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POWER SYSTEM OPERATION MANAGEMENT CHALLENGES CAUSED BY HIGH-VOLTAGE IN THE SOUTH-EASTERN EUROPEAN REGION

Samo Gašperič[1,3], Andrej Vrbinc[1], Tomaž Tomšič[1], Franc Kropec[1], Marijan Borić[2], Zvonimir Brleković[2], Zoran Bunčec[2], Tomislav Vuković[2]

Abstract: One of the goals of Transmission system operators (TSOs) is to maintain the voltage profile of the transmission network within acceptable voltage ranges defined in Commission Regulation (EU) 2017/1485, which ensures safe and reliable operation of the transmission system. Following the successful completion of the SINCRO. GRID project in September 2022, the Slovenian (ELES) and Croatian transmission system operator (HOPS) have secured their own sources of reactive power for voltage regulation, in addition to the operating production units. During the SINCRO.GRID project planning phase, it was estimated that these devices would be sufficient to maintain the voltage profile within acceptable limits in the transmission network of both operators. However, a growing trend of high reactive power flows has been observed in European transmission networks connected to the south-eastern region, leading to overvoltage's in the area. Due to the increasing number of incidents where transmission network voltages exceed acceptable levels, this issue has been given high priority within ENTSO-E. In this paper, we will analyse the voltage conditions in the Slovenian and Croatian transmission networks, identify the causes of excessive voltages, and present potential strategies to reduce the number of operating hours during which voltages remain too high.

Keywords: electric power system, transmission system, voltage profile, reactive power flows

INTRODUCTION

The change in the structure of electricity generation and cross-border power flows indicates that the need for reactive power sources by transmission system operators (TSOs) is different from the period when electricity generation relied on system power plants that predictably produced both active and reactive power on a large scale. With the help of the European project SINCRO.GRID, ELES and HOPS have installed compensation devices:

- 220 kV static var compensator (SVC) in SS Konjsko, in the range of +70/- 250 Mvar,
- 220 kV variable shunt reactor in SS Melina, in the range of 70-200 Mvar,
- 220 kV variable shunt reactor in SS Mraclin, in the range of 30-100 Mvar,
- 400 kV variable shunt reactors (VSR) in substation (SS) Divača and SS Cirkovce, each in the range of 70-150 Mvar,
- 400 kV mechanical switch condenser with damping network (MSCDN) in SS Divača, in the range of 100 Mvar,
- 400 kV static synchronous compensator (STATCOM) in SS Beričevo, in the range of +/- 150 Mvar,

these significantly contribute to maintaining the voltage profile in the Slovenian 400 kV and Croatian 220 kV networks.

In the last four years, the voltage issues faced in the Slovenian Croatian transmission networks before 2020 has been indicated. In the papers [1-3] and studies [4, 5, 13], experts analysed the causes of excessive voltages and proposed solutions for effective management of the conditions in the transmission network, which led to the SINCRO.GRID project.

The current problem of high voltages in the ELES and HOPS transmission networks is often a result of low loads on the transmission networks in Southeast Europe and their inability to compensate for local reactive power. Voltage profiles in both ELES and HOPS are approaching the upper limit values, which are exceeded for certain periods, such as longer holidays. This is presented in detail in the second chapter of the paper.

The issue of uncoordinated reactive power excesses in transmission networks is already being addressed by working groups [6] under the auspices of the European Network of Transmission System Operators for Electricity (ENTSO-E). Each TSO's task is to prepare for scenarios in a timely manner, especially those where the situation cannot be managed with the available control devices (generators, control transformers, compensation devices) within the entire electric power system (EPS).

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[1] *ELES d.o.o., Slovenia*
[2] *HOPS Plc., Croatia*
[3] *Correspondence email: samo.gasperic@eles.si*

Given that an increasing number of distributed electricity sources with limited reactive power production are planned in Europe, and that we do not expect a significant increase in the capacity of compensation devices in the transmission networks of neighbouring TSOs in the south-eastern European (SEE) region in the near future, we are actively studying various options for containing excesses of permitted voltages.

1. REGULATION ON VOLTAGE AND REACTIVE POWER LIMITS IN ENTSO-E

In the ENTSO-E transmission networks, the requirements for voltage and reactive power management are precisely defined, as these quantities are crucial for the stable and efficient operation of the EPS. The regulation stipulates that transmission system operators must ensure appropriate voltage profiles by managing reactive power flows. Voltage limits are typically defined in relation to the nominal value, with minor deviations allowed depending on the voltage level and national regulations.

Ensuring adequate reactive power flow is essential for maintaining voltage within prescribed limits, preventing voltage drops, and improving the efficiency of the transmission system. The European Commission (EC), through the Network Code on Requirements for Grid Connection (RfG [7]), sets requirements for generators, system operators, and large consumers regarding reactive power production. These requirements include obligations related to the operation of synchronous generators, the use of compensation devices (such as capacitor banks and shunt reactors), and advanced control systems.

In addition to European regulations, individual countries have their own regulations that set specific requirements for voltage and power factor regulation at different voltage levels. The aim of these measures is to ensure the efficient operation of the power system and reduce losses, as well as the negative impacts on equipment and end users.

1.1. Summary of SO GL on Prescribed Operating Voltage Limits

The SO GL [8] document issued by the EC, states in Chapter 2, Articles 27-29 that each TSO shall, in accordance with Article 18 [8], endeavour to ensure that voltages remain within the prescribed limits during normal operation. The prescribed operating limits for steady-state voltages are provided in Table I.

Table I: Steady-state voltage limits [8]

Voltage level [kV]	Voltage range	
	SO GL [8]	
	Min	Max
	[kV]	[kV]
220	198	246
400	360	420

If the voltage at the connection point exceeds the prescribed limits, system operators must take measures in accordance with Article 22(c) of the SO GL [8] to restore the voltage to the prescribed range. To effectively manage reactive power, transmission system operators may utilize all available resources within their control area, including blocking automatic transformer regulation, reducing voltage, and disconnecting consumers in the event of undervoltage. When determining voltage regulation measures, system operators shall coordinate with significant network users, distribution system operators, and neighbouring transmission systems. If necessary, they may also require distribution system users to implement specific measures to support the stability of the transmission system.

In accordance with the national regulations and standard transmission system operation practices across the EU, HOPS has the ability to utilize cost free voltage regulation services from generation units operating within the mandatory power factor range of $-0.95 \leq \cos\varphi \leq +0.95$. This capability enables continuous voltage support without the need for additional contractual arrangements or compensation within the defined operational limits.

2. VOLTAGE ANALYSIS IN ELES'S AND HOPS'S TRANSMISSION NETWORK

2.1. Voltage Analysis in the 400 kV Network of Slovenia

The analysis of voltage conditions in the Slovenian transmission network was conducted for all nodes—SSs. The analysis of voltage conditions for the 400 kV and 220 kV voltage levels is presented separately. The input data consist of measured voltage values with an hourly resolution. The analysis covers a five-year period, from the beginning of 2020. to the end of 2024.

Figure 2 shows box plots (quarterly diagrams) of voltage measurements on 400 kV busbars of SSs in the Slovenian transmission network over the five-year period from 2020 to 2024. Since all SSs have dual-system busbars, the average voltage values of both busbar systems are presented. If one busbar was de-energized, only the voltage values of the operational busbar were considered. Umax,ICS represents the upper permissible voltage limit according to regulations [8], which is set at 420 kV for the 400 kV level.

Overvoltages were more pronounced in 2020, when electricity consumption significantly decreased across the entire ENTSO-E area due to the COVID-19 pandemic. In 2021, no overvoltages were detected, which we attribute to the installation of new compensation devices as part of the SINCRO.GRID project [10].

After 2021, an increasing voltage trend emerged, particularly in 400 kV nodes in the south of Slovenia. The

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primary cause of this voltage increase is the large flows of reactive power from the southeastern region, entering the Slovenian network from the Croatian transmission system. These flows could not be fully compensated during short periods (e.g., during the International Workers' Day holidays and New Year's holidays), even with all available compensation devices and operating generation units.

The trend of worsening voltage conditions is particularly noticeable at SS Krško and SS Maribor. Since SS Cirkovce and SS Maribor are electrically close, significant changes at one node affect both. At the SS Divača, voltages are regulated using a 400 kV VSR (70–150 Mvar) and by adjusting the target flow with a phase-shifting transformer.

In 2024, the number of anomalies exceeding the sample's maximum value increased significantly across all nodes compared to previous years, indicating reduced control over voltage fluctuations in the network. No data is available for the Cirkovce substation for 2020 and 2021, as the construction of the 400 kV switchyard at Cirkovce was in progress.

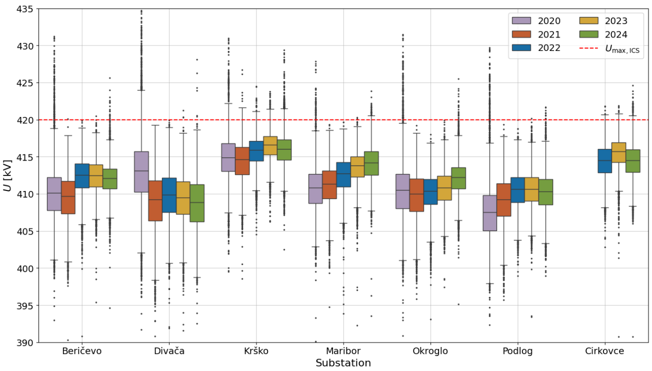

Figure 2: Voltage Diagram at the 400 kV Level by SSs (2020-2024).

The bar chart in Figure 3 shows the percentage of time during which voltages on the 400 kV busbars exceeded the permissible limit Umax,ICS. While this information is not clearly visible in the quarterly charts, it is crucial for accurately illustrating these violations. It should be noted that the voltages shown represent hourly averages and do not account for rapid fluctuations occurring at the second or minute level.

The voltage increases shown in Figure 2 are also reflected in the number of average voltage values exceeding Umax,ICS. The highest voltages were recorded at the SS Krško, where voltage levels exceeded the permissible limit for more than 3.5% of the time in 2024. Overvoltages at SS Krško were also reflected, to an almost equal extent, at the SS Cirkovce. In both cases, the number of exceedances increased by more than 3.5 times compared to 2023.

At the SS Maribor, the number of exceedances rose to a level approximately equal to that observed before the installation of compensation devices. Overvoltages increased across all substations, with voltage control at the SS Divača being the most effective due to the presence of compensation devices and the assistance of a phase-shifting transformer.

The voltage profile in the transmission network is influenced by several factors, the key ones being electricity consumption (line load), generation, and cross-border reactive power flows. Since electricity consumption varies throughout the day, week, and season, gaining a broader insight into voltage conditions is essential.

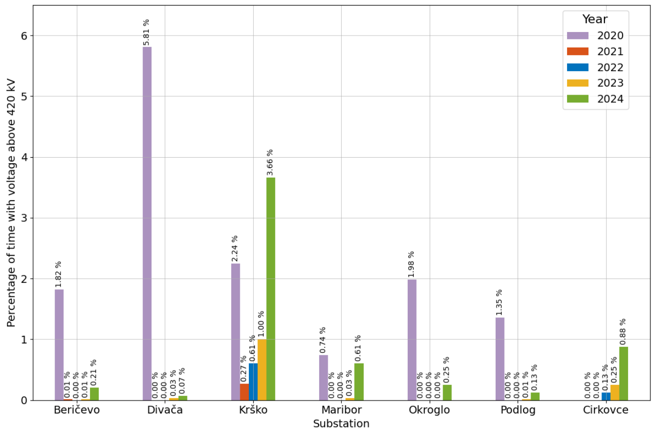

Figure 3: Percentage of Operating Time Above Permissible Voltage by SSs at the 400 kV Level (2020–2024).

2.2. Voltage Analysis in the 400 kV Network of Croatia

HOPS operates a 400 kV, 220 kV, and 110 kV transmission network, interconnected with four neighboring TSOs: ELES (Slovenia), MAVIR (Hungary), EMS (Serbia), and NOSBIH (Bosnia and Herzegovina). Due to its geographical position, HOPS is particularly well connected with NOSBIH, which influences power flows and voltage management in the Croatian grid, both positively and negatively.

To enhance voltage stability and minimize cross-border impacts, HOPS has invested in compensation devices that enable effective reactive power management within its grid. Voltage regulation in Croatia is primarily handled by generators, transformers, and compensating devices. However, since most generators are connected to the 220 kV and 110 kV networks, the 400 kV system lacks sufficient reactive power support, leading to challenges in maintaining a stable voltage profile.

As part of the SINCRO.GRID project, a coordinated systematic voltage regulation strategy was introduced to address significant variations in voltage, especially at the 400 kV and 220 kV voltage level. These measures significantly improve voltage control within the Croatian grid while ensuring minimal adverse effects on neighbouring transmission networks.

The analysis of voltage conditions in the Croatian transmission network was conducted for all nodes SS.

The analysis of voltage conditions for the 400 kV and 220 kV voltage levels is presented separately. The input data consists of measured voltage values with an hourly resolution. The analysis covers a five-year period, from the beginning of 2020 to the end of 2024.

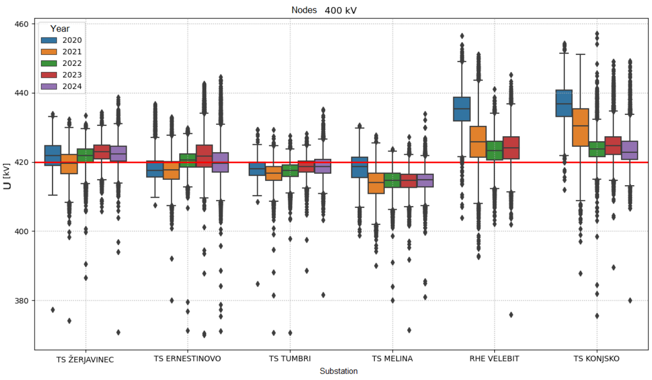

Figure 4: Voltage Diagram at the 400 kV Level by SSs in HOPS (2020–2024).

Figure 4 shows voltage measurements on 400 kV busbars of SSs in the Croatian transmission network over the five-year period from 2020 to 2024. The upper permissible voltage limit according to regulations [8] is set at 420 kV for the 400 kV level.

After 2021, a slightly increasing voltage trend emerged in 400 kV nodes in the northern part of Croatia. In the southern part of Croatia, although it significantly decreased after the SINCRO.GRID project, the voltage trend still remains high, and it still remains above the expected values. The primary cause of this voltage increase after 2021 is intense RES integration at DSO and TSO level in combination with large flows of reactive power from the SEE region, entering the Croatian network from the Bosnian transmission system. These flows could not be fully compensated during short periods, even with all available compensation devices and operating generation units.

The trend of slight worsening voltage conditions after 2021 is noticeable at SS Žerjavinec, SS Tumbri and SS Ernestinovo. Since SS Žerjavinec and SS Tumbri are electrically close, significant changes at one node affect other as well.

The bar chart in Figure 5 shows the percentage of time during which voltages on the 400 kV busbars exceeded the permissible limit Umax,ICS. While this information is not clearly visible in the quarterly charts, it is crucial for accurately illustrating these violations. It should be noted that the voltages shown represent hourly averages and do not account for rapid fluctuations occurring at the second or minute level.

The highest voltage conditions were recorded in southern part of Croatia especially at the RHPP Velebit and SS Konjsko which are electrically very close to border with SEE region.

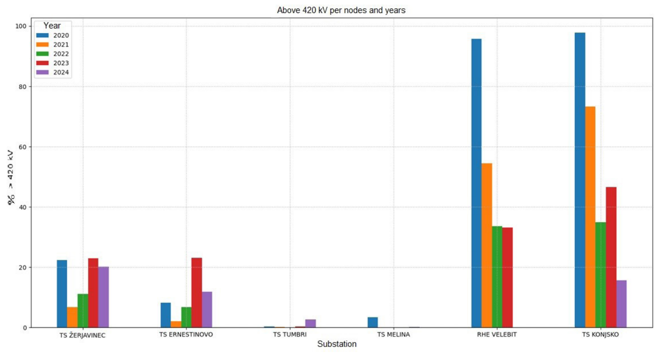

Figure 5: Percentage of Operating Time Above Permissible Voltage by SSs at the 400 kV (2020–2024).

2.3. Voltage Analysis in the 220 kV Network of Slovenia

Figure 6 presents voltage levels at the 220 kV level for the period 2020–2024. Voltage increases at the 400 kV level also impact 220 kV voltages. SS Krško does not have 220 kV busbars, and SS Cirkovce dismantled its 220 kV system in 2020, replacing it with a 400 kV system, so no data is available from 2021 onwards. At the 220 kV level, voltages have been rising across the transmission network since 2021. Compared to the 400 kV level, there are no significant exceedances of Umax, ICS which is 245 kV at the 220 kV level. The highest voltages occur at the SS Kleče and SS Divača, where maximum values reach the upper permitted limit. However, at the 220 kV level, maximum measured values are more constrained within the statistical deviation than those at the 400 kV level.

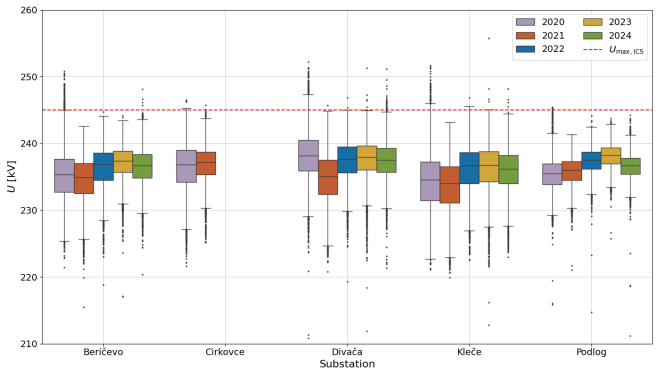

Figure 6: Voltage Diagram at the 220 kV Level by SSs (2020–2024).

2.4. Voltage Analysis in the 220 kV Network of Croatia

Figure 7 presents voltage levels at the 220 kV level in the form of quarterly diagrams for the period 2020–2024. At the 220 kV level, voltage conditions are significantly better, primarily because all of the SINCRO.GRID compensation devices were connected at this voltage level. The only exception is the 100 Mvar shunt reactor at SS Ernestinovo, which is connected at the 110 kV level and was installed prior to the SINCRO.GRID project. Since 2021, voltages at the 220 kV level have shown a slight upward trend across the transmission network. Compared to the 400 kV level, there have been no significant exceedances of Umax,ICS, which is set at 246 kV for the 220 kV level.

The highest voltage values are recorded at HPP Zakučac, HPP Orlovac, and SS Bilice, where values approach the upper permitted limit. These substations are located close to the southeastern region. A deviation of higher voltage values was observed at SS Mraclin in 2024, caused by the unavailability of the shunt reactor due to substation reconstruction works at the 220 kV voltage level.

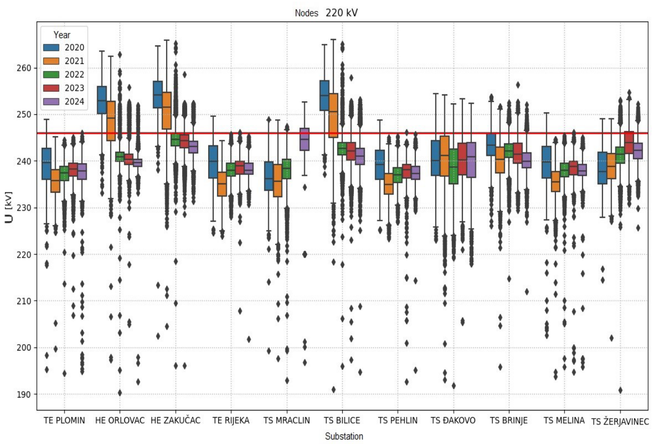

Figure 7: Voltage Diagram at the 220 kV Level by SSs in HOPS (2020–2024).

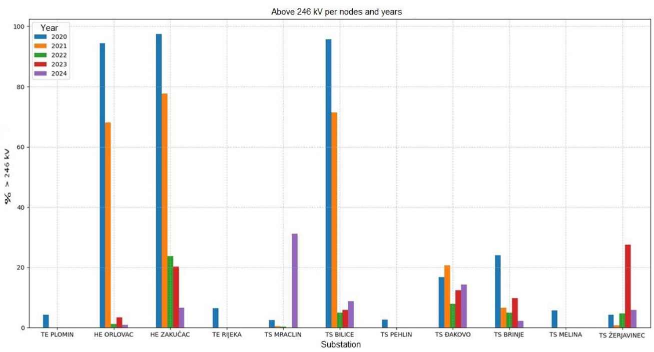

Figure 8: Percentage of Operating Time Above Permissible Voltage by SS at the 220 kV (2020–2024).

The bar chart in Figure 8 shows the percentage of time during which voltages on the 220 kV busbars exceeded the permissible limit Umax,ICS. While this information is not clearly visible in the quarterly charts, it is crucial for accurately illustrating these violations.

The highest voltage conditions were recorded in southern part of Croatia especially at the HPP Zakučac, HPP Orlovac and SS Bilice which are located electrically very close to border with SEE region. Last year, HPP Zakučac completed the renewal of its control systems and is now capable of participating in voltage regulation within the prescribed cos φ limits. As a result, voltage conditions in the surrounding area have significantly improved.

2.5. International Impact on Voltages and Reactive Power Flows in the Slovenian Transmission Network

Reactive power has a direct impact on the voltage profile, making it essential to analyse its sources in the transmission network as part of the voltage increase assessment. The main sources of capacitive reactive power include low-loaded OHLs, HV cables, and reactive power flows from neighbouring transmission networks. These can be compensated by loaded 110 kV load nodes and transit active power flows. However, the reduction of active and reactive power from the distribution network due to the operation of solar power plants is not the focus of this paper.

Figure 9 presents a quarterly diagram of average hourly reactive power measurements recorded in transmission lines on the Slovenian side for the period 2020–2024. The total reactive power across all voltage levels is shown separately for each neighbouring TSO. A positive reactive power value indicates the export of reactive power from the ELES network to a neighbouring TSO, while a negative value signifies the import of reactive power from a neighbouring TSO. Each TSO is responsible for controlling reactive power within its internal network. The inability or lack of reactive power control devices results in uncoordinated reactive power flows on interconnections.

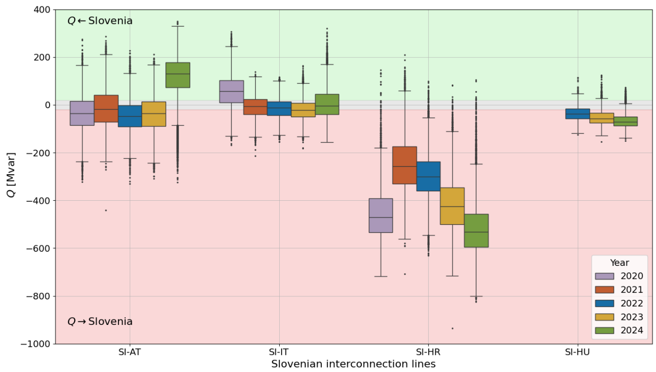

Figure 9: Quarterly Diagram of the Total Reactive Power of All Cross-Border Lines in Slovenia by Year.

The diagram highlights a significant difference between reactive power flows at the Slovenian-Croatian border compared to other borders. For most of the time, reactive power flows from Croatia to Slovenia. The decrease in reactive power flow from the HOPS network to ELES between 2020 and 2021 resulted from the installation of 220 kV compensation devices in the HOPS network and the end of COVID-related measures.

At the Austrian border, reactive power flows are slightly shifted toward the import of reactive power from Austria. However, an exception occurred in 2024, when the flow direction changed from Slovenia to Austria. Meanwhile, reactive power flows at the Italian border are symmetrically distributed around zero, which can be attributed to the operation of the 400 kV VSR at the SS Divača. Since the construction of the 400 kV OHL Cirkovce–Heviz to Hungary, reactive power has been imported more than 75% of the time.

Higher voltages are expected in the area when active power approaches zero and when reactive power flow from Croatia to Slovenia increases. The period of higher voltages occurred mainly in the spring months, when active power flowed toward Slovenia for a time. This was a consequence of the Krško Nuclear Power Plant regular overhaul, which lasted throughout April 2024.

2.6. International Impact on Voltages and Reactive Power Flows in the Croatian Transmission Network

Regardless of the previously described efforts and countermeasures, that are built into the Croatian network recently which could be considered sufficient for managing voltage conditions in HOPS network, voltage conditions were not always within the permitted limits but exceeded them. The following factors/reasons could have a negative impact on voltage management in HOPS:

- increasing integration of RES in DSO reduces the load on the TSO network and we expect an increase in voltage (due to the TSO/DSO profile),
- some transmission power lines were built according to a common plan within the former state of Yugoslavia with a length of over 200 km (these power lines produce significant amounts of reactive power and affect voltage conditions, especially if they will be less heavily loaded in the future due to increasing integration of RES in DSO network),
- HOPS do not have control over the DSO units related to voltage regulation (which may be a problem in the future),
- as mentioned in the introduction to this chapter, due to its location and geographical shape HOPS/Croatia is significantly well connected with NOSBIH. So, in case where there is insufficient compensation within the SEE region, HOPS is conditioned by high reactive power flows from NOSBIH (reactive power flows are measured in our substations) and can only transfer them to other neighbouring TSOs and
- in the future HOPS plan to install additional shunt reactors.

The graph in Figure 10 shows the monthly net value of reactive energy from January 2019 to December 2024 between the HOPS and NOSBIH (these values were measured in Croatian border substations, not at the border itself).

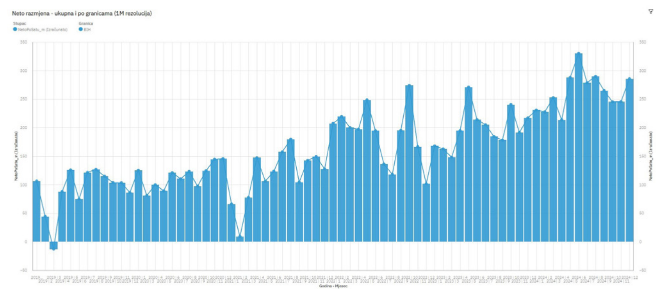

Figure 10: Monthly Net Value of Reactive Energy from January 2019 to December 2024 Between the Croatian and Bosnian Border.

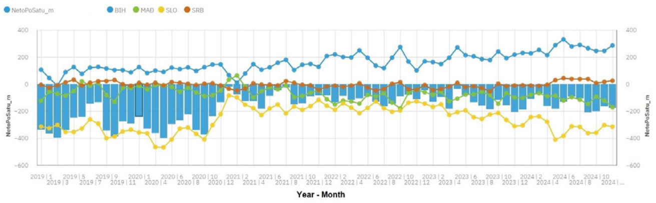

Figure 11: Net Sum of Hourly Reactive Energy Import/Export From the Year 2019 to the Year 2024 Between HOPS and Neighbouring TSOs.

Figure 11 shows the import of reactive energy from NOSBIH (in diagram's upper part) and the export from HOPS to neighbouring TSOs (in the diagram's lower part) is at approximately identical levels. It can be concluded that the Croatian TSO is currently sufficiently compensated because the reactive power flows entering HOPS leave it mostly in the ELES power network (data were measured in our border's substations). It is worth pointing out that the root cause for such large reactive power infeed originates from a broader area, not just the neighbouring TSOs.

3. MEDIUM-TERM MANAGEMENT OF VOLTAGE CONDITIONS

Based on the results, we can conclude that ELES is successfully managing the increasing voltage levels in its transmission network. Despite growing challenges from increased reactive power flows from SEE Europe, ELES has established effective tools to monitor and mitigate these excesses. The voltage control and regulation system enable efficient adjustment of operating conditions, ensuring power system stability.

ELES has no direct influence over reactive power compensation in the SEE region, as this is driven by broader regional conditions and the operational characteristics of neighbouring TSOs'. Excessive cross-border reactive power flows in the SEE region stem from insufficient compensation capacities, which in turn contribute to elevated voltages in the Slovenian network. So far, ELES has largely managed to compensate for high reactive power flows through appropriate measures and with the support of SCADA/EMS, ensuring that voltage conditions in Slovenia have only rarely exceeded permissible limits.

ELES do not consider installing additional compensation devices as a viable solution to address reactive power surpluses from external systems. While ELES has mechanisms to regulate reactive power surpluses, it cannot fully offset all imported reactive power. Investing in additional compensation devices to counteract reactive power flows from neighbouring countries would be an unjustified cost without resolving the root cause. Instead, the issue must be addressed at its source—through investments in additional reactive power sources within transmission systems experiencing surpluses.

HOPS maintains voltage levels within the prescribed limits for the majority of the year. However, HOPS is fully aware of the recurring challenges during low-load periods, particularly in spring and autumn, as well as during public holidays. As part of our medium-term strategy, HOPS intends to utilize generation units outside their mandatory cosφ operating range, with appropriate financial compensation for the provision of such voltage control services. This approach is currently pending regulatory approval.

Furthermore, HOPS plans to invest in additional compensation equipment in parts of the network where critical voltage regulation issues have been identified.

4. CONCLUSION

Based on the results presented in this paper, we can conclude that ELES and HOPS has been experiencing a trend of increasing voltage in the transmission network in recent years, particularly at the 400 kV and 220 kV voltage levels. The installed compensation devices are currently sufficient to manage steady-state voltage conditions, but challenges arise with rapid voltage fluctuations within an hour.

A key factor affecting voltage conditions in Slovenia is the large, uncoordinated reactive power flows from the SEE region, which further burden the network and require precise management and adjustment of control measures. One of recognized challenges for neighbouring transmission system operators is to maintain similar voltage setpoints in electrically close nodes to keep exchange of reactive power flows on borders inside allowed ranges. Due to this reason, it is necessary to consider introducing application support for joint TSO optimization of voltage conditions [11, 12]. The current trend of increasing reactive power flows and rising voltage levels in the Slovenian transmission network suggests that, in the future, the existing compensation devices may no longer be sufficient to maintain voltage within prescribed limits. This is already occurring at certain times of the year, such as during the International Workers' Day holidays and New Year holidays.

The highest voltage levels are observed at the Krško substation, which is the only connection point for which ELES can report voltage incidents to ENTSO-E in accordance with the ICS scale. ELES and HOPS have already co-invested in compensation devices through the SINCRO.GRID project, but voltage conditions are deteriorating due to the lack of reactive power sources and compensation devices in SEE European networks. Since high voltages in the Slovenian transmission network are primarily influenced by reactive power flows from NOSBIH and HOPS, the feasibility of installing additional compensation devices solely within the Slovenian transmission network is questionable—both financially and in terms of effectiveness in stabilizing voltage conditions.

ELES is actively working on addressing this issue at the ENTSO-E level, where strategies are already being developed to mitigate inadequate voltage conditions in the region. In the future, the interaction between TSOs and DSOs will also play a crucial role, as the increased integration of renewable energy sources at medium and low voltage levels will impact reactive power compensation dynamics. This will likely lead to a reduction in the reactive power sink in the distribution network, further influencing voltage conditions in the transmission network. Therefore, close cooperation between system operators and coordinated planning of future measures at the European level will be essential for ensuring long-term network stability.

Due to Croatia's strong interconnection with Bosnia and Herzegovina (NOSBIH), inadequate compensation within the SEE region results in high reactive power flows into Croatia. HOPS currently lacks control over DSO voltage regulation, which could present future challenges due to large and increased RES integration. HOPS plans to expand its network of compensation devices in the future to enhance voltage stability and reactive power management.

The installation of additional compensation devices in the SEE region, combined with a coordinated regional strategy for reactive power management, could be crucial in effectively mitigating uncontrolled reactive power flows in the area. To achieve this goal, it would be highly beneficial to create a joint project involving the affected TSOs of the SEE region, similar to the successfully collaborated and completed SINCRO.GRID project.

REFERENCES

[1] E. Planinc, F. Kropec, »Obvladovanje visokih napetosti v prenosnem omrežju Republike Slovenije«, paper ŠK C2-02, 12. Conference of Slovenian Electric Power Engineers CIGRE-CIRED, Portorož, 2015.

[2] P. Omahen, »Razkorak med dobavljivim in potrebnim obsegom sistemskih storitev iz proizvodnih enot v EES Slovenije«, paper ŠK C2-01, 12. Conference of Slovenian Electric Power Engineers CIGRE-CIRED, Portorož, 2015.

[3] P. Omahen, »Enovita regulacija napetosti z napravami SINCRO.GRID«, paper ŠK C2-01, 14. Conference of Slovenian Electric Power Engineers CIGRE-CIRED, Laško, 2019.

[4] G. Omahen, D. Matvoz, M. Maksič, A. Souvent, »Koncept reševanja napetostnih profilov z uporabo naprednih sistemov za regulacijo napetosti«, študija št. 2245/1, EIMV, 2014.

[5] B. Hlebčar, J. Jurše, L. Valenčič, »Obvladovanje napetostnih razmer v EES Slovenije«, study no. 2103, EIMV, 2011.

[6] ENTSO-E: Operational Voltage Management Report, WG Voltage Management, 2025.

[7] European Commission. Commission Regulation (EU) 2016/631 of 14 April 2016 Establishing a Network Code on Requirements for Grid Connection of Generators. Official Journal of the European Union, št. L 112, 2016, str. 1–68. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32016R0631, accessed 26.2.2025.

[8] European Commission: Commission Regulation (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation (SO GL). Official Journal of the European Union, L 220/1, 2017.

[9] ENTSO-E. Incident Classification Scale. Incident Classification Scale Subgroup, 4 Dec. 2019.

[10] SINCRO.GRID: https://www.sincrogrid.eu, accessed 3.2.2025.

[11] M. Rekić, R. Rubeša, Z. Bunčec, T. Šesnić, M.N. Raič, T. Stupić, “Uspostava i prva iskustva u radu sustava za sekundarnu U-Q regulaciju u HOPSu”, HRO CIGRE, 2021.g.

[12] R. Rubeša, Z. Bunčec, M. Rekić, T. Stupić, “Practical experience of using fully automated centralized voltage regulation in transmission system”, CIGRE Paris, 2022.g.

[13] Studija izvodljivosti ugradnje kompenzacije jalove snage u prijenosnoj mreži Hrvatske, EIHP, studeni 2015.

BIOGRAPHY

Samo Gašperič received the Dipl. Eng., M.Sc., and Ph.D. degrees from the Faculty of Electrical Engineering, the University of Ljubljana, Slovenia, in 1997, 2002, and 2016, respectively. From February 1997 to November 1998, he worked as an engineer in the distribution company Elektro Ljubljana. In November he joined Laboratory of Electric Power System at the Faculty of Electrical Engineering, the University of Ljubljana where he worked as teaching assistant. Since October 2019, he has worked at Slovenian Transmission System Operator, ELES. His areas of work and interest include power system analysis, reactive power optimisation, SCADA/EMS and FACTS devices. He is a Member of CIGRE and ENTSO-E PG Voltage Control in SEE Region. He is also the author of many scientific and professional papers.

Andrej Vrbinc received his B.Sc. and M.Sc. degrees from the Faculty of Electrical Engineering, University of Ljubljana, Slovenia, in 2007 and 2011, respectively. From November 2007 to March 2018, he worked as a Senior Operator at the National Control Center of the Slovenian Transmission System Operator, ELES. Since April 2018, he has been serving as the Head of the National Control Center at ELES. His areas of expertise include real-time operation, operational security, system restoration, and voltage management. He is an active member of the ENTSO-E System Operation Committee, the ENTSO-E RG CE Plenary, the ROSC Implementation Working Groups, and CIGRE Study Committee C2. He is also the author of numerous scientific and professional papers.

Tomaž Tomšič received his M.Sc. degree in Electrical Engineering from the Faculty of Electrical Engineering, University of Ljubljana, Slovenia, in 2007. From 2004 to 2007, he worked as a Junior Researcher at the Faculty of Electrical Engineering, University of Ljubljana, focusing on power system security and operational reliability. Since 2007, he has been employed at the Slovenian Transmission System Operator ELES, where he currently serves as Head of the Operation Support Department. His areas of work and interest include:

- Power system security and operational reliability
- Calculation of cross-border transmission capacities
- Congestion management
- International coordination in power system operation
- SCADA/EMS systems

He has actively contributed to several major international projects, including SINCRO.GRID, GreenSwitch, and many others aimed at enhancing system flexibility and security. He is the author of numerous technical contributions and plays an active role in developing advanced solutions for power system operation.

Franc Kropec received Dipl. Eng. degree from the Faculty of Electrical Engineering, University of Ljubljana, Slovenia, in 1996. From October 1996 to July 1998, he worked as an engineer at the distribution company Elektro Maribor. Since August 1998, he has been with the Slovenian Transmission System Operator, ELES. His professional interests are primarily focused on power system operation, with an emphasis on voltage and frequency control, operational planning, and coordination of system operation issues. He is a member of CIGRE and the ENTSO-E CSO SG.

Marijan Borić received dipl.ing.el degree from the Faculty of Electrical Engineering, Mechanical Engineering

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and Naval Architecture, University of Split, Croatia, in 2002. From 2003 till 2006 he worked in Project office in Distribution Company in Sisak, and from 2006 he worked in Croatian Transmission System Operator Plc. (HOPS), in planning department. Mr. Borić is head of System operation Planning Service in HOPS responsible for:

- Operational planning
- Forecast of losses, renewable, load, consumption
- Power system security and operational reliability
- Calculation of cross-border transmission capacities
- Congestion management
- Outage planning

Mr. Borić is a regular author and participant at professional and scientific conferences such as HRO CIGRE and member of ENTSO-E CSO SG group.

Zvonimir Brleković, M.E.E., is Head of System Control at the National Control Centre (NCC) of the Croatian Transmission System Operator Plc. (HOPS), a position he has held since 2021. He received his Master of Electrical Engineering degree from the Faculty of Electrical Engineering and Computing, University of Zagreb, in 2005. Mr. Brleković has been employed at HOPS since 2006, where he previously served as a system dispatcher responsible for the real-time operation of the Croatian power system. He holds professional certifications in power system dispatching and acts as a mentor and examiner in dispatcher training and licensing. His professional interests include power system operation, restoration, simulation training, SCADA/EMS applications and other topics related to electricity market processes. He actively participates in several ENTSO-E, CCR and RCC working groups. Mr. Brleković is a regular author and participant at professional and scientific conferences such as HRO CIGRE and others.

Zoran Bunčec, M.E.E., is Head of System Operation Service of the Croatian Transmission System Operator Plc. (HOPS) responsible for National Control Center, Regional Centers and Education. He received his Master of Electrical Engineering degree from the Faculty of Electrical Engineering and Computing, University of Zagreb, in 2006.

Mr. Bunčec has been employed at HOPS since 2006, where he started as a power system dispatcher responsible for the real-time operation of the Croatian power system. He holds professional certifications in power system dispatching and acts as a mentor and examiner in dispatcher training and licensing. His professional interests include power system operation, restoration, simulation training, SCADA/EMS applications and other topics related to electricity market processes. He actively participates in several ENTSO-E, CCR and RCC working groups. Mr. Bunčec is a regular author and participant at professional and scientific conferences such as IEEE, CIGRE, HRO CIGRE and others.

Tomislav Vuković obtained a Master's degree in Electrical Engineering from the Faculty of Engineering, University of Rijeka, in 2015, earning the title Master of Electrical Engineering. In 2016, he joined HOPS, Croatian Transmission System Operator Plc., where he began working as a Dispatcher at the Regional Control Center managing regional grid operations. Since 2023, he has been serving as a Dispatcher at the National Control Center, focusing on system operation and balancing, voltage management, and network optimization. He has participated in several internal projects related to voltage control and power system optimization and is an active member of the ENTSO-E PG Voltage Control in SEE Region group. His main professional interests include real-time operation, congestion management, power system analysis, system restoration, and voltage and frequency control.