, mostly above the upper limit.

From March to May 2025, as consumption decreased, a constant increase in maximum voltage values can be observed, reaching their peak on the day of the incident (see Chapter 3.1).

For the sake of clear representation, the following figures illustrate the development of the voltage situation at each MEPSO substation over the last three months.

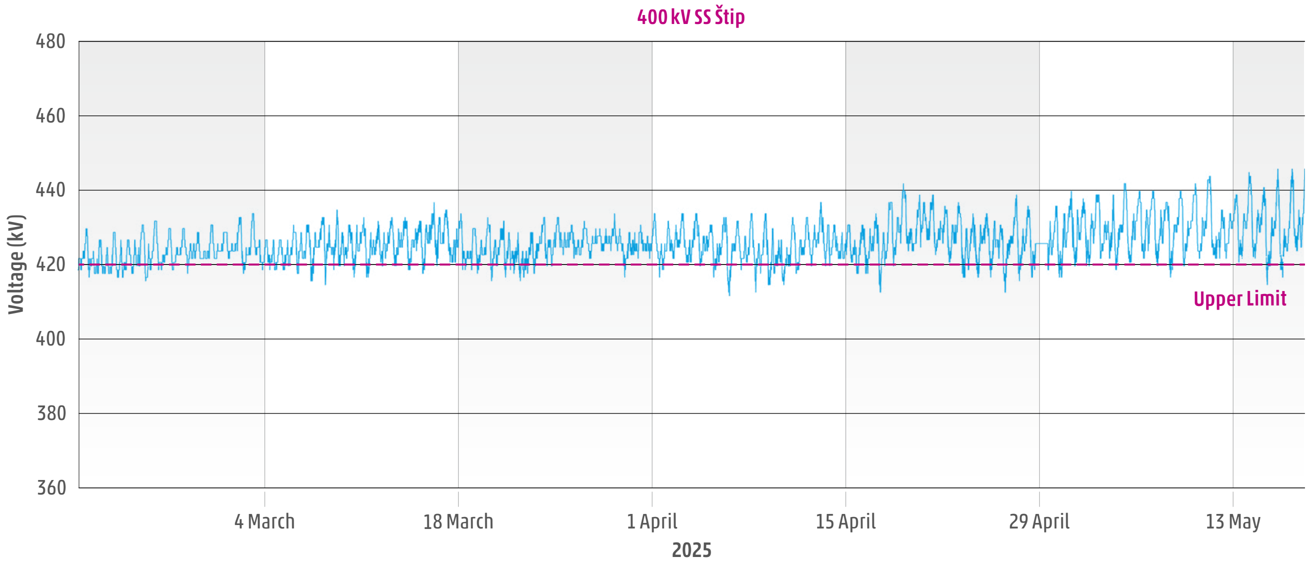


Figure 7.13: 400 kV voltage measurement in SS Štip (MEPSO) from March through 18 May 2025

Figures 7.13–18 show the voltage values for 400 kV SS Štip for the analysed period from March through 18 May. It can be seen that at each timestamp, the voltage levels exceeded the reference voltage value of 400 kV. In approximately 85 % of the timestamps, they surpassed the allowed upper limit of 420 kV, reaching a maximum of 449.5 kV on the day of the incident.

The voltage situation at 400 kV SS Dubrovo was similar to that of 400 kV SS Štip. At each timestamp, the voltage levels exceeded the reference voltage value of 400 kV. In approximately 80 % of the timestamps, they surpassed the allowed upper limit of 420 kV, reaching a maximum of 449.5 kV on the day of the incident.

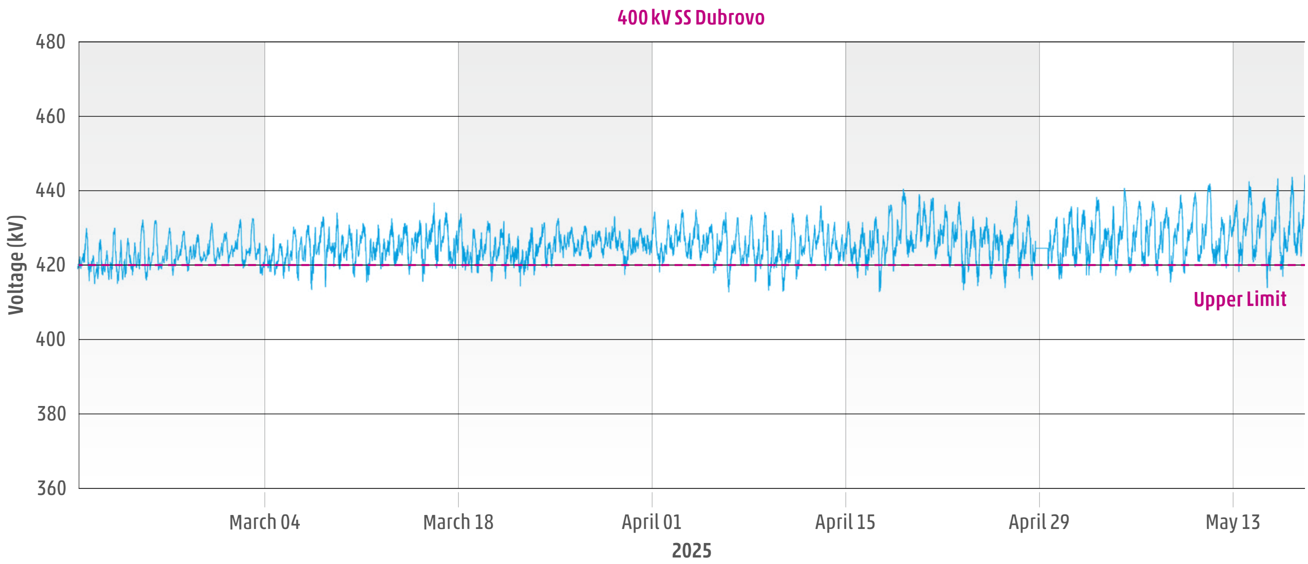


Figure 7.14: 400 kV voltage measurement in SS Dubrovo (MEPSO)

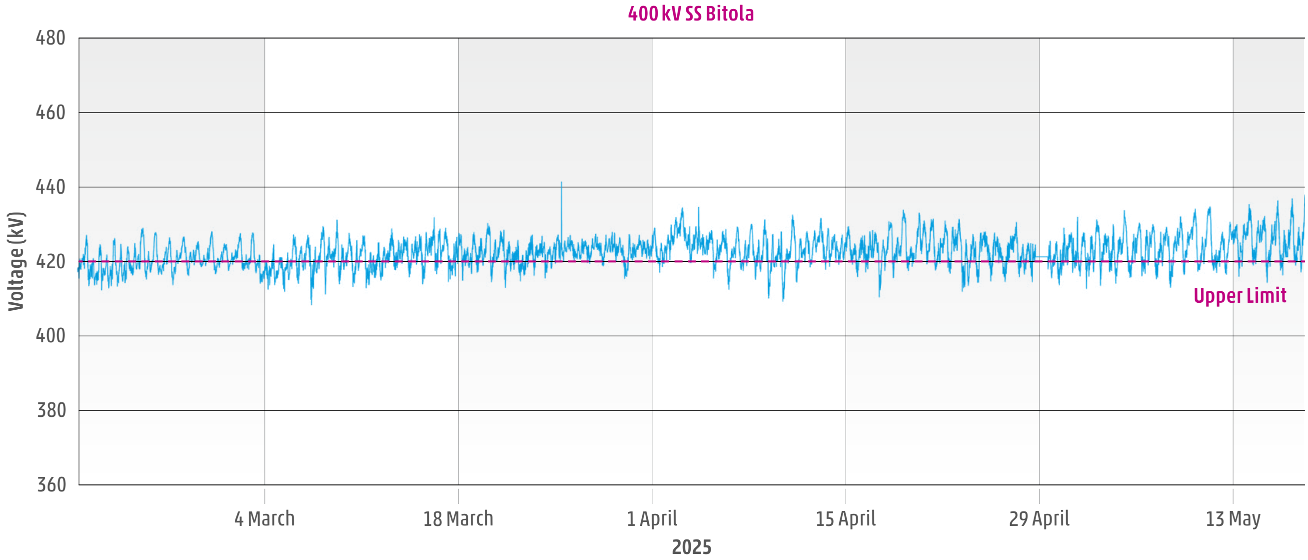


Figure 7.15: 400 kV voltage measurement in SS Bitola (MEPSO)

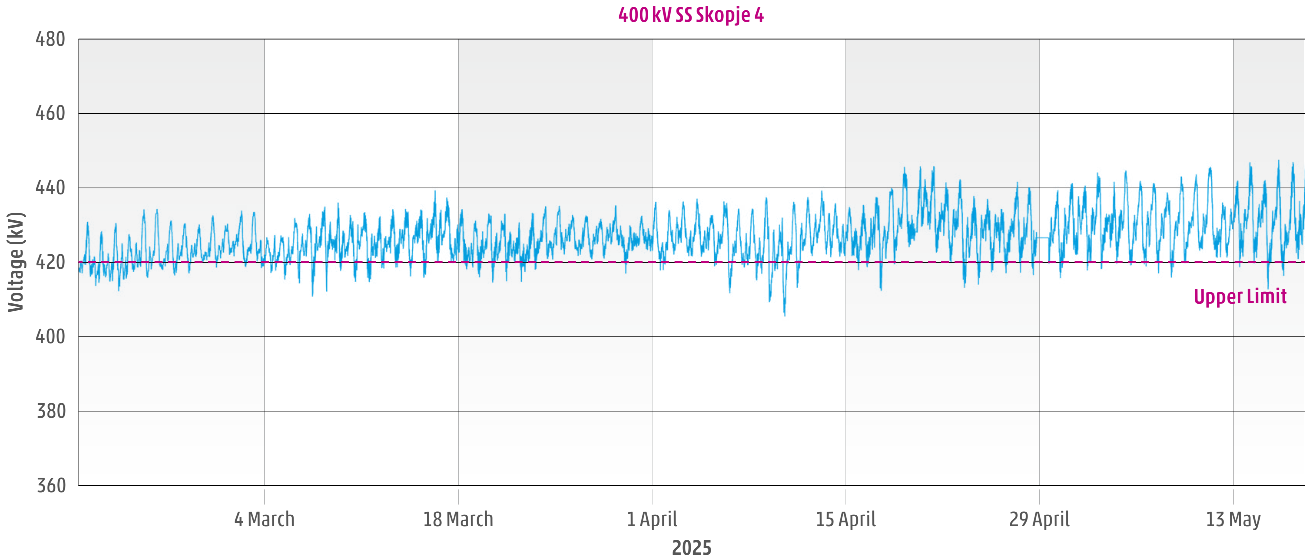


Figure 7.16: 400 kV voltage measurement in SS Skopje 4 (North Macedonia)

Skopje 4 (Figure 7.16) is an internal substation within the Macedonian transmission network. It is not directly connected to any neighbouring TSO by an interconnection line, but it is linked via a 400 kV OHL to Skopje 5, which in turn is connected to the KOSTT transmission system through an interconnection.

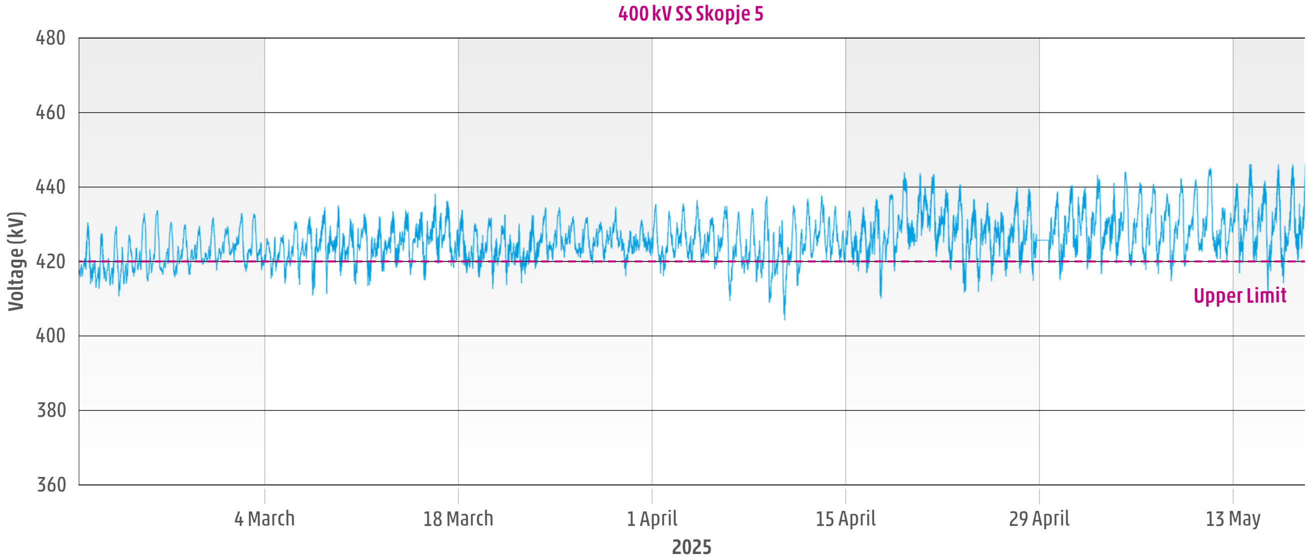


Figure 7.17: 400 kV voltage measurement in SS Skopje 5 (MEPSO)

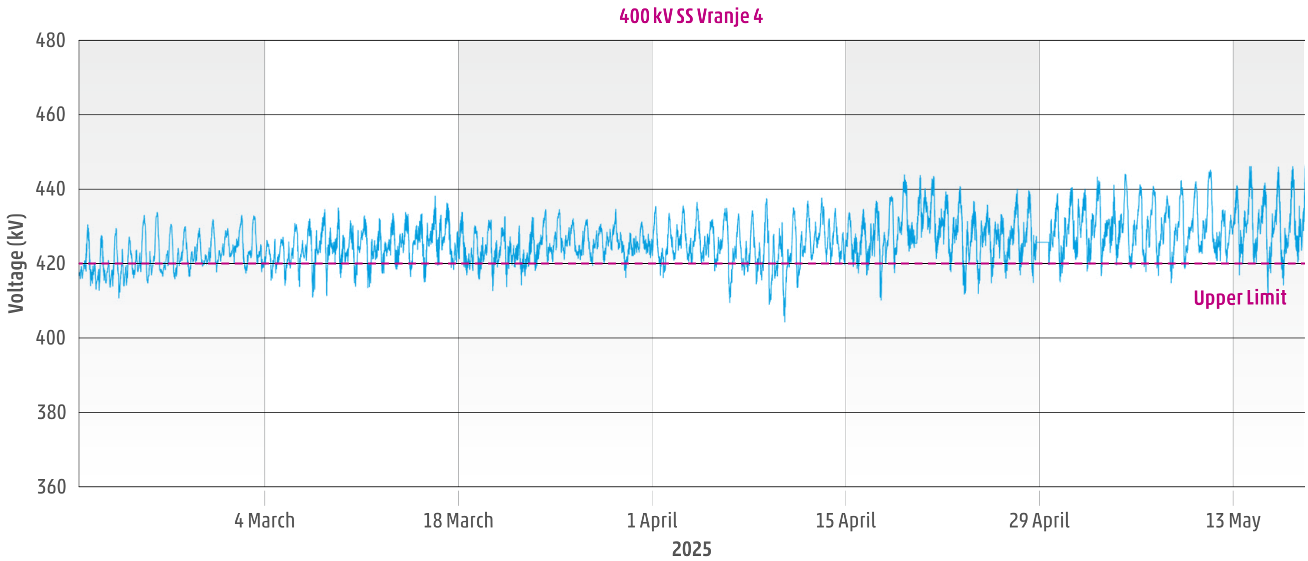


Figure 7.18: 400 kV voltage measurement in SS Vranje 4 (EMS)

During the period around 18 May 2025, the recorded voltage at Vranje 4 (Figure 7.18) temporarily exceeded 450 kV, which is above the upper operational limit.

Reactive Power Flows (TSO–TSO)

The following figures present the reactive power flows on all MEPSO's transmission TIEs over a three-month period. The figures show measurements at both sides to include the capacitive nature of each TIE.

The overview of interconnectors shows that there are no significant reactive power flows on most interconnectors. The only exception is the Bitola–Meliti (IPTO) (Figure 7.22) interconnector. This can be explained by the generation from the Bitola power plant into the 400 kV grid.

Avoiding relevant reactive power exchanges between the grids of neighbouring TSOs means that the reactive power demand of the two long interconnectors (OHL Štip–C.Mogila (ESO) and OHL Dubrovo–Thessaloniki (IPTO)) has an additional negative impact on the North Macedonian grid. During the night, when the load across the entire region is low and barely any active power is being transported over the interconnectors, this effect is even stronger and contributes to high voltages in neighbouring substations.

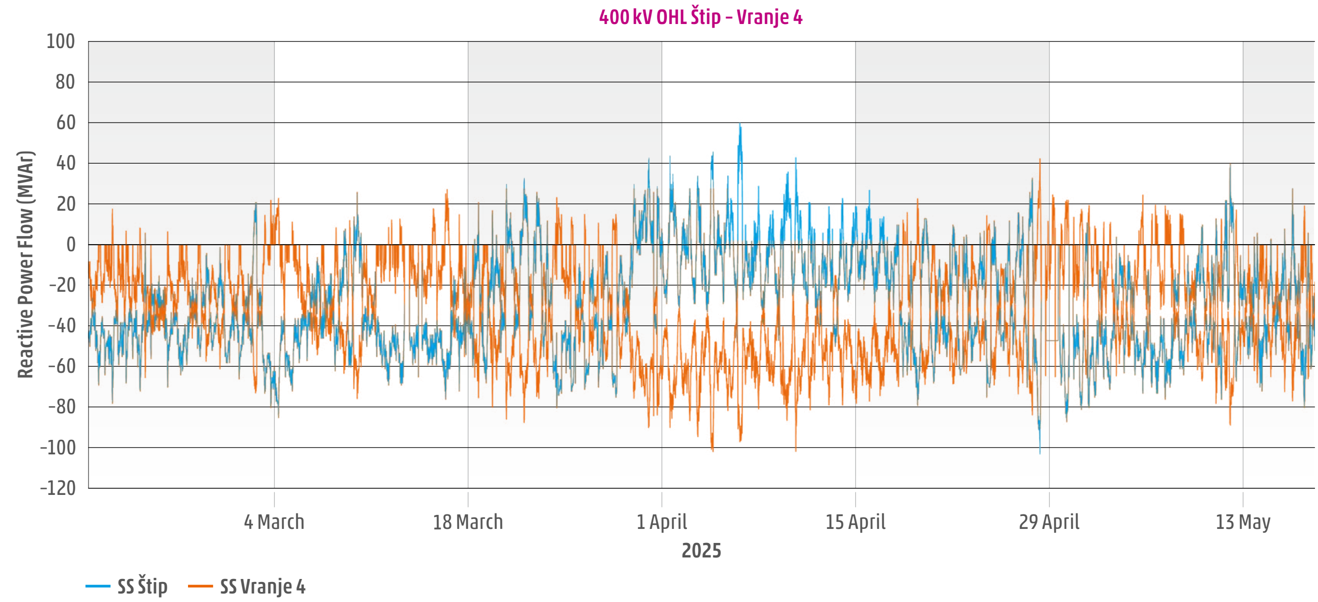


Figure 7.19: Reactive power measurements on the 400 kV OHL Štip–Vranje 4 (EMS)

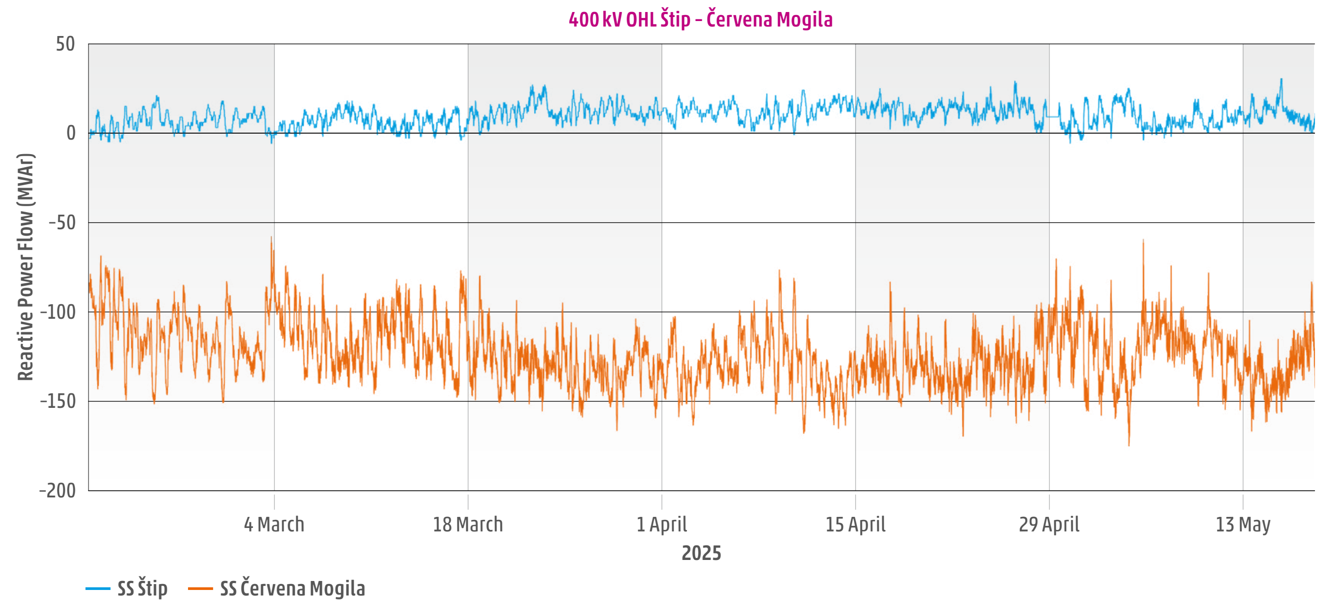


Figure 7.20: Reactive power measurements on the 400 kV OHL Štip–C.Mogila (ESO)

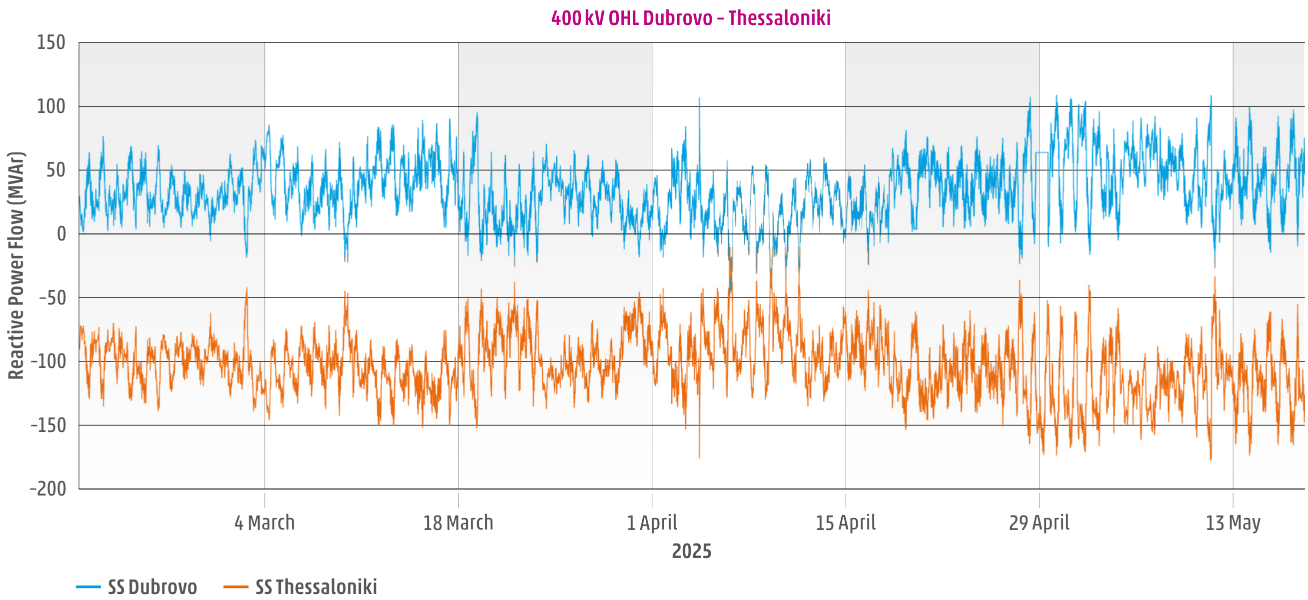


Figure 7.21: Reactive power measurements on the 400 kV OHL Dubrovo-Thessaloniki (IPTO)

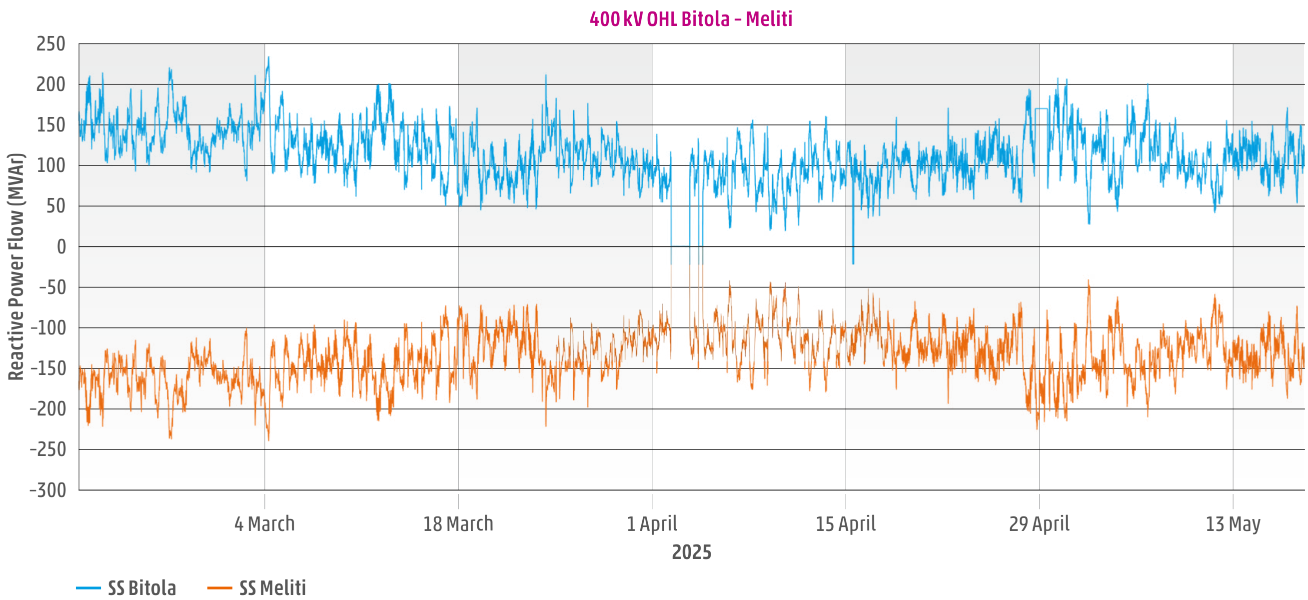
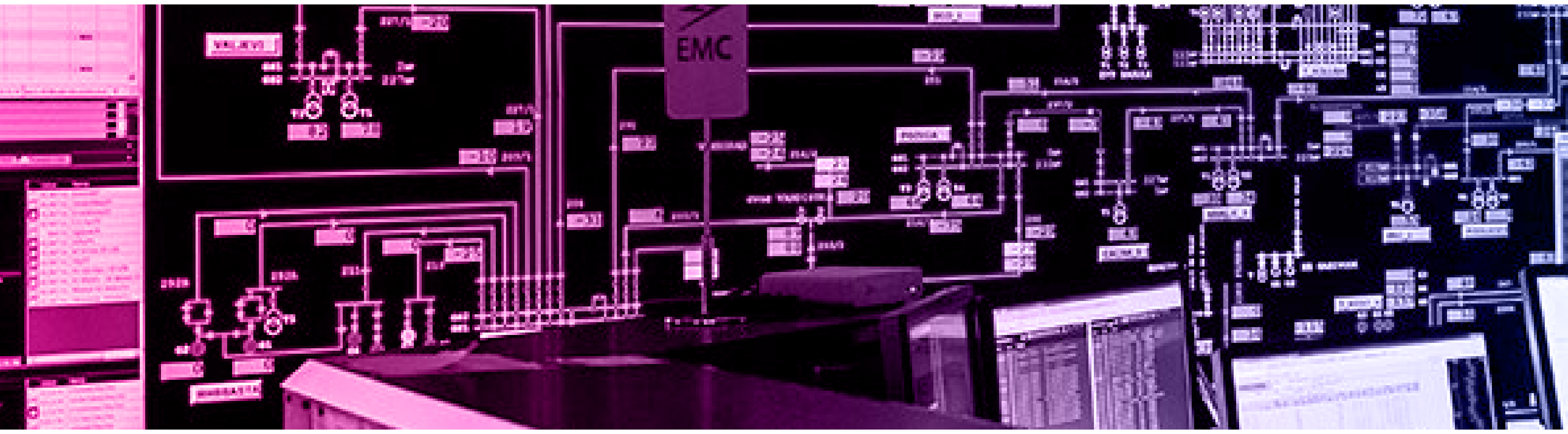


Figure 7.22: Reactive power measurements on the 400 kV OHL Bitola-Meliti (IPTO)



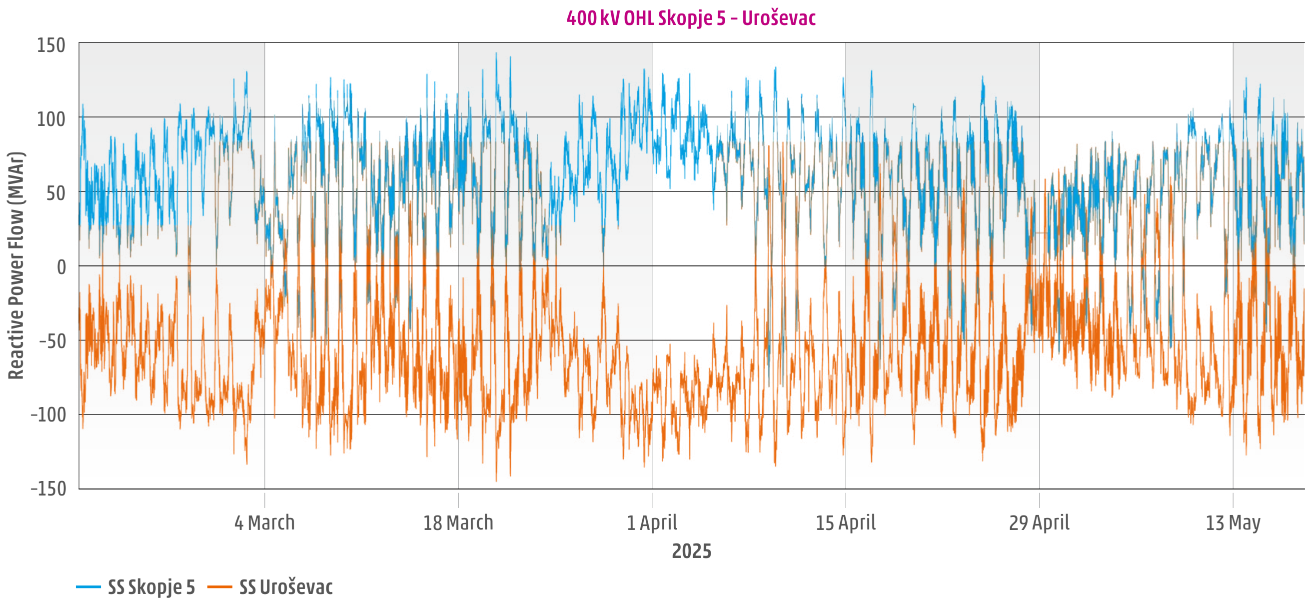


Figure 7.23: Reactive power measurements on the 400 kV OHL Skopje 5-Uroševac (KOSTT)

7.3.3 Provision of Reactive Power by Generating Units Before and on the Day of the Incident

Although thermal generating units are technically specified to provide reactive power support in line with MEPSO's requirements and the North Macedonian Grid Code, their actual capability is constrained by age-related technical limitations and degradation of excitation and control systems, which restrict their effective reactive power range.

Table 7.2 shows the reactive power compensation measures that were active prior to the blackout.

Generator	R+ (MVAr)	R– (MVAr)	Direction	Voltage Level (kV)
TPP Bitola, Block 3	0	6.6	Absorption	400
TPP Bitola, Block 1	0	2.2	Absorption	110
WPP Bogdanci	0.12	0	Injection	110
WPP Demir Kapija	3.3	0	Injection	110
HPP Špilje	0	0.25	Absorption	110

Table 7.2: Reactive power that was absorbed/injected prior to the blackout at 5:00 AM

Figures 7.24 and 7.25 show the reactive power absorption and generation by generators on the day of the incident.

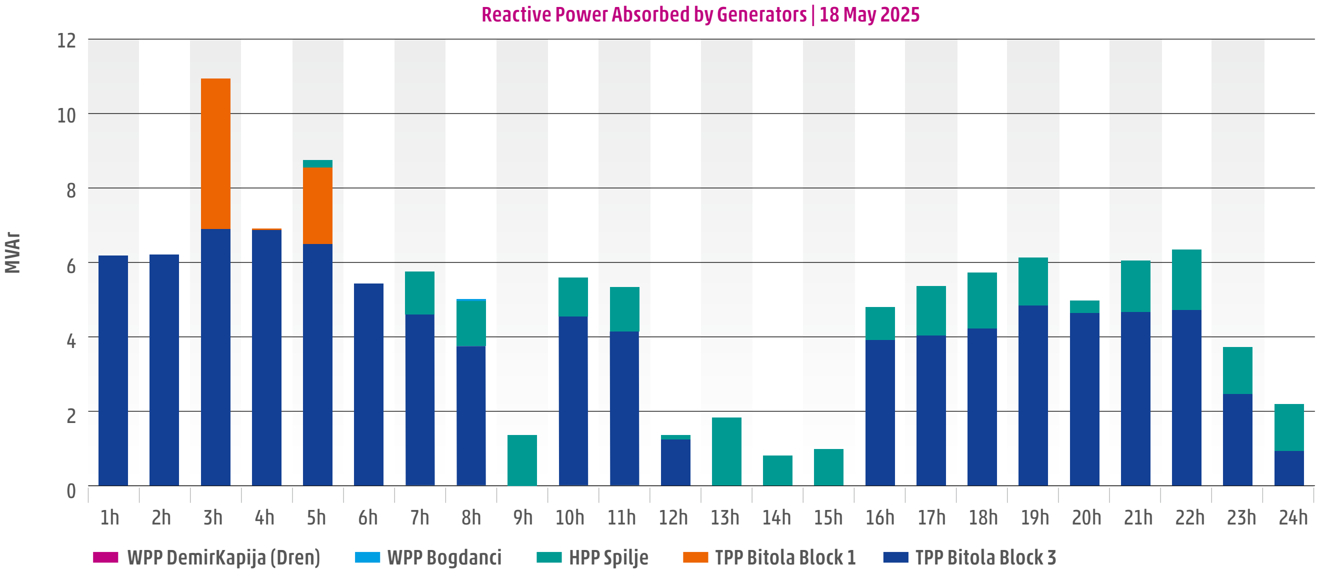


Figure 7.24: Reactive power absorption by generators on 18 May 2025

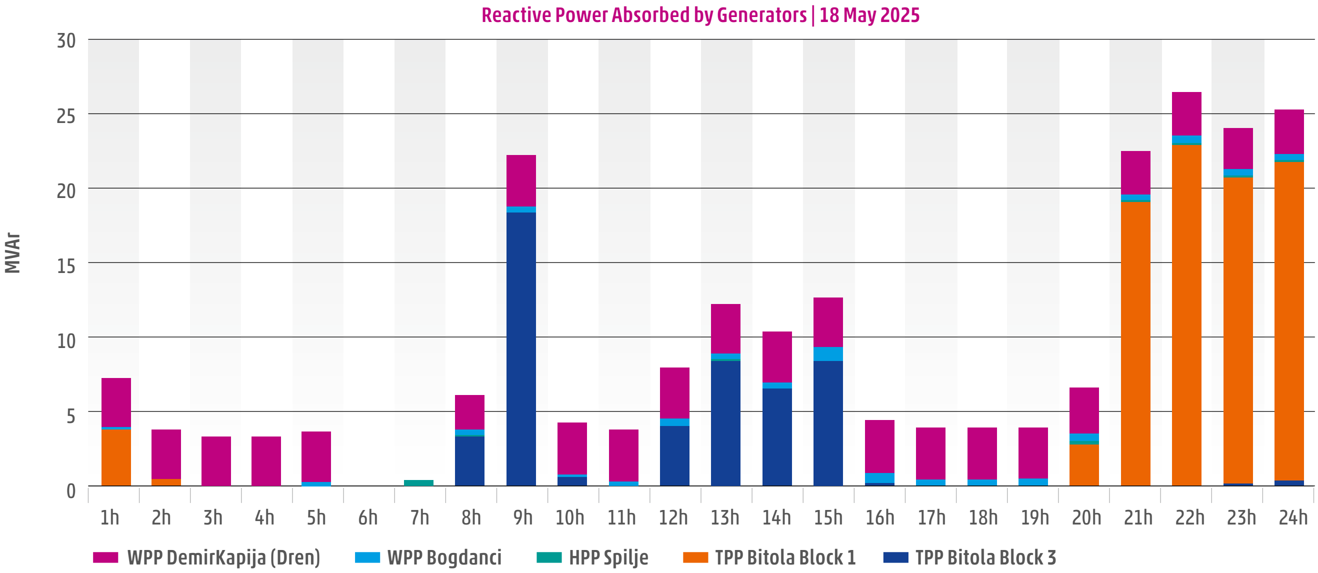


Figure 7.25: Reactive power generation by generators on 18 May 2025

7.3.4 Challenges in MEPSO's Transmission System and Measures Taken to Manage Overvoltage Situations

High voltages – especially in spring and autumn – have been observed in the MEPSO transmission system since 2023. Particularly during the night, consumer load and generation are low, and international transits of active power are minimal. Combined with the absence of reactive power compensation units, this leads to higher voltage values than the limits specified in the North Macedonia Grid Code, applicable during the time of the incident (see voltage requirements in Section 7.2.1).

Figure 7.26 shows, for all 400 kV stations in the MEPSO grid, the number of hours during which at least one busbar exceeded the 440 kV limit in the period 19 Apri–17 May. This indicates that, in the four weeks prior to the incident, at all stations in the North Macedonian transmission grid, except SS Bitola regular significantly.

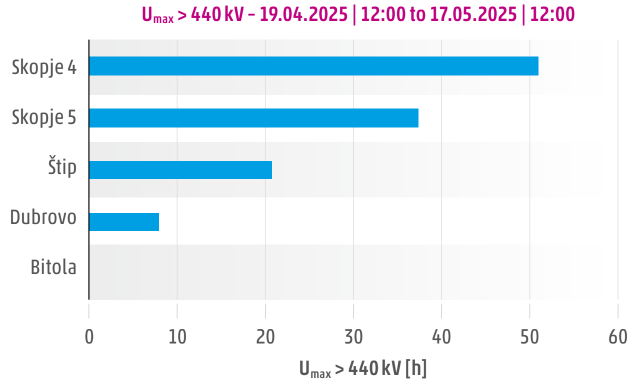


Figure 7.26: Number of hours during which at least one busbar exceeded the 440 kV limit for all 400 kV stations in the MEPSO grid in the period 19 April–17 May 2025

7.3.4.1 Operational Measures Usually Applied by MEPSO in Response to Overvoltage Conditions

Disconnection of the 400 kV OHL Skopje 4–Bitola 2

Since 2023, the disconnection of the 400 kV OHL Skopje 4–Bitola 2 has been used as a regular operational measure. During low-load hours, this line is routinely disconnected to reduce voltage levels in the 400 kV network and, depending on system conditions, may remain out of service during the day as well.

Tap Changer Operation

The on-load tap changer (OLTC) system provides ±10 × 1.25 % voltage regulation. The tap position can be changed automatically by the local automatic voltage regulator (AVR) or manually through local control while the transformer is energised. Remote automatic control via SCADA is currently not implemented. The following transformers are equipped with automatic regulation:

- **Skopje 1/5:** TR1 and TR2
- **Štip:** TR

Manual regulation (DETC) – with designation ±2 × 2.5 %. This regulation is manual, performed by an operator, and can only be carried out when the transformer is de-energised.

The following transformers are equipped with manual regulation:

- **Skopje 4:** TR1 and TR2
- **Bitola 2:** TR1

Operators in the NCC monitor voltage levels and, when necessary, issue instructions to adjust the transformer tap positions.

7.3.4.2 Operational Measures Applied by MEPSO in the Weeks Before the Incident in Response to Overvoltage Conditions

In the weeks before the 18 May 2025 incident, the measures described above appeared to be insufficient. This led to adjustments to tap changers and the activation of the overvoltage protection on the 400/110 kV power transformers.

Due to persistently high voltage conditions in the transmission network, the OLTCs for 400/110 kV transformers were set to the lowest tap position (position 1) to reduce the 110 kV voltage level two weeks prior to the incident.

Thus, as part of the measures to manage overvoltages and ensure system stability, the voltage protection settings on the 400 kV transformers were readjusted on 11 May, one week before the incident.

The transformers' voltage protection settings were increased to the following values:

» **Skopje 5:** Both transformers (TR1 and TR2) were set at 449.6 kV; however, only one transformer was in operation.

» **Skopje 4:** TR2, the transformer in operation, was set at 449.6 kV. The other transformer, TR1, was disconnected due to the needs of the transmission system, especially due to low loads during this period.

» **Štip:** Set at 449.2 kV.

» **Bitola 2:** One of the transformers, TR2, was reset to 441 kV. TR1 was previously disconnected and was out of service.

In addition, the 110 kV transmission line **Bitola 1–Prilep 1** had remained disconnected since 19 March 2025 at 9:00 for reconstruction works, which reduced the operational security of the transmission network and significantly limited operational flexibility, thereby increasing the system's sensitivity to any additional outages.

7.3.4.3 Operational Measures Applied by MEPSO and Neighbouring TSOs on the Day of the Incident (18 May 2025)

In the MEPSO transmission system, on 18 May 2025, the 400 kV line between SS Skopje 4 and SS Bitola 2 was disconnected by the dispatcher as a general remedial action for high voltage reduction. The exact timeline can be found in Table 2 in Chapter 3.1. This is not an interconnection but rather an internal line, and dispatchers use this measure only during the night hours. At that time, both 400/110 kV transformers at SS Dubrovo were out of service.

The application of non-costly remedial actions to mitigate overvoltage in MEPSO's neighbouring TSOs is described below.

In the ESO transmission system, the following measures were taken on the day of the incident:

» All shunt reactors were switched on.

» All operational TPPs regulated voltage in accordance with their technical capabilities.

» During the restoration process, the following lines were disconnected to further stabilise voltage levels:

  – OHL 400 kV NPP Kozloduy–Mizia

  – OHL 400 kV Varna–Medgedia

  – OHL 400 kV Sofia West–Blagoevgrad

In the IPTO transmission system, the usual measures were taken to mitigate overvoltages in the vicinity of the substations connected to the MEPSO system, namely Meliti and Thessaloniki. In particular, the 100 Mvar/150 kV reactor in 400 kV/150 kV SS Kardia and the 100 Mvar/400 kV reactor in 400 kV/150 kV SS Amyndeo were connected. The following transmission lines were disconnected:

» 400 kV OHL Amyndeo–Lagadas

» 400 kV OHL Thessaloniki–Ag. Dimitrios

» 400 kV OHL Filippi–Lagadas (two lines)

In the KOSTT transmission system, there were no non-costly remedial actions applied.

In the EMS transmission system, the following lines were out of operation to reduce high voltage:

» 220 kV OHL Bajina Basta–Sremska Mitrovica 2

» 220 kV OHL Pozega–Kraljevo 3

» 220 kV OHL Nis 2–Krusevac 1

» 400 kV OHL Mladost–Novi Sad 3 CKT 2

» 400 kV OHL Pancevo 2–Resita (TEL) CKT 1 (CKT 2 is out of operation normally)

» 400 kV OHL Subotica 3–Sombor 3

Figure 7.27 shows all transmission lines in the SEE region that were disconnected for voltage control.

Figure 7.27: Disconnected OHLs in the SEE region for voltage control purposes.

* Kosovo: This designation is without prejudice to positions on status, and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo declaration of independence.

7.4 Assessment of the Available Means for Voltage Control

7.4.1 Assessment of RCC Support in the Operational Planning Phase

At the moment of the incident in the MEPSO grid, the SCC, acting as the RCC, was providing the following files to its TSO service users after each DACF and IDCF process:

1/ GMs in UCTE format

2/ N-X security analysis

3/ CGM border reports

It should be noted that the first IDCF process at the SCC covers the period 00:00–08:00CE(S)T, the second IDCF process covers 09:00–16:00 CE(S)T, and the third IDCF process covers 17:00–24:00 CE(S)T.

In September 2025, SCC developed and began providing its TSO service users, following each DACF and IDCF process, with two additional files:

1/ Base case load flow results

2/ N-X voltage reports

In this way, in addition to monitoring the current/thermal limits of transmission system elements in the base case and N-1 (or N-X) conditions, voltage monitoring at the nodes in both base case and N-1 (or N-X) conditions was also introduced.

Since December 2025, SEleNe acts as the designated RCC for MEPSO. At the operational level, IGMs are developed and analysed within the CSA process on a daily basis. In addition to monitoring thermal loadings and potential overloads, particular attention is also given to the voltage conditions across the system, ensuring that voltage profiles remain within acceptable operational limits.

7.4.2 Voltage Control: Assessment of the Means for Voltage Management

From the North Macedonia Grid Code, MEPSO's voltage management means include direct control of transmission system elements, reactive power resources, and system topology.

MEPSO can directly influence voltage through:

- Transformer tap changer adjustments at transmission substations
- Phase-shifting transformer regulation to influence power flows and voltage distribution
- Modification of network topology, including switching actions and selective disconnection of internal transmission lines
- Switching on or off reactive power compensation devices such as capacitors and reactors
- Use of power electronics-based devices for voltage and reactive power control
- Coordination with neighbouring TSOs to define appropriate voltage regulation regimes
- Participation in cross-border voltage regulation to minimise reactive power flows on interconnectors
- Countertrade and redispatch measures that indirectly support voltage control by modifying power flows

MEPSO also relies on the reactive power capabilities of connected users:

- Synchronous generators can be instructed to adjust reactive power output or voltage setpoints.
- Asynchronous generation units with converters can be requested to modify reactive power output.
- Coordination with DSOs allows blocking of automatic voltage regulation of transformers and implementation of voltage reduction measures at the distribution level.
- Manual load reduction can be applied where necessary to support operational security.

Investment Measures

The proposed reactive power compensation devices proposed in the Regional Feasibility Study for Voltage Profile Improvement WB17-REG-ENE-01 to be installed are presented in Table 7.3.

	OST	CGES	EMS	KOSTT	NOS BIH/EL.PRENOS BIH	MEPSO
Location	SS Elbasan	SS Lastva SS Ribarevine	SS Vranje	SS Ferizaj	SS Tuzla SS Mostar	SS Dubrovo SS Ohrid
Shunt capacity	120 MVAr	250 MVAr 150 MVAr	100 MVAr	150 MVAr	220 MVAr 120 MVAr	150 MVAr 100 MVAr
Voltage level	400 kV	400 kV	400 kV	400 kV	220 kV or 400 kV	400 kV
Device type	Fixed shunt reactor	Variable shunt reactor	Variable shunt reactor	Variable shunt reactor	Variable shunt reactor	Variable shunt reactor

Table 7.3: The proposed reactive power compensation devices in the Regional Feasibility Study for Voltage Profile Improvement WB17-REG-ENE-01

If everything proceeds according to the planned timeline, the 150 MVAr shunt reactor in SS Dubrovo is expected to be commissioned by the end of Q2 2026. In addition, a 200 MVAr shunt reactor in SS Vranje is anticipated to be operational by the end of 2026, followed by a 100 MVAr shunt reactor in SS Uroševac, expected to be commissioned by the end of 2027.

In order to enable full utilisation of the proposed voltage-reactive power equipment, together with the effects of reactive power control to be provided by the system users, the Regional Feasibility Study for Voltage Profile Improvement WB17-REG-ENE-01 also recommends establishing a dedicated regional voltage control centre for real-time voltage control and the minimisation of power losses. This includes the planning, monitoring, analysing, and recording of reactive energy exchanges at interconnection lines.

These proposed solutions will provide sufficient technical resilience for various future system uncertainties related to:

- Deviation of voltage profiles between simulations and real-time system data
- Demand forecast uncertainties
- Identification of future critical operating regimes from the system voltage perspective
- Establishing the level of transits and power exchanges in the region to be expected and facilitating the reduction of carbon intensity in the power sector

Based on the assessment conducted during this investigation, the Expert Panel considers that the identified overvoltage problems in the transmission network of the SEE region will unlikely be resolved by the implementation of individual TSOs' countermeasures, including the installation of voltage/reactive power control devices.

7.5 Assessment on the System Defence Plan Regarding Voltage Control

The MEPSO System Defence Plan and Restoration Plan, dated September 2023, are aligned with the required structure, scope, and main procedural elements defined in the NC ER and Synchronous Area Framework Agreement (SAFA) for the Regional Group Continental Europe (RG CE) Policy on Emergency and Restoration (E&R).

The aim of this chapter is to provide a clear overview of the key aspects that require expansion, clarification, further implementation, or introduction in the next revision of the System Defence Plan, the Restoration Plan, and the System Protection Strategy. The proposed recommendations seek to strengthen methodological consistency, improve transparency for internal and external stakeholders, and enhance practical usability for transmission control centre operators, DSOs, SGUs, and neighbouring TSOs during emergency and restoration situations.

The MEPSO Defence Plan explicitly states that it includes all requirements of NC ER and the relevant provisions of the RGCE SAFA Policy on E&R. In particular:

- The plan reproduces the full set of NC ER obligations, including those related to design, implementation, activation of defence measures, LFDD, overfrequency protection, voltage collapse protection, and frequency deviation management procedures.
- It explicitly states that "all requirements from NC ER will be implemented in the Defence Plan".

As a result, the overall structure of the System Defence Plan is fully aligned with NC ER and consistent with the principles of RG CE SAFA Policy E&R.

The System Defence Plan encompasses inter-TSO coordination, testing of critical tools and facilities, frequency deviation management prior to the nomination of a frequency leader, and LFDD. It further includes provisions covering LFDD design and implementation, minimum technical requirements, geographical distribution of load shedding, coordination with DSOs, and relay testing, which are consistent with the requirements of SAFA Policy 5 on E&R.

In addition, the System Defence Plan addresses the same core operational measures foreseen in Policy E&R, including management of the frequency restoration controller (FRC), activation of LFSM, and the application of additional TSO measures.

While the System Defence Plan demonstrates a high level of structural and regulatory alignment with the NC ER and ENTSO-E policy, the current edition does not consistently define clear implementation timelines for several of the described measures. In particular, the plan primarily specifies what measures are required to exist, but not when they are to be implemented, tested, or fully operationalised. As a result, certain requirements remain defined at a conceptual level and are not yet translated into time-bound and verifiable implementation steps.

7.5.1 Identified Weaknesses

The review identified several areas where the existing System Defence and Restoration Plans would benefit from improved coverage of emerging operating regimes and clearer operational structuring, in order to enhance practical usability during emergency and restoration situations.

1/ High-voltage/low-load regimes

The System Defence Plan primarily analyses operational scenarios related to underfrequency events and system separation. Other increasingly relevant system operating conditions are not explicitly addressed as standalone scenarios. In particular, operating regimes characterised by low system load combined with high RES production, seasonal conditions such as spring and autumn minimum load periods, and periods with high or low cross-border power transits, are not systematically reflected in the current set of analysed Defence Plan scenarios.

As a result, voltage-related risks, reactive power behaviour, OLTC operation, and switching sequences under these operating conditions are not fully assessed within the Defence Plan framework. This limits the practical applicability of voltage deviation procedures and reduces the visibility of preventive actions for non-classical but increasingly frequent system states.

Some of these operating regimes are increasingly characterised by reduced synchronous generation and lower system inertia, leading to faster frequency dynamics and reduced reaction time for defence measures. Explicit consideration of these characteristics would enhance the robustness of the analysed scenarios.

2/ Gap between documented measures and operational procedures at the TSO–DSO interface

The System Defence Plan defines a comprehensive set of defence measures, including LFDD, load-shedding stages, and coordination with DSOs. However, several of these measures have not been implemented.

In particular, while load-shedding stages and percentages are defined, the plan does not consistently describe:

» Feeder-level implementation at the distribution level

» Real-time activation logic and confirmation signals to the NDC

» Feedback mechanisms between DSOs and the NDC during activation and restoration phases

In addition, references to the testing of critical tools and facilities remain largely generic. A consolidated and time-bound testing framework covering all main and backup defence and restoration tools is not explicitly defined, nor are testing activities systematically linked to operational planning, coordination with DSOs and SGUs, or verification of tool readiness.

Similarly, within the System Restoration Plan, several restoration-related processes –particularly those related to load re-energisation and coordination with DSOs – are described predominantly in narrative form. These processes are not consistently structured as standalone operational procedures aligned with the logical sequence of the corresponding provisions in NC ER and SAFA.

As a result, while the technical content is present, operational clarity during restoration phases might be reduced, especially with respect to:

» Sequencing of reconnection actions

» Allocation of responsibilities between the NDC and DSOs

» Real-time coordination and confirmation during progressive load restoration

3/ System protection versus equipment protection

The current documentation does not include a dedicated chapter addressing system protection strategy, which is conceptually distinct from the protection of individual network elements. As a result, the distinction between measures intended as part of system-wide defence and those aimed at local asset protection is not always clearly articulated, particularly under high-voltage and low-load operating conditions.

7.5.2 Identified Areas of Improvement on MEPSO Defence Plan

This subchapter highlights the identified areas of improvement regarding the MEPSO System Defence Plan. Chapter 8.3 lists the corresponding recommendations derived from this analysis.

1/ Expansion of analysed operating regimes and system stress scenarios

It is recommended to expand the scope of analysed operating scenarios in the next revision of the System Defence Plan to explicitly cover a wider range of system operating regimes, beyond classical underfrequency and system separation events.

In particular, the Defence Plan should include dedicated scenarios addressing:

» Low-load conditions combined with high renewable energy infeed and/or high import dependency, particularly during spring and autumn periods

» Operating regimes characterised by a reduced share of synchronous generation, such as situations dominated by wind, solar generation, or imports, resulting in altered frequency dynamics and reduced system inertia

» Operating conditions with high and low cross-border power transits, including seasonal summer and shoulder-period patterns

These scenarios should assess voltage behaviour, reactive power balances, OLTC operation, switching sequences, and the availability and effectiveness of preventive and corrective operational measures under such conditions.

Low-load and high-voltage operating conditions have become increasingly relevant in practice and represent a significant source of system stress. Explicitly addressing these regimes would strengthen the preventive character of the Defence Plan and improve the practical applicability of voltage deviation procedures under non-classical but increasingly frequent system states.

2/ Operationalisation of load-frequency defence measures at the distribution level

It is recommended to further operationalise load-frequency defence measures through their systematic implementation at the distribution level, supported by clearly defined feeder selection principles and structured communication arrangements between DSOs and the NDC.

The next revision of the Defence Plan should:

- Define the principles for feeder-level implementation of load-frequency defence measures at the distribution network level
- Specify the required signalling, status indication, and feedback from DSOs to the NDC during activation and restoration phases
- Clarify the operational interfaces and responsibilities between DSOs and the NDC during both activation of defence measures and subsequent system recovery

Strengthening the operational integration of distribution-level load-frequency measures would significantly improve their reliability and effectiveness during severe frequency disturbance scenarios.

3/ Review of industrial consumers included in under-frequency load-shedding schemes

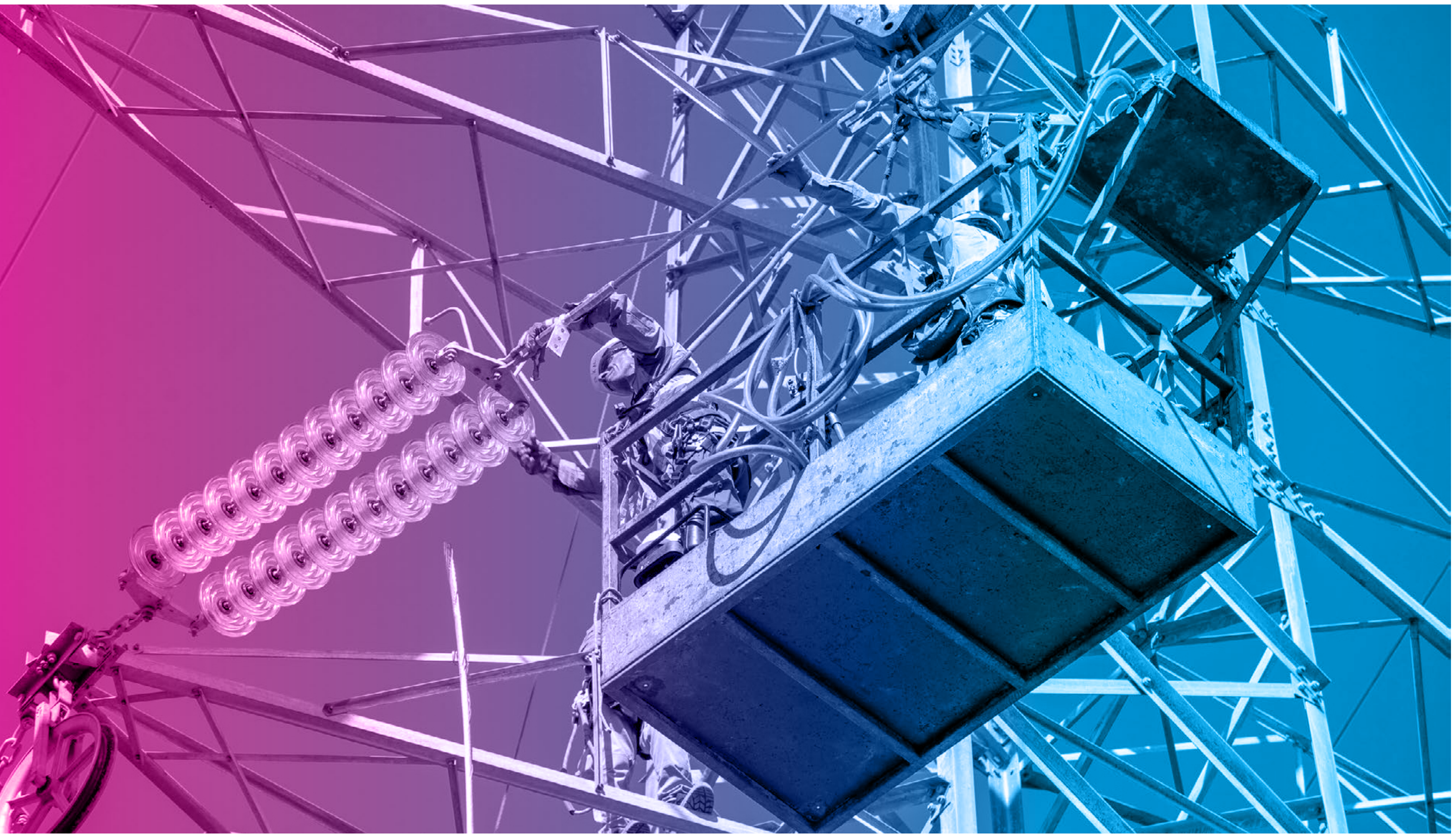
It is recommended to review and update the list of industrial consumers included in the underfrequency load shedding arrangements, with the objective of ensuring realistic, reliable, and operationally usable load-shedding contributions.

The review should take into account:

- The variability and predictability of industrial consumption profiles
- The actual availability of industrial load under different market and operating conditions
- The suitability of specific consumers for inclusion in automated versus manual load-shedding schemes

Based on this review, the Defence Plan should clearly distinguish between:

- Distribution-based automated load-shedding measures forming the primary defence layer
  - Transmission-connected industrial loads used as supplementary or last-resort measures



7.6 Next Steps and Measures Taken on Voltage Control in North Macedonia Since the 18 May 2025 Incident

In response to the increasing challenges related to high voltage levels and reactive power management, MEPSO has undertaken a set of targeted operational and technical measures aimed at improving voltage control within the transmission system.

Activation of Q-night mode on inverters of large PV power plants: pilot project in Oslomei and Novaci

One of the key measures implemented is the activation of the Q-night mode on inverters of large PV power plants connected to the transmission network. This approach enables PV plants, which are otherwise inactive during nighttime, to actively participate in reactive power management. By compensating for the reactive power generated by their connection cables and, where possible, absorbing additional reactive power from the grid, these units help reduce voltage levels during low-load periods. Initial results from pilot locations (such as Oslomej and Novaci) indicate a measurable improvement in the voltage profile, particularly during nighttime hours, confirming the effectiveness of this measure.

Testing the under-excitation operating mode of the CCGT TE–TO Skopje

In parallel, MEPSO has conducted testing of the under-excitation operating mode of the CCGT TE–TO Skopje to assess its capability to absorb reactive power from the system. Both simulation analyses and real-time testing confirmed that operating the plant in inductive mode helps reduce voltage levels at nearby substations (Skopje 4 and Skopje 5), particularly at the 400 kV level. This demonstrates the potential of conventional generation units to provide valuable reactive power support under high-voltage, low-load conditions.

Further operational measures

These activities were supported by coordinated operational actions, including adjustments of transformer tap positions and temporary modification of control modes (e.g. switching OLTC operation from automatic to manual where necessary), to ensure stable system behaviour during testing and avoid unwanted oscillations.

Overall, these measures represent important initial steps towards the active utilisation of both renewable and conventional generation units for voltage regulation. They also reflect MEPSO's transition towards a more dynamic and flexible approach to reactive power management in a system with increasing penetration of RES.

As part of the ongoing regulatory and technical developments, MEPSO is in the process of preparing an updated version of the North Macedonian Transmission Code, in alignment with the recently adopted Energy Law. Further details can be found in Chapter 8.1.

Within this process, it is expected that the provisions related to voltage control and reactive power support will be further aligned with European practices and relevant applicable legislation. The revised framework will aim to introduce clearer and more comprehensive requirements for all system users, particularly in the context of increasing RES integration.

A key direction of this update is the transition towards a more active and coordinated approach to voltage and reactive power management, ensuring the involvement of all relevant energy sector stakeholders. This includes transmission-connected generators, DSOs, and other network users, who are expected to play a more active role in providing voltage support and maintaining system stability.

Overall, these developments are expected to strengthen the regulatory basis for voltage control, enhance system flexibility, and support the secure operation of the transmission system under evolving operating conditions.

8 ACTIONS TAKEN AFTER THE INCIDENT IN NORTH MACEDONIA, ROOT CAUSES, RECOMMENDA-TIONS, AND NEXT STEPS

This chapter provides a structured overview of the actions and measures taken after the incident, the conclusions drawn therefrom, as well as recommendations and areas for improvement provided in order to strengthen operational reliability and voltage control in the SEE region.

- » Section 8.1 presents the root causes, contributing factors, and conclusions drawn from the incident.
- » Section 8.2 details the initial actions taken by MEPSO and ERC in response to the event, outlining the immediate steps implemented to address the situation.

The Expert Panel of this investigation has conducted a thorough analysis of this incident and identified several root causes and contributing factors. Recommendations and areas for improvement have been provided in order to strengthen operational reliability and voltage control in the SEE region.

- » Section 8.3 addresses the recommendations directly related to the principal causes of the incident.
- » Section 8.4 covers additional areas of improvement that, although not directly responsible for the blackout, are deemed important for future prevention and system security enhancement.

8.2 Root Causes, Contributing Factors, and Conclusions of the Incident

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

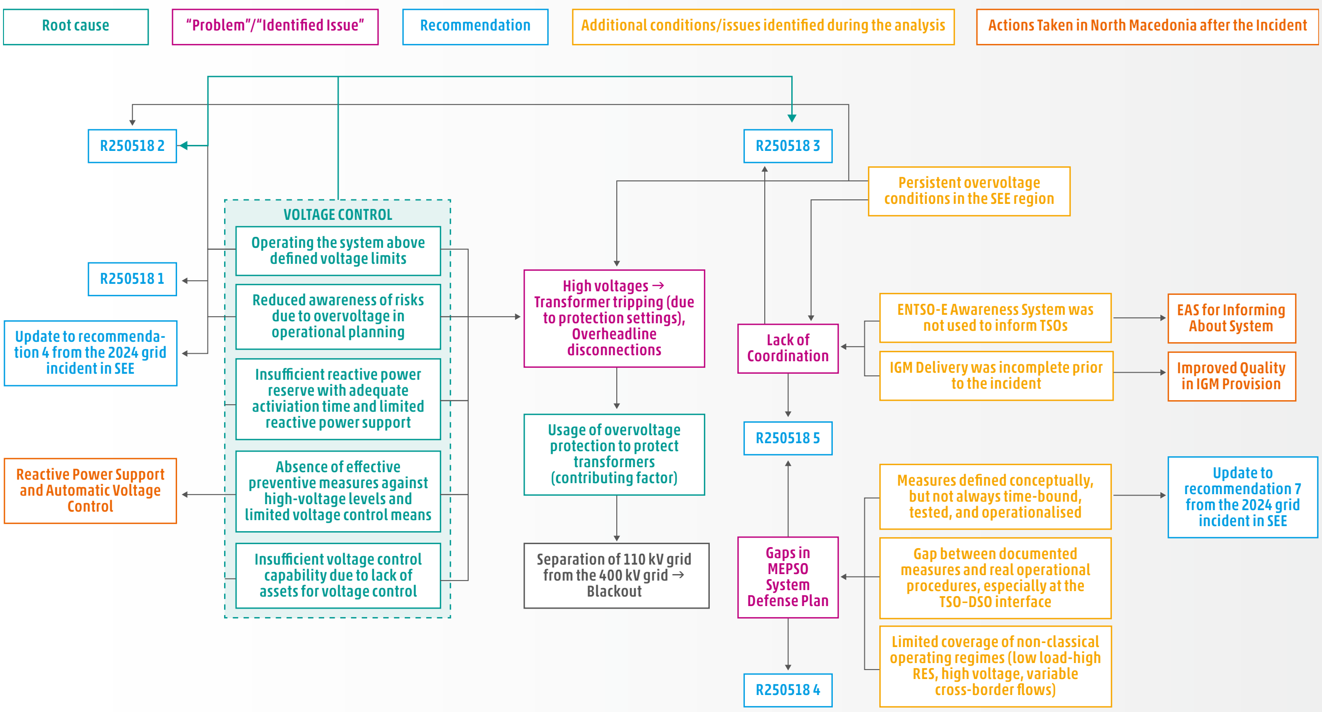


Figure 8.1: Rootcause Tree of 18 May 2025 Grid Incident

The root cause tree presented above serves as a concise summary of the sequence of events linked to the comprehensive root cause analysis undertaken for the incident. This section provides an overview of the factors that contributed to the event and presents the root causes identified by the Expert Panel:

1/ Operating the system above defined voltage limits

Prior to the event, the 400 kV network frequently experienced nighttime overvoltage conditions during spring periods with low demand and minimal active power flows, as highlighted in Chapter 7. With transmission lines connected but lightly loaded, the system injected an excess of reactive power, not compensated by other elements of the system, causing voltages at several 400 kV substations to rise above the normal operating range.

It is to note that such situations (overvoltage/excess of reactive power) had been occurring beforehand (as described in Chapter 3 and 7), but the blackout only occurred on a specific day when the circumstances most exacerbated the underlying issue.

2/ Reduced awareness of risks due to overvoltage operational planning

In the operational planning time frame, the available coordinated assessments did not flag violations, and the system was considered N-1 secure regarding line loadings. However, it was identified that all 400 kV nodes in the control area predicted to exceed acceptable operational voltage limits. As a result, voltage limit exceedances were the only indication of developing system vulnerability. No other indicators pointed to broader system stability degradation.

3/ Insufficient reactive power reserve with adequate activation time and limited reactive power support

The investigation concluded that overvoltage mitigation relied primarily on operational actions (e.g. disconnecting an internal 400 kV line), with limited utilisation of voltage control capabilities of system users (such as generators) and a lack of integrated network components with voltage control capability, such as shunt reactors.

4/ Absence of effective preventive measures against high-voltage levels[16] and limited voltage control means

The investigation found that only temporary actions were taken to mitigate recurrent high-voltage conditions (above 420 kV), including transformer protection setting adjustments and the disconnection of one internal 400 kV OHL, yet overvoltage still escalated into multiple 400/110 kV transformer trips. This shows that the operationally available countermeasuresand voltage-control means were not effective in containing high-voltage conditions.

5/ Insufficient voltage control capability due to lack of assets for voltage control

MEPSO's transmission system has no installed any assets for the means of voltage control installed. However, the installation of a shunt reactor is planned for 2027, as outlined in Chapter 7.4.2.

Point 6 was also identified by the Expert Panel as an operational decision that contributed to the incident.

6/ Usage of overvoltage protection to protect transformers (contributing factor)

As described in Chapter 3.2, MEPSO has installed overvoltage protection for transformers at the 400 kV level. Consequently, transformers are configured to disconnect when the overvoltage protection thresholds are reached.

During the event, several 400/110 kV transformers at different 400 kV substations tripped due to overvoltage conditions. At 04:59, this led to the separation between the 400 kV and 110 kV networks and caused a blackout of the 110 kV transmission network.

Therefore, the installation of the transformer overvoltage protection and the resulting progressive loss of the transformer are considered **contributing factors to the blackout of the 110 kV transmission network**.

16 Voltage levels above 420 kV.

8.2 Actions Taken in North Macedonia After the Incident

8.2.1 Actions Taken by the TSO MEPSO

Improved Quality in IGM Provision

Following the incident, MEPSO delivers IGMs regularly, in line with applicable standards, including systematic checks of voltage profiles and reactive power behaviour. From December 2025 to February 2026, MEPSO demonstrated a high level of quality in the delivery of their IGMs for both the DACF and D2CF processes, (Figure 8.2 and 8.3, provided by SEleNe CC).

During this period, MEPSO provided IGMs for 81 days for the DACF process and 80 days for the D2CF process. This consistent provision contributed positively to overall modelling quality and supported the subsequent processes carried out by SEleNe CC, including regional voltage and reactive power assessment.

DACF: Total Percent of Substitute MK IGMs (Dec 2025 - Feb 2026)

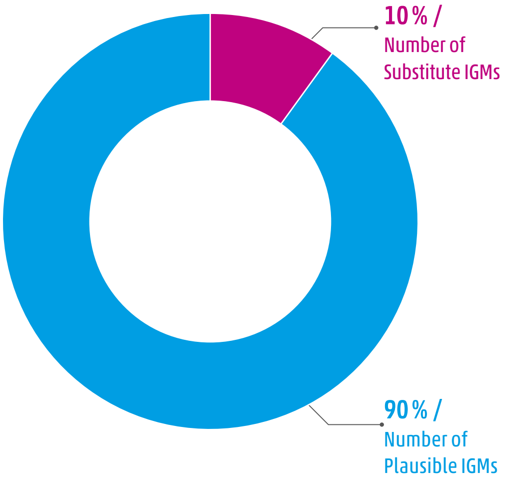


Figure 8.2: Total percentage of IGMs delivered by MEPSO to SEleNe CC in the DACF process (Dec 2025-Feb 2026)

IDCF: Total Percent of Substitute MK IGMs (Dec 2025 - Feb 2026)

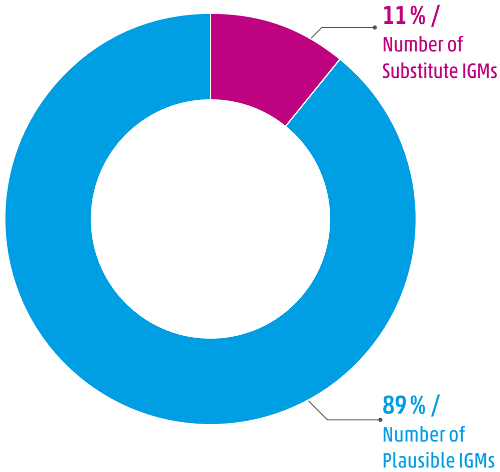


Figure 8.3: Total percentage of IGMs delivered by MEPSO to SEleNe CC in the IDCF process (Dec 2025-Feb 2026)

Reactive Power Support and Automatic Voltage Control

As mentioned in Chapter 7, the results of the regional feasibility study on voltage support in the SEE region led to a concrete investment: the procurement of a 150 MVAr variable shunt reactor to strengthen voltage control and system stability.

MEPSO further notes that the shunt reactor implementation is ongoing and should be finalised by 2027. The device will be equipped with automatic control functionality for voltage regulation.

Alongside the hardware measure, the Macedonian NRA and MEPSO state that, through amendments to relevant secondary legislation and the reactive-power tariff framework, the automatic application of appropriate generator reactive power control modes will be enabled where technically feasible.

EAS for Informing About System States

Since the incident occurred, MEPSO has used the EAS systematically to inform all TSOs about their system state.

8.2.2 Actions Taken by the North Macedonian NRA (ERC)

After the incident, the NRA – the Energy, Water Services and Municipal Waste Management Regulatory Commission of the Republic of North Macedonia (ERC) – took several measures. ERC conducted monitoring activities and inspections at the TSO and DSO premises, discussing the urgent actions required and the importance of strengthening cooperation with DSO.

In November 2025, during the adoption of the secondary act, ERC approved a new tariff system for the transmission of electricity. Under this system, electricity producers connected to the electricity transmission system are required to pay compensation for excessive reactive power only when they are taking active power, unless the TSO requires them to consume reactive energy.

Furthermore, in the decision of 5 December 2025 on setting the transmission tariff for 2026, ERC required the TSO to ensure full technical and personnel readiness to implement the obligations under the Energy Law. This means MEPSO must urgently upgrade and adjust their SCADA system and ensure the availability of qualified professional staff.

On 23 February 2026, ERC adopted a new Rulebook on Licensing, which introduced a requirement that temporary generation licenses can only be extended if the generator submits proof from the TSO confirming the completion of the required testing stages. The goal is to ensure that new generators conduct compliance testing promptly.

8.3 Recommendations

8.3.1 Recommendation from Past Incidents (Linked to Root Cause)

Change needed (in bold from Recommendation 4 from the 2024 grid incident in SEE: Develop KPIs for voltage stability risk and risk of rapid voltage change

Description	Analysis of the possibility to identify, and if possible, the development of a guideline for indicators to detect potential reduced voltage stability and risk of **rapid voltage change**.		
Justification	Any indication that the grid is in a weakened state can create a sense of urgency to act before any other incident occurs, and as such this might avoid **rapid voltage changes**, if actions can be taken sufficiently fast 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

Change needed (in bold) for Recommendation 7 from the 2024 grid incident in SEE: Voltage and reactive power assessment

Description	ENTSO-E to develop a guideline of best practices on voltage support measures and studies on voltage stability. TSOs to assess that a plan for realising sufficient voltage support measures is in place, **remains adequate, and is updated as necessary**. Where relevant, these measures should be added to the TYNDP and national grid development plans.		
Justification	Having sufficient MVAr support measures will help avoid voltage collapse **or fast overvoltage-induced cascading disconnections in a weakened grid**.		
Delivery Owner	TSOs and voltage experts in ENTSO-E StG Resilient Operation	Priority	High

8.3.2 New Recommendations on Voltage Control for the SEE Region (Linked to Root Cause)

New rec R250518_1: Systematically monitor voltage violations beyond the defined operational limits in the SEE region

R250518_1	**Systematically monitor voltage violations (between 400 kV and 110 kV level) beyond the defined operational limits in the SEE region**		
Deliverable	Implementation of a monitoring of voltages and reactive power flows, particularly with regard to the recurrent violation of voltage thresholds in the SEE region		
Justification	The voltage limits in the SEE region are currently not subject to coordinated monitoring, which is essential given the violationof operational voltage limits in per applicable requirements.		
Delivery Owner	ENTSO-E, TSOs of the SEE region	Priority	High

New rec R250518_2: Develop action plan to improve the overvoltage situation (above 420 kV) in the SEE region

R250518_2	**Develop action plan to improve the overvoltage situation (above 420 kV) in the SEE region**		
Deliverable	ENTSO-E to develop an action plan for the SEE region with the active participation of the TSOs, DSOs, NRAs, and RCCs of the region. The action plan should outline the trajectory and steps needed to design a power system capable of continued operation within prescribed voltage ranges -- in this case particularly to minimise the occurrence of overvoltages. In this regard, the plan should consider an analysis of: » Regular reporting of voltage incidents per the existing ICS methodology » Potential updates of the ICS methodology » A review of overvoltage protection philosophy » Identification of short-, medium-, and long-term coordinated operational measures » Appropiate voltage control by inverters across all voltage levels: TSOs, DSOs and SGUs operating power-generating facilities to ensure that generators use an appropiate voltage control mode, replacing the use of fix power factor on RES where still applicable, and being actively supported by NRAs to achieve this objective. » Assessment of structural/infrastructure investment measures to reduce high voltage levels in the medium and long term to be designed by relevant parties. » Evaluation of the role of renewable generation, low-load situations, and cross-border exchanges in contributing to high voltage conditions. » Consideration of improved regional coordination with the support of RCCs in the operational planning phase (linked to R250518_7) » Review and update (if necessary) the bilateral system operation agreements, ensuring that the needed coordinated measures are formally agreed on among the SEE region's TSOs » Potential involvement of Energy Community Secretariat		
Justification	To ensure that the system is operated within the voltage ranges in line with the applicable requirements (or to the extent possible). The action plan should propose operational, regulatory, and infrastructure investment measures to mitigate high voltage levels in the short, medium, and long term.		
Delivery Owner	TSOs of the SEE region, Energy Community Secretariat	Priority	High

New rec R250518_3: Deliverable: Alignment of SEE Region TSOs on operational measures for ensuring voltage control

R250518_3	**Alignment of SEE region TSOs on operational measures to ensure voltage control**		
Deliverable	» Establish a proper working mode for future-proof coordination on voltage control measures among TSOs in the SEE region, with support from ENTSO-E » Continue the ongoing work of the ENTSO-E RG CE Project Group on Voltage Control in the SEE Region and implement the outcomes defined by the PG		
Justification	TSOs in the SEE region should establish an appropriate structure to align operational planning on measures for ensuring voltage control, potentially supported by the RCC (Selene). This particularly involves enhancing voltage and reactive power flow calculations at the RCC level to extend TSOs' voltage control not only in real time but also in intraday and day-ahead process and on the regional level.		
Delivery Owner	TSOs of the SEE region, RCC (SEleNe CC), ENTSO-E	Priority	High

8.3.3 Recommendations for MEPSO on System Defence Plan (Not Linked to Root Causes)

During the incident investigation, it became evident that recommendations should address not only the root causes but also areas for MEPSO to update their System Defence Plan. Accordingly, MEPSO conducted a holistic assessment, which was reviewed by the Expert Panel, to identify aspects requiring improvement beyond voltage control and the root causes of the incident.

R250518_4	Expand analysed scenarios to include low-load/high-RES		
Deliverable	Expand the analysed Defence Plan scenarios to explicitly include low-load operating conditions with high renewable energy infeed, reduced synchronous generation, and low system inertia, in order to assess voltage behaviour, reactive power management, and system dynamics under increasingly frequent non-classical operating regimes.		
Justification	These operating conditions are no longer exceptional and introduce specific voltage control, reactive power, and fast frequency dynamics challenges that are not adequately addressed by Defence Plan scenarios focused primarily on underfrequency events and system separation.		
Delivery Owner	MEPSO	Priority	Medium

R250518_5	Operationalise LFDD and restoration procedures at the distribution level		
Deliverable	Translate documented load-frequency defence and restoration automatic measures into clearly defined, feeder-level operational procedures at the distribution network level, ensuring consistent implementation during activation and restoration phases.		
Justification	Without practical feeder-level procedures and predefined restoration sequences, load-frequency defence measures remain largely theoretical and cannot be reliably or uniformly applied under real-time emergency conditions.		
Delivery Owner	MEPSO	Priority	Medium

R250518_6	Define clear responsibilities, signalling, and feedback between DSOs and National Dispatching Centre		
Deliverable	Define clear operational responsibilities, signalling requirements, and real-time feedback mechanisms between DSOs and the National Dispatching Centre (MEPSO) to support coordinated activation, monitoring, and restoration of defence measures.		
Justification	Lack of clarity regarding responsibilities and absence of structured signalling and feedback increase the risk of delayed, uncoordinated, or incomplete actions during disturbances, reducing the effectiveness of defence and restoration processes.		
Delivery Owner	MEPSO, Macedonian DSOs, ERC	Priority	Medium

R250518_7	Strengthen system-level protection logic		
Deliverable	Develop a dedicated system-level protection strategy, distinct from equipment protection, with coordinated protection settings and clearly defined implementation timelines to support stable islanded operation of the 110 kV network following separation from the 400 kV system. This should be incorporated into the System Defence Plan and should be revised every two years to remain aligned with any changes in the system.		
Justification	In the absence of a coordinated system protection concept, protection actions may remain fragmented and asset-focused, limiting the ability of the 110 kV network to maintain stability and controlled operation during islanding and restoration scenarios.		
Delivery Owner	MEPSO	Priority	Medium

8.3.4 Relevant Recommendations from the 28 April 2025 Incident Final Report on the System Defence Plan

The following two recommendations concerning the System Defence Plan are drawn from the final report of the 28 April 2025 incident and are also relevant to this incident. These three recommendations should therefore also be applied by MEPSO and are linked to the individual recommendations established for MEPSO above.

- R250428_15 – DER-aware dynamic LFDD: Recommends updating LFDD schemes to account for modern transmission networks → linked to R250518_5
- R250428_16 – Defence observability and readiness (data and drills) → linked to R250518_6
- R250428_17 – Modernised System Defence Plan for fast voltage deviations: Recommends that TSOs modernise their system defence plans to address fast voltage-related situations → linked to R250518_4

8.4 Further Focus Areas and Next Steps

Alignment of SEE Region TSOs on operational measures for ensuring voltage control

Currently, the RGCE PG Voltage Control in the SEE region focuses on improving coordination of voltage management and cross-border reactive power flows in southeast Europe.

The group focuses on systematically collecting data on voltages and cross-border reactive power flows, supported by visualisations across different time frames for the entire SEE region. These visualisations help evaluate recent regional voltage conditions and trends, and improve understanding of underlying patterns in regional reactive power flows. They form the basis for technical discussions within the PG Voltage Control in SEE, aimed at enhancing TSOs' operational practices for managing voltage control in SEE, especially those affecting neighbouring TSOs.

PG Voltage Control in SEE also reports on the assessment of existing TSO agreements related to voltage control, including each TSO's reporting of voltage conditions and identified issues with voltages and reactive power flows, along with proposed short- and long-term solutions for each TSO.

All reporting and data collection are structured to support TSOs' development departments to facilitate grid development plans for voltage control in the SEE region.

The PG Voltage Control in SEE is reviewing international operational procedures and tools to identify areas for improvement that could facilitate better voltage control in SEE.

During the groups work, several tools and processes were identified as potentially useful for improving voltage control:

- A new version of the EAS currently being developed will provide improved regional voltage visibility
- Enhanced voltage and reactive power flow calculations at the RCC level to support TSOs' voltage-control in real time by having a better awareness of the voltage situation in intraday and day-ahead processes on a regional level
- Improved coordination of voltage management with capacity calculation procedures

The results of this project will be used to implement recommendations R250518_1, R250518_2, and R250518_3.

Review of the ENTSO-E best practices document on overvoltage protections

The ENTSO-E application guideline for protections describes the use of overvoltage protection for reactive power compensation assets, while its application for other use cases (e.g. protect network branch elements) is only briefly mentioned.

Within WG Protection Equipment, it is recommended to review and, where necessary, update the existing ENTSO-E best practices document[17] on overvoltage protection in light of lessons learned from this incident. All ENTSO-E members should also reassess their policies and settings for installing overvoltage protections in network branch elements, ensuring alignment with any revised guidelines.

Evaluation of possible changes needed in next amendments of SOGL (SOGL 2.0) concerning operational voltage limits

The Expert Panel urges all European TSOs to respect all operational security limits in operational security assessments as defined in Article 25 of SOGL. In particular, identified voltage limit violations should be addressed with appropriate criticality. Necessary remedial actions should be undertaken if the results in operational planning (e.g. day ahead forecast) identify exceeding operational voltage limits according to SOGL.

Furthermore, the Expert Panel encourages the TSOs, beside investigating the SEE-specific structural violation of voltage limits and the development of the action plans referred to in R250518_2, to also jointly evaluate the appropriateness of the current SOGL provisions related to the concept of maintaining system voltages within-operational voltage limits. Should improvements to the applicable rules be identified, they should be considered during the amendment of the SOGL.

17 **Best Protection Practices for HV and EHV AC-Transmission Systems of ENTSO-E Electrical Grids**.

LIST OF ABBREVIATIONS

AAA	Adequacy Assessment Agent
ACER	Agency for the Cooperation of Energy Regulators
CCC	Coordinated Capacity Calculation
SA CE	Synchronous Area Continental Europe
CEST	Central European Summer Time
CGES	Transmission System Operator of Montenegro
CGM	Common Grid Model
CSA	Coordinated Security Analysis
CW	Calendar Week
CZC	Cross Zonal Capacity
DCC	Demand Connection Codes
DSO	Distribution System Operator
DSO CC	Distribution System Operator Control Center
EAS	ENTSO-E Awareness System
EC	European Commission
EMS	Transmission System Operator of Serbia
ENTSO-E	European Network of Transmission System Operators for Electricity
ESO	Transmission System Operator of Bulgaria
EU	European Union
HOPS	Transmission System Operator of Croatia
HPP	Hydro Power Plant
ICS	Incident Classification Scale
IGM	Individual Grid Model
IOP	Interoperability Test
IPTO	Transmission System Operator of Greece
IT	Information Technology
KOSTT	Transmission System Operator of Kosovo[18]
LT	Loss of Tools
MEPSO	Transmission System Operator of North Macedonia
NC ER	Network Code on Emergency and Restoration
NCC	National Control Center
NOS BiH	Transmission System Operator of Bosnia and Herzegovina
NRA	National Regulatory Agency
NTC	Net Transfer Capacity
OHD/OHL	Overhead Line
OPC	Operational Planning Coordination
OST	Transmission System Operator of Albania
OV	Overvoltage
PPM	Power Plant Module
PV	Photovoltaic (Power Plant)
RC	Remaining Capacity
RCC	Regional Coordination Center
RfG	Requirements for Generators
RIAR	Post-Operation and Post-Disturbances Analysis
RRC	Regional Coordination Centre
RSC	Regional Security Centre
SAFA	Synchronous Area Framework Agreement
SAM	Synchronous Area Monitor
SCC	Security Coordination Center (RCC in Belgrade)
SCADA	Supervisory Control and Data Acquisition
SCADA/EMS	Supervisory Control and Data Acquisition / Energy Management System
SEE	South-East Europe
SEE MG	South-East Europe Maintenance Group
SEleNe CC	Regional Coordination Center in Thessaloniki
SOFT	Switch on fault protection
SOGL	System Operation Guideline
SPGM	Synchronous Power Generating Modules
SS	Substation
STA	Short-Term Adequacy
SVC	Static VAR Compensator
TEIAŞ	Transmission System Operator of Turkey
TEL	Transmission System Operator of Romania
TIE	Tie-Lines/Interconnection
TPP	Thermal Power Plant
TR	Transformer
TSCNET	Regional Coordination Center in Munich
TSO	Transmission System Operator
UPS	Uninterruptible Power Supply
UTC	Coordinated Universal Time
WOPT	Weekly Operational Planning Teleconference

18 This designation is without prejudice to positions on status, and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo declaration of independence.

DRAFTING TEAM

Ana Cigaran Romero	ENTSO-E (Expert Panel convenor)
Nora Filipczak	ENTSO-E
Rory McBride	50Hertz
Jonas Derpmann	Amprion
Dieter Binon	ELIA
Nemanja Bralušić	EMS
Nikos Soultanis	IPTO
Igor Stojanovski	MEPSO
Elena Ackoska	MEPSO

Vanco Sahpaski	MEPSO
Mario Xhyra	OST
Rafal Kuczyński	PSE
Predrag Simić	SCC
Nikola Bošković	SCC
Maria Katsiantoni	SEleNe CC
Marco Dijkstra	TenneT NL
Roberto Puddo	Terna
Strahinja Ljiljak	Transnet BW

EXPERT PANEL MEMBERS

Ana Cigarán Romero	ENTSO-E (Expert Panel convenor)
Nora Filipczak	ENTSO-E
Rafal Kuczyński	ENTSO-E (RG CE convenor)
Rory Mcbride	50Hertz
Georgios Antonopoulos	ACER
Uros Gabrijel	ACER
Domen Kodric	ACER
Alina Poanta	ANRE
Marco Pasquadibisceglie	ARERA

Anna Carlen	EI
Elena Markova	ERC
Elena Kolevska	ERC
Pavel Simoncik	ERU
Rosen Ulinski	ESO EAD
Elena Ackoska	MEPSO
Igor Stojanovski	MEPSO
Mario Xhyra	OST
Luca Ortolano	Terna

Publisher

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info@entsoe.eu
info@acer.europa.eu

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