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RIGA TECHNICAL
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Aigars Sīlis

POWER SYSTEM MANAGEMENT UNDER MARKET CONDITIONS WITH HIGH DISPERSION OF RENEWABLE ENERGY PRODUCTION

Doctoral Thesis

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RIGAS TECHNICAL UNIVERSITY
Faculty of Computer Science, Information Technology and Energy
Institute of industrial electronics, electrical engineering and energy

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POWER SYSTEM MANAGAMENT UNDER MARKET CONDITIONS WITH HIGH DISPERSION OF RENEWABLE ENERGY PRODUCTION

Doctoral Thesis

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DOCTORAL THESIS PROPOSED TO RIGA TECHNICAL UNIVERSITY FOR THE PROMOTION TO THE SCIENTIFIC DEGREE OF DOCTOR OF SCIENCE

To be granted the scientific degree of Doctor of Science (Ph. D.), the present Doctoral Thesis has been submitted for defence at the open meeting of RTU Promotion Council on 29 August 2024 at 10.00 at the Faculty of Computer Science, Information Technology and Energy of Riga Technical University, 12/1 Āzenes Street, Room 306.

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DECLARATION OF ACADEMIC INTEGRITY

I hereby confirm that the Doctoral Thesis submitted for the review to Riga Technical University for promotion to the scientific degree of Doctor of Science (Ph. D.) is my own. I confirm that this Doctoral Thesis has not been submitted to any other university for promotion to a scientific degree.

Aigars Sīlis……………………………. (signature)

Date: ………………………

The Doctoral Thesis has been written in English. It consists of an Introduction, 4 chapters, Conclusions, 18 figures, 3 tables, and 14 appendices; the total number of pages is 143. The Bibliography contains 97 titles.

ABSTRACT

The European power system is transforming rapidly to climate changes mitigation integrating more renewables, developing flexibility and enable consumers to play a more dominant role. For electricity markets, this transition means that trading needs to move closer to real time while respecting system adequacy, affordability, and security. As the system is changing, the more efficient planning, scheduling and balancing of the power system also needs to be developed. This thesis provides an analysis of operation of common balancing area based on a case study of the Baltic common electricity energy market model. This model includes day-a-head, intraday and balancing markets. The objectives of development of the common Baltic market were to increase security, balancing efficiency, to increase availability of resources and to reduce the costs of energy. Establishing the common Baltic balancing market required harmonization of market frameworks of the three Baltic States including the settlement rules between market parties, introduction of a coordinated balance control on a regional level and introduction of common balancing IT platform. However, to stop climate change, it is necessary not only to eliminate the emissions of electricity generation, but also to solve a more complex problem - to eliminate emissions in other infrastructures, particularly in transport. The part of thesis is devoted to the consideration of significant capacities of RES (10 GW) and 2 million of electric cars that are expected to be commissioned until 2050 year. The issue of the region's ability to self-sufficiency, export/import of energy and to reduce emissions into the atmosphere is being investigated [1] The analysis is completed on the basis of modeling the behavior of the power system of Baltic States taking into account the connections with Sweden, Finland and Poland.

The list of the most interesting problems includes the following tasks:

- An in-depth analysis has been conducted on the goals, tasks, resolution methods, and technologies pertinent to the transformation of the energy systems in the Baltic States, alongside the identification of the most critical research directions;
- Reserve Power Estimation in Alignment with the Baltic Power System 2050 Development Plan is conducted;
- An assessment of the risks of generation capacity shortages to cover peak load and deficits in balancing capacity within the next decade has been conducted. An analysis of the implementation of balancing capacity markets and capacity remuneration mechanisms as measures capable of mitigating this risk has also been performed;
- Considering the substantial integration of renewable energy sources (10 GW) and 2 million electric vehicles, scenarios for achieving self-sufficiency in the Baltic region's energy systems have been thoroughly investigated.. The issue of the region's ability to export/import of energy and to reduce emissions into the atmosphere is being investigated;
- Based on data from Nordic and Baltic markets, it is demonstrated that contracts linked to dynamic market prices of electricity provide lower prices for end-users;

- A market-driven strategy has been devised to manage storage state of charge for energy providers participating in primary frequency regulation. This approach showcases its capacity to maintain sufficient resilience even in the face of worst-case scenarios, even when the device is concurrently supplying multiple reserve products.

PATEICĪBAS

Vēlos izteikt lielu pateicību Latvijas Zinātņu akadēmijas korespondētājloceklim **Antanam Sauļum Sauhatam** un profesoram **Gatim Junghānam** par viņu sniegto atbalstu un iedrošinājumu zinātniskajā darbā.

Esmu pateicīgs RTU akadēmiskai saimei, jo īpaši Kārlim Baltputnim, Ļubovai Petričenko, Romanam Petričenko un Zanei Brokai no RTU par palīdzību pie sarežģītiem tehniskajiem jautājumiem un palīdzību visa promocijas darba sagatavošanas laikā.

Pateicos par iesaisti arī saviem kolēģiem Ansim Žbanovam, Kalvim Ertmanim, Antonam Kutjunam un Aleksandram Ļvovam no AS “Augstsprieguma tīkls.

Sirsnīgākais paldies manai sievai Diānai un meitām Elizabetei un Esterei, kā arī mammai Annai, kuru neizsīkstošais atbalsts un dedzīgā interese par promocijas darba gaitu bija kā dzinējspēks mana promocijas darba sagatavošanas laikā. Es esmu pateicīgs par minēto cilvēku un ģimenes nepārtraukto atbalstu un ieguldījumu, kas man palīdzēja sasniegt savu mērķi un veicināja manu izaugsmi kā cilvēku un pētnieku.

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INTRODUCTION

BACKGROUND AND RELEVANCE OF THE RESEARCH

In the European Union, efforts are currently underway to develop an energy policy framework aimed at facilitating the shift towards clean energy [1] and bolstering the security and reliability of energy provision. The Clean Energy Package, comprising a comprehensive set of regulations and directives, is poised to bring about significant transformations [3][4][5][6]within the electricity sector across Europe and the Baltic States. By 2050, the Baltic states have set ambitious targets: to ramp up renewable energy production to 100%[7]. Further proliferation of RES necessitates increased investments and efforts in ensuring balance of energy generation and consumption. Intermittent generation and the poorly controllable nature of consumption elevates the problems of **energy storage and limited capacities of power plants and interconnecting power lines**[8]. On the other hand, the **demand side** of electricity is also expected to experience rapid changes due to electrification of several sectors of the economy, such as industry, transport, agriculture, buildings and waste management[9].

This new policy framework enhances legal certainty by enacting the inaugural national energy and climate plans, thereby fostering investments in this pivotal sector. Moreover, it seeks to notably elevate the role of consumers and afford them opportunities to actively engage in the energy transition process. Two fresh targets have been established for the European Union (EU) to achieve by 2030:

1) a binding renewable energy target of at least 32%; and

2) an energy efficiency target of no less than 32.5% - with a potential upward revision in 2023.

As for the electricity market, the new policy reaffirms the 2030 interconnection target of 15% of installed generation capacity, thus extending the 10% target set for the period leading up to 2020 [10].

To achieve the stated objectives, a series of technical measures must be implemented to safeguard the affordability, stability, and security of electricity systems. Among these measures are:

- Synchronization of the Baltic transmission network with the Continental European energy system by 2025. Baltic transmission system operators will need to ensure the capability to participate in frequency regulation both under normal conditions and in the event of incidents following the disconnection of a large generator or interconnection line failure. Therefore, Baltic TSOs will need to maintain frequency regulation and balancing reserves as stipulated by the Continental European synchronous operation agreement.

- Modernization of transmission and distribution power grids, including the interconnection of tie power lines to accommodate the forecasted sharp growth in electricity demand.
- Installation of energy storage units, including synchronous condensers, hydro pump power plants, and batteries. The necessity of batteries is emphasized in a study commissioned by the Baltic state grid operators - Lithuania's "Litgrid," Latvia's "Augstsprieguma tīkls" (AST), and Estonia's "Elering" - conducted by Japan's energy company TEPCO Power Grid Inc. The study underscores that the development of Battery Energy Storage Systems (BESS) represents the most effective strategy for Lithuania, Latvia, and Estonia to ensure the reliable and resilient operation of their electricity grids, particularly as they strive for complete reliance on renewable energy sources. Specifically, implementing a grid-forming battery system with a capacity of 240 MW would mitigate the challenges posed by the diminishing output of synchronous generators and the increasing integration of wind and solar power generation, thereby enhancing system stability[11].

The outlined measures present a significant challenge for power systems researchers, development planners, and decision-makers, including transmission system operators. There is still a need to create extremely expensive power generating and balancing resources [12], reinforce transmission and distribution grids, transform energy consumption, and to develop a sophisticated management and control system based on a fully-fledged energy markets including balancing reserve market. Promoting consumer response and aggregation is also crucial.

The implementation of the aforementioned plans for energy transformation requires concerted efforts and actions from researchers, engineers, and managers from various economic sectors, as well as multi-billion-dollar investments even in the case of relatively small regions like the Baltic countries. The industry for producing necessary equipment is rapidly developing, prices of solar and wind energy elements are falling [13], information technologies and communication are advancing rapidly, and electrification of transportation is underway. However, many problems remain unsolved or are inadequately addressed. This dissertation identifies one of them, labelling it with two key words - **continuous balancin**g and **adequacy**. Henrik Nordstrom, at all [12] refer the issue of **continuous balancing** in a power system as a task **to supplying the demanded power at every time instant** [12]. Resource adequacy in the field of electric power is the ability of the electric grid to satisfy the end-user power demand at any time. The adequacy standard should satisfy the chosen reliability index, typically the loss of load expectation of 1 day in 10 years (so called "1-in-10") [13].

When solving the continuous balancing problem, we will confine ourselves to extreme specific cases:

1. Long-term planning of the energy system structure, where the main challenge is ensuring the balance of accessible power generation and uncontrollable consumption[14].

2. Managing the operation mode of the energy system, where despite the variability of generation and consumption, frequency is maintained within acceptable narrow limits.

Both mentioned problems will be considered within the conditions and peculiarities of the energy systems of the Baltic region.

HYPOTHESIS, OBJECTIVE AND TASKS OF THE THESIS

Hypothesis

By developing an appropriate power system structure and utilising energy storage technologies, it is possible to provide a cost-effective and energy-efficient energy supply. This can improve system adequacy, stability, and flexibility, while also mitigating resource and electricity market price volatility caused by an increase in intermittent renewable generation in the Baltic region.

Objective

The objective of this Thesis is to develop and evaluate a methodology and algorithms to facilitate the selection of technologies, grid management, operation and development plans and control algorithms. The aim is to promote a seamless energy transition for end users, ensuring that electricity remains safe, reliable and affordable.

Tasks

1. An in-depth analysis has been conducted on the goals, tasks, resolution methods, and technologies pertinent to the transformation of the energy systems in the Baltic States, alongside the identification of the most critical research directions.
2. Reserve Power Estimation in Alignment with the Baltic Power System 2050 Development Plan is conducted.
3. An assessment of the risks of generation capacity shortages to cover peak load and deficits in balancing capacity within the next decade has been conducted. An analysis of the implementation of balancing capacity markets and capacity remuneration mechanisms as measures capable of mitigating this risk has also been performed.
4. Considering the substantial integration of renewable energy sources (10 GW) and 2 million electric vehicles, scenarios for achieving self-sufficiency in the Baltic region's energy systems have been thoroughly investigated. The issue of the region's ability to export/import energy and to reduce emissions into the atmosphere is being investigated.
5. Based on data from Nordic and Baltic markets, it is demonstrated that contracts linked to dynamic market prices of electricity provide lower prices for end-users.
6. A market-driven strategy has been devised to manage storage state of charge for energy providers participating in primary frequency regulation. This approach showcases its

capacity to maintain sufficient resilience even in the face of worst-case scenarios, even when the device is concurrently supplying multiple reserve products.

RESEARCH METHODS AND TOOLS

Research results presented in the Doctoral Thesis were performed using adapted software modelling tools and algorithms developed at the Institute of Power Engineering of Riga Technical University.

When modelling the different future scenarios (Chapters 2, 3, and 4), MATLAB and Excel were used to organise the input data by scaling and adjusting it according to the situation assumptions. For power system transient stability simulations, ETAP 12.5 grid simulation software was used (under the license provided by the Riga Technical University).
For modelling power systems, electricity market data sets from NordPool, JSC "Augstsprieguma tīkls, JSC "Latvenergo", and Latvian Environment, Geology and Meteorology Centre were adapted and used.

SCIENTIFIC NOVELTY

An exhaustive analysis has been undertaken on the objectives, tasks, resolution methods, and technologies relevant to the transformation of the energy systems in the Baltic States, coupled with the identification of the most critical research directions. Additionally, a methodology for estimating the capacity of reserve power plants has been developed in connection with the Baltic Power System 2050 Development Plan, considering the influence of Poland, Sweden, and Finland [16].
An evaluation of the risks associated with generation capacity shortages to meet peak load demands and address deficits in balancing capacity over the next decade has been carried out. Additionally, an analysis of the implementation of balancing capacity markets and capacity remuneration mechanisms as measures to mitigate these risks has been conducted.

Furthermore, in light of the significant integration of renewable energy sources (10 GW) and 2 million electric vehicles, comprehensive scenarios for achieving self-sufficiency in the Baltic region's energy systems have been thoroughly explored. Additionally, the region's capability to facilitate energy export/import and reduce emissions into the atmosphere is under investigation.

An assessment of the impact of balancing market conditions and the applicability of battery energy storage systems (BESS) on the operation of the Baltic energy system was conducted. To simulate the operation of BESS, simulation software for the BESS control model was developed, and its operation was simulated under various specified operating modes and scenarios.

Based on data from Nordic and Baltic markets, it is demonstrated that contracts linked to dynamic market prices of electricity provide lower prices for end-users[17].

A market-driven strategy has been devised to manage the storage state of charge for energy providers participating in primary frequency regulation. This approach showcases its capacity to maintain sufficient resilience even in the face of worst-case scenarios, even when the device is concurrently supplying multiple reserve products. Two main markets were examined – Baltic balancing market and Baltic day-ahead market.

PRACTICAL SIGNIFICANCE OF THE RESEARCHE

The practical significance of the research studies carried out by the author during the development of the Doctoral Thesis have contributed to several research and innovation projects. Listed below, they include not only national and international scientific projects but also contract work for a major industry stakeholder..

1. Research contract “Development of mathematical models for an economic assessment of demand-side flexibility resources and activation optimization of balancing reserves” (2017–2018), commissioned by “Augstsprieguma tīkls” AS (the Latvian TSO).
2. Project “Innovative emergency control of RES-dominated low-inertia power systems (INNOVA)” (2024–2026), funded by the Latvian Council of Science.
3. Project “Future-proof development of the Latvian power system in an integrated Europe (FutureProof)” (2018–2021), funded by the Ministry of Economics of the Republic of Latvia within the National Research Programme “Energy”.
4. H2020 INTERRFACE project, funded by the European Union’s Horizon 2020 research and innovation program under grant agreement No. 824330.

AUTHOR'S CONTRIBUTIONS

During the development of the Doctoral Thesis, the author participated in several collaborative projects, implying tight cooperation with other expert members of the RTU Institute of Power Engineering. Namely, the Baltic state power system parameter search tool and EV Assess tool were adopted by the author together with researchers K. Baltputnis, Z. Broka, R. and L. Petrichenko under the supervision of Professor A. Sauhats and Professor G. Junghans. The author was involved in all stages of the work, including data extraction, model conceptualisation and definition, case studies, and result analysis.

SCIENTIFIC CONFERENCES AND JOURNALS

The research results included in the Doctoral Thesis were presented and discussed at **5** international scientific **conferences**. Additionally, **8** papers were published in **international journals**, and conference proceedings, and **1** in **Latvian journals**. In addition, a number of publications have been published on local web sites.

1. **A Sīlis**, A., Lavrinovičs, V., Junghāns, G., Sauhats, A. *Benefits of Electricity Industry Switching from Fixed to Spot-Linked End-User Prices*. In: 2018 15th International Conference on the European Energy Market (EEM 2018), Poland, Lodz, 27-29 June, 2018. Piscataway: IEEE, 2018, pp.999-1003. ISBN 978-1-5386-1489-1. e-ISBN 978-1-5386-1488-4. e-ISSN 2165-4093. Available from: doi:10.1109/EEM.2018.8469824

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16. Baltputnis, K., Broka, Z., **Sīlis, A**., Cingels, G., Junghāns, G. *Efficient Market-Based Storage Management Strategy for FCR Provider with Limited Energy Reservoir*. In: 2023 19th International Conference on the European Energy Market (EEM 2023): Proceedings, Finland, Lappeenranta, 6-8 June, 2023. Piscataway: IEEE, 2023, pp. 211-216. ISBN 979-8-3503-2452-

5. e-ISBN 979-8-3503-1258-4. ISSN 2165-4077. e-ISSN 2165-4093. Available from: doi:10.1109/EEM58374.2023.10161770

VOLUME AND STRUCTURE OF THE THESIS

This Thesis is written in English. It consists of an introduction, four main chapters, conclusions and a bibliography with 97 references. The Report contains 18 figures and 3 tables. The volume of the Thesis is 143 pages. The appendices encompass the articles relevant to the Thesis research field.

Chapter 1 provides an overview of the current status of the Baltic power system, alongside anticipated future developments concerning the synchronization of the Baltics with the ENTSO-E grid by 2025, and articulates the climate neutrality targets set for 2050. Background information on power system infrastructure, including power lines, primary power plants, inertia, frequency, and synchronous condensers, is examined. The benefits of the electricity industry transitioning from fixed to spot-like end-user prices are highlighted.

Chapter 2 elucidates the role and benefits of regional balancing areas within the context of addressing future challenges to system adequacy resulting from energy transmission. It delves into the significance of these areas in orchestrating balancing markets effectively.

Chapter 3 introduces a comprehensive concept and methodology for forecasting system adequacy from 2030 to 2050. It establishes a structured framework for estimating reserve power, leveraging insights from the Baltic power system's 2050 development plan. The analysis employs both historical and forecasted data, utilizing the Fourier transformation of prices to enhance accuracy and reliability. The estimation of reserve power is firmly grounded in alignment with the objectives outlined in the Baltic power system's 2050 development plan. The in-house RTU power market model is used.

Chapter 4 is devoted to the consideration of scenarios for the development of the energy systems of the Baltic countries. Significant capacities of RES (10 GW) and 2 million electric cars are expected to be commissioned by the 2050 year. The issue of the region's ability to self-sufficiency, export/import of energy, and reduce emissions into the atmosphere is being investigated. The analysis is completed on the basis of modelling the behaviour of the power system of Baltic states, taking into account the connections with Sweden, Finland and Poland. The chapter elucidates the market-based storage management strategy for FCR providers with limited energy reservoirs within the context of addressing future challenges to system adequacy.

1. TRANSFORMATION OF THE ENERGY SECTOR IN THE BALTIC STATES

1.1. BALTIC POWER SYSTEM

The objectives of the Latvian transmission system operator, in accordance with the guidelines of the European Union's common energy policy, are to ensure the stable operation of the electricity transmission system and secure electricity supply to consumers [17]. At the same time, the transmission system operator must promote the functioning of the electricity market [18] and assist the electricity production industry in gradually transitioning to more environmentally friendly electricity generation. The Latvian electricity market is relatively small - from the perspective of electricity consumption [19], Latvia's market size accounts for less than 2% of the total Scandinavian-Baltic market, or approximately 0.25% of the total European electricity market. Ensuring self-sufficiency in electricity supply and security for Latvia would come at a very high cost. Therefore, integration into the unified European electricity market is critically important for Latvia [20]. Over the past decade, the Baltic transmission system operators have been tirelessly working towards the integration of the Baltic energy system into the European market [21]. The first interconnection between the Baltic and Scandinavian transmission systems was commissioned in the beginning of 2007, with a capacity of 350 MW (Estonia-Finland) [22]. In 2023, four interconnections between the Baltic and European transmission systems have been put into operation[23], with a total installed capacity of 2200 MW, representing approximately 50% of the maximum Baltic electricity consumption. The construction of interconnections has significantly increased the security of electricity supply in the Baltic region and ensured the integration of the Baltic States into the European electricity market.

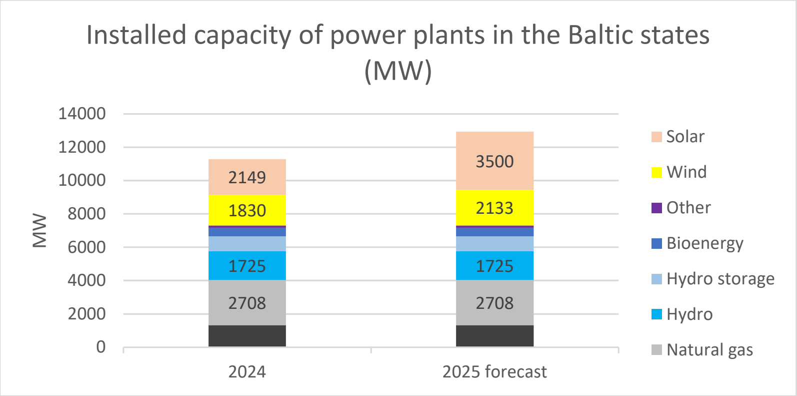


Fig. 1.1 Installed capacity of the power plants in the Baltic states (MW)[24].

In the Baltics, a reduction in production capacity is expected. Currently, the total installed capacity in Baltic power plants (Fig. 1.1) amounts to around 9000 MW[24], which is approximately twice the maximum consumption in the Baltic region.

Among these, about 5000 MW of installed capacity (Fig. 1.2) is in large thermal power plants (mainly using gas and coal as fuel). According to the capacity adequacy assessment conducted by Baltic transmission system operators for the next decade [25], a significant decrease in production capacity is foreseen after 2020, as older gas and coal-fired power plants exit the market.

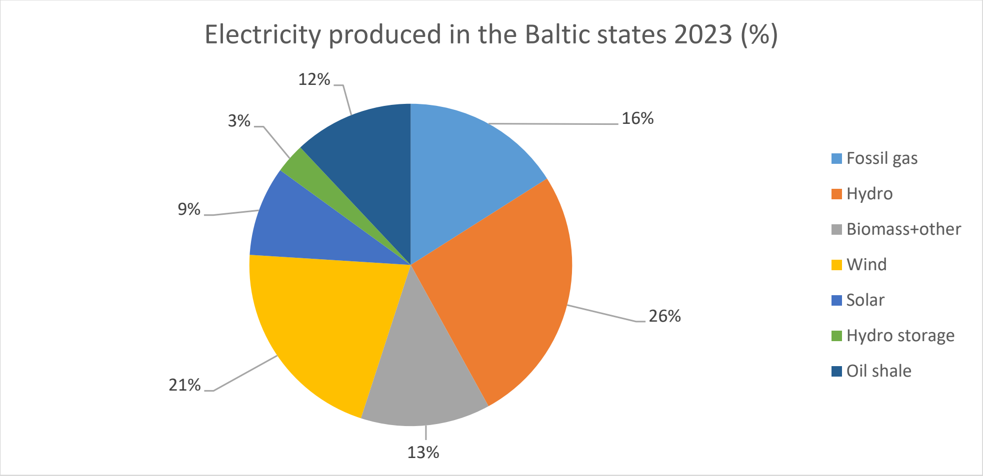


Fig. 1.2 Electricity produced in the Baltic States 2023 [26].

By 2030, production capacities totaling around 2300 MW could be closed in the Baltics, which is roughly half of the existing capacity of large thermal power plants. As production capacities decrease in the Baltics, the importance of interconnections will increase in ensuring electricity supply. Interconnections will ensure both electricity exchange and the provision of system services (reserves) necessary for the security of supply between countries [27].

The costs of production technologies based on renewable energy sources are rapidly decreasing worldwide[28]. It is expected that in the future, decentralized generation and generation based on renewable energy sources will continue to develop in Europe and Baltics [29]. Currently, there are already about 5500 units of decentralized generation operating in the Baltics, and further development is expected in the future. The total installed capacity of wind power plants in the Baltics currently exceeds 1871 MW, but solar 2280 MW, [24] which is approximately 87% of the Baltic peak consumption (MW) (Fig. 1.2)[30] . Considering the competitive costs of wind generation compared to other generation types, further development of this generation type is expected in the Baltics. Strengthening and integrating the Baltic transmission network with the European transmission network is a prerequisite for enabling the further connection of large volumes of renewable energy power plants to the Baltic energy system. The transmission system operators of the Nordic and Baltic countries have jointly conducted an analysis of electricity supply adequacy in the region (Fig. 1.3). According to an ENTSO-E report [31], the upcoming winter of 2022,

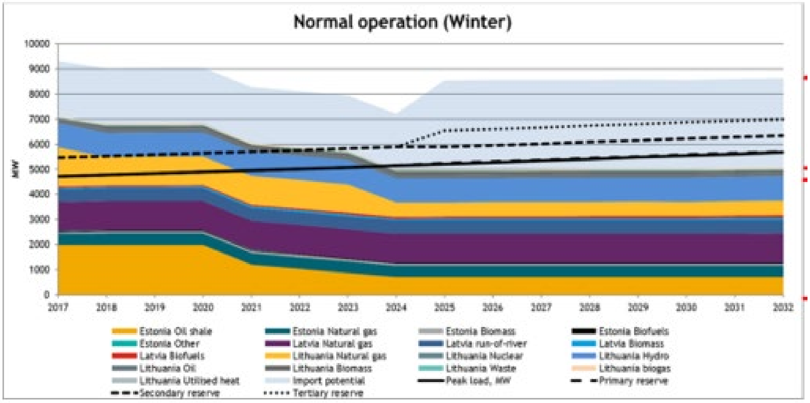


Fig. 1.3 Assessment of Production and Interconnection Capacity Adequacy. Source: AST, Elering, Litgrid.

particularly in January and February, is expected to carry a higher risk of energy unavailability and overall lower security reserves compared to previous years. In the event of low water levels in hydroelectric reservoirs, risks of electricity supply adequacy may arise in the southern parts of Sweden and Norway, as well as in the eastern regions of Denmark. If there is a reduction in production capacity at nuclear power plants, risks of energy inadequacy may increase in southern Sweden and Finland - in electricity trading areas that depend on imports.

Alongside the construction of interconnections between the Baltic and European transmission systems, Baltic transmission system operators are strengthening the Baltic transmission network.

In the development plan of Latvia's electricity transmission system, investments totaling 445 million euros are planned for the period from 2023 to 2032 [32]. For five projects, with estimated investments of 224 million euros over a 10-year period. Currently, financing has been allocated to three projects - the construction of the third

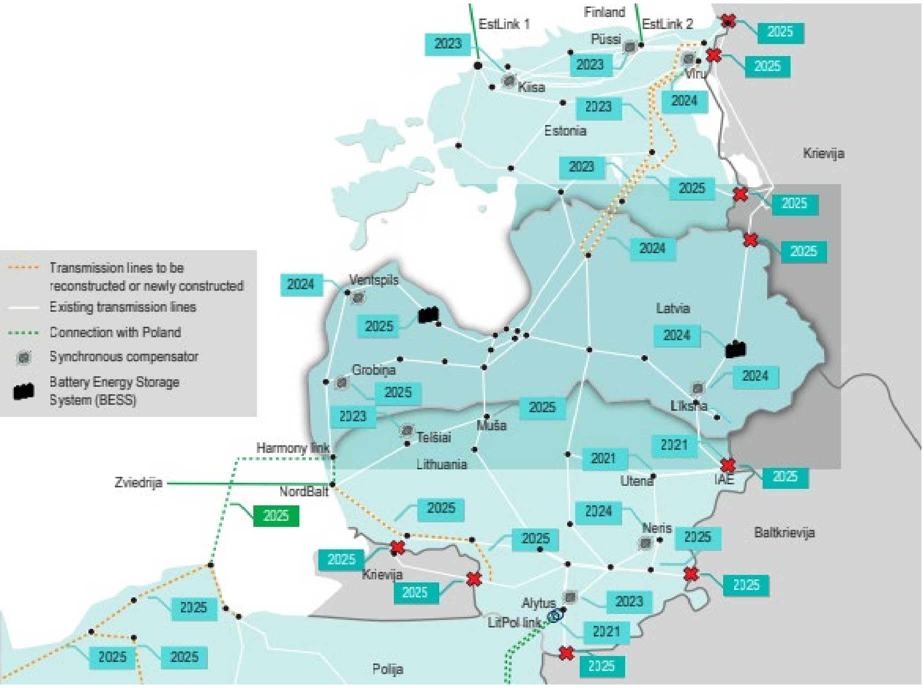


Fig. 1.4 Key Development Projects of the Baltic 330 kV Transmission Network.

phase of the "Kurzeme Loop" transmission line and substations (total investment - 128 million euros), the construction of the third interconnection transmission line between Latvia and Estonia and the expansion of the substation (total investment - 102 million euros), and the construction of new 330 kV transmission lines connecting Riga TEC-2 with Riga HES (total investment - 20 million euros) (Fig. 1.4) [27].

1.2. THE PARTS OF THE EUROPEAN SINGLE ELECTRICITY MARKET

The harmonization of the Baltic electricity market model with the unified European market model [33] continues. Creating a unified regional electricity market requires more than just building interconnections. Different market models can significantly restrict or even block cross-border trading despite the existence of physical interconnections. Therefore, based on the European Commission's electricity network codes, transmission system operators of EU member states are implementing a unified market model in their respective countries with the aim of ensuring that the electricity market in Europe operates effectively as one cohesive market [34].

The European electricity market model consists of four parts:

- **The Day-Ahead Market** is currently the main market where standardized supply transactions for the next day are closed by the purchased and sold volume of electricity per hour. The European Network Code establishes rules for the creation of a coordinated European Day-Ahead Market. Therefore, transmission system operators of EU member states, in collaboration with electricity exchanges, are implementing the Multi-Regional Coupling project, where the main principle is a unified platform and a unified algorithm for determining prices and cross-border flows. This complex project, the largest of its kind in EU practice, is being successfully implemented, and currently, 75% of the entire European electricity market is integrated through the centralized platform, including Latvia and the rest of the Baltic states.
- **The Intraday Market** also serves as a physical delivery market, which opens immediately after the closure of the Day-Ahead Market. In this market, participants can enter into delivery transactions up to 1 hour before the real-time hour. With the increasing variability and decentralization of generation, it becomes increasingly challenging for market participants to balance supply and demand in the Day-Ahead Market. Therefore, in the Intraday Market, participants can make additional transactions to balance supplies. The European Network Code sets out requirements for the establishment of a coordinated European Intraday Market. Therefore, European transmission system operators, in collaboration with exchanges, are working on the creation of a unified European Intraday Market platform (the XBID project). The first phase of this extensive project was introduced in the first quarter of 2018, and the first set of EU member states, including the Baltic states, will begin organizing the Intraday Market through the unified European XBID platform. Over the past few years, the day-ahead and intraday markets underwent significant progress in terms of market integration. Both markets now fully couple all European bidding zones, thereby ensuring that electricity exchanges always occur in the direction that maximises social welfare. To do so, capacity is implicitly allocated to the electricity trades that create most welfare to the coupled European bidding zones. Since all bidding zones are now part of a single coupled market in the day-ahead and intraday timeframe [21]
- **The balancing market** is a crucial tool for transmission system operators to fulfill one of their most important functions - ensuring continuous balance of electricity in the system, where rapidly increasing variable and distributed generation exists. In the balancing market, market participants sell manually activatable **frequency regulation reserves to the transmission system operators in real-tim**e (for example, increasing or decreasing power generation at power plants upon the request of the system operator). With the aim of introducing a unified European balancing market based on a unified European balancing market platform, currently more than 20 European transmission system operators, including those from all Baltic states, are working on the Unified Balancing Market

Platform project (the MARI project). The Electricity Balancing Regulation, which entered into force in 2017, lays down detailed rules on electricity balancing. It further allows TSOs to voluntarily engage in cooperations where they harmonise the procurement and exchange of balancing capacity and the sharing of reserves, including the allocation of cross-zonal capacity. Finally, it strives to implement an integrated balancing market, where TSOs will procure, exchange, and use both balancing energy and capacity in an economically efficient and market-based manner [35]. The main achievements accomplished in 2022 in the balancing timeframe undoubtedly relate to the go-live of two European balancing platforms, the automatic frequency restoration reserve (aFRR) platform and the manual frequency restoration reserve (mFRR) platforms (respectively in the context of the projects named PICASSO and MARI) [21].

- **The Capacity Market** serves to guarantee sufficient reliable volume of energy is accessible by providing payments to encourage investment in new capacity or for existing power plant to remain in use. In addition to the European platforms for the exchange of balancing energy, there are three cooperations which allow for the exchange of balancing capacity:
    - Nordic aFRR market: Pursuant to Article 41 of the Electricity Balancing Regulation, the Nordic TSOs submitted to the Nordic NRAs a methodology for a market-based allocation process of cross-zonal capacity for the exchange of balancing capacity or sharing of reserves. This methodology was referred to ACER, which approved it in August 2020. Following ACER's Decision, the Nordic TSOs implemented the Nordic aFRR capacity market, which began its operation on 7 December 2022. Taking stock of this successful implementation project, a common Nordic capacity market also for mFRR is expected to follow in the coming years for mFRR as well [21], [36].

1.3. STRATEGIES FOR POWER SYSTEM FREQUENCY REGULATION

Power systems are planned to operate at a specific nominal frequency, typically 50 Hz or 60 Hz, depending on the region. Variations in power demand, changes in generation capacity, and unforeseen events such as equipment failures can cause deviations in system frequency. Frequency control and regulation refer to the instruments and techniques engaged in maintaining the frequency of a power system within acceptable, strongly restricted bounds. In an interconnected power grid, the frequency of the alternating current (AC) waveform must be regulated closely to ensure the stable operation of electrical devices and equipment. Frequency control and regulation encompass a spectrum of actions that can be categorized into two primary groups: emergency control and regulation.

1. **Emergency Control**: Emergency control measures are implemented to restore the grid's frequency to its nominal value during unplanned, sudden and, severe frequency deviations.

These measures are crucial to prevent cascading failures and blackouts. Emergency control actions may include actions to balance energy supply with demand:

- Load shedding;
- Generator tripping;
- Leveraging stored energy resources, such as Battery Energy Storage Systems (BESS), to either inject or withdraw additional power from the grid as needed.

2. **Frequency Regulation**: FR refers to the continuous adjustment of power generation or demand to maintain system frequency within acceptable limits **under normal operating conditions.** FR systems continuously monitor grid frequency and correct generator outputs in real-time to keep the frequency within a specified range. FR systems use feedback control loops to maintain the balance between generation and consumption, making rapid adjustments based on frequency deviations. Power systems frequency control and regulation become more complex in interconnected grids where multiple utility companies and generation sources are involved. Interconnected grids require precise synchronization of frequency and phase between different regions to maintain system stability.

Overall, frequency emergency control and regulation ensures grid stability, reliability, and resilience against disturbances and emergencies, and play a crucial role in performing these tasks successfully. Frequency regulation encompasses three distinct groups of measures: primary, secondary, and tertiary regulations.

1. **Primary Frequency Regulation:** Primary frequency regulation is the immediate response of power generation sources to changes in load demand or generation capacity. Automatic generation control (AGC) systems continuously monitor system frequency and adjust generator output accordingly to restore frequency deviations within seconds or minutes. Generators with fast response times, such as gas turbines and hydroelectric plants, often provide primary frequency regulation.
2. **Secondary Frequency Regulation**: Secondary frequency regulation supplements primary frequency control by providing additional fine-tuning of generation output to maintain system frequency within tighter tolerances. This is typically achieved through automatic generation control algorithms and coordinated actions among multiple generators and control devices.
3. **Tertiary frequency regulation:** Tertiary frequency regulation refers to the fine-tuning adjustments made to power generation or consumption in response to longer-term fluctuations in grid frequency. Unlike primary and secondary frequency regulation, which address immediate and short-term frequency deviations, tertiary regulation handles more gradual changes over extended periods (in Baltic 1 h.). Tertiary frequency regulation operates on a longer time scale compared to primary and secondary regulation. While primary and secondary regulation respond to frequency deviations within seconds or

minutes, tertiary regulation may involve adjustments over minutes to hours. Tertiary frequency regulation resources typically include slower-responding assets such as reserve power generation capacity, demand response programs, energy storage systems (such as batteries or pumped hydro storage), and interconnection with neighboring power systems or grid regions.

In implementing listed frequency regulation measures, two types of reserves are maintained- **containment reserves and restoration reserves**.

Frequency Containment Reserve (FCR):

- Frequency containment reserve denotes a reserve capacity that can be rapidly activated to neutralize deviations in system frequency.
- FCR is part of the primary frequency regulation mechanism.
- FCR is provided by generators and other resources that are capable of quickly adjusting their output in response to frequency deviations. These resources are typically equipped with automatic frequency control systems.

Frequency Restoration Reserve (FRR):

- FRR is a reserve capacity that is activated in the event of significant disturbances or contingencies that cause severe frequency deviations.
- FRR is part of the secondary frequency regulation mechanism.
- FRR resources are typically slower-responding compared to FCR resources, but provide larger reserves and can sustain their output for longer durations.
- FRR resources may include additional generation capacity, energy storage systems, or demand response programs that can be activated to restore system frequency.

In summary, Frequency Containment Reserve (FCR) and Frequency Restoration Reserve (FRR) are two types of reserve capacity within a power system that are activated to regulate system frequency and maintain stability in response to changes in power demand or supply and unexpected disturbances or contingencies. FCR provides rapid response to small frequency deviations, while FRR provides additional reserve capacity to address larger disturbances and restore system frequency to its nominal value [38]- [43].

1.4. TREND OF CHANGE

In the future, the risk of insufficient electricity supply capacity will increase. The national energy and climate plans[44] developed by the Baltic states for the period up to 2030 envisage a significant increase in the share of renewable energy resources in final consumption[47]. Therefore, in the next decade, there is expected to be a notable development of wind, solar[47], and distributed generation in the Baltic electricity system[51], leading to an increased need for balancing capacity. The planned synchronization of the Baltic energy system with the continental European power system in 2025 will also **increase the need for frequency and balancing reserves** [51]. At the same time, as non-competitive thermal power plants are phased out, centralized and controllable capacities in the Baltics will decrease. With this trend continuing, the risk of insufficient electricity supply capacity will increase in the future. Therefore, it is important to be aware of activities that help [58]-[66] mitigate this risk and to take timely action. Renewable energy resources replacing fossil fuels.

In recent years, there have not been rapid changes in the structure of Baltic electricity production [26], but there's a clear persistent trend towards increasing production from renewable energy resources[45] and decreasing production from fossil fuels. Electricity consumption has been stable with a slight upward trend in recent years. Over the past five years, consumption in Estonia has increased by 7%, while in Latvia, it has increased by 2%. Data published by Lithuania [47] shows a 26% increase in consumption over the past five years, but most of the reported consumption growth since 2017 is due to changes in consumption accounting methodology, including consumption from the Kruonis Hydroelectric Power Plant in pump mode. In recent years, around 80% of consumed electricity in the Baltic region has been generated locally, with approximately 60% derived from fossil fuels (mainly coal and natural gas) and 40% from renewable energy resources (mainly hydro and wind energy). In 2017 and 2018, electricity generation from renewable energy resources reached historically high levels, exceeding 10 TWh and 8 TWh respectively.

The largest CO2 emitters will be phased out of the market. Estonia's coal-fired power plants have played a significant role in the Baltic energy system. In recent years, coal-fired power plants have produced around 9-10 TWh of electricity annually, accounting for approximately half of the total generation in the Baltic region. It's important to note that since coal is sourced domestically in Estonia, these power plants have ensured electricity production independent of external resource suppliers.

However, coal combustion generates a considerable amount of emissions, especially CO2 emissions., Thus the profitability of these power plants is particularly affected by changes in the price of CO2 emission quotas in the European market. In recent years, the stable production volumes of coal-fired power plants have been consistently supported by low and stable prices of CO2 emission quotas (Fig. 1.5). However, as of the beginning of 2019, the price of CO2 emission quotas exceeded 20 EUR per tonne, reaching as high as 29 EUR per tonne in July alone. As a result, electricity generation from coal-fired power plants significantly decreased.

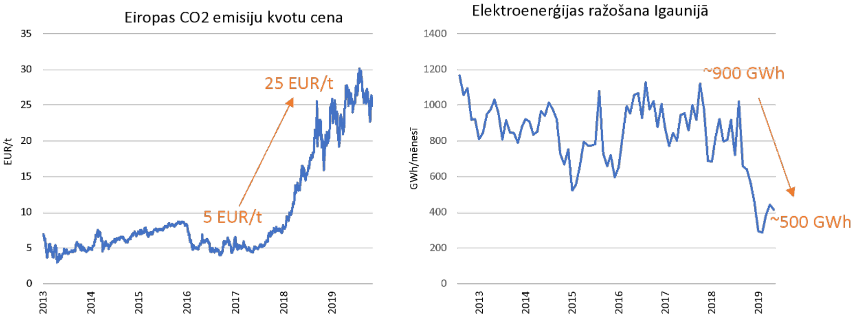


Fig. 1.5. CO2 Emission Allowance Price in Europe (EUR/t) and Electricity Generation in Estonia. Source: Nord Pool.

In July 2019, the Estonian national energy company Eesti Energia announced that, for the first time in the company's history, there was no electricity production in coal-fired power plants during an 8-hour period on June 28. In January 2019, electricity generation at Narva power plants reached 1900 MW during peak consumption hours, while in June, generation fluctuated within a range of 50-200 MW.

In the first ten months of 2019, Estonia produced 517 GWh of electricity, which is 41% less than in a similar period in 2018. Overall in the Baltic region, electricity generation decreased by 22% during the same period.

In the region, **centralized,** regulated production **capacity is lessening**. Over the past five years, the total installed capacity of power plants in the Baltic region has been relatively stable and currently exceeds 9000 MW, which is approximately twice the peak maximum consumption in the Baltics. Over the last five years, the installed capacity of gas-fired power plants has decreased by 25% (about 1000 MW), primarily due to the closure of older gas-fired power plant units in Lithuania. Meanwhile, the significant increase in production capacity has been facilitated by the commissioning of new wind and biomass power plants (with a total capacity of approximately 600 MW), as well as the commissioning of the new 300 MW Auvere coal-fired power plant in Estonia in 2015.

It is expected that in the coming years, the capacity of large centralized base power plants in the Baltics will continue to decrease, mainly due to the reduction in production from non-competitive older thermal power plant units in Estonia and Lithuania. At the same time, largely due to the development of wind farms, it is anticipated that the total installed production capacity in the Baltic region will increase. Considering the National Energy and Climate Plans published by the Baltic States, which outline the countries' intentions regarding the development of renewable energy production by 2030, it can be concluded that by 2030, the amount of electricity generated from renewable energy sources in the Baltics could reach at least 13 TWh per year, which is 5 TWh per year more than in 2018 and corresponds to at least 40% of electricity consumption in the Baltics [52]-[56]. Moreover, it is expected that wind farms will provide the majority of the new production capacity.

In the coming years**, the risk of insufficient electricity supply capacity will increase**. The Baltic transmission system operators regularly assess the security of the Baltic region's electricity systems and the adequacy of capacity in the region. The TSOs prepare scenarios for the development of generation capacity, which provide an idea of how the balance between generation capacity and demand will change in the coming years, as well as the risks to energy supply security. According to the TSO's assessment, it will be technically feasible to cover maximum loads in the Baltic region with local generation capacity (without support from electricity supply via interconnections from neighboring energy systems) until 2020. After 2020, the adequacy of the Baltic States' electricity supply capacity will depend on imports via interconnections from neighboring electricity systems. The reserve capacity available for peak load coverage will significantly decrease after 2025 when the Baltic transmission system disconnects from the integrated Russian energy system and begins synchronous operation with the Continental European electricity system. However, after 2030, the generation and import capacity of the Baltic energy systems will no longer be sufficient to cover peak loads and ensure an adequate level of security in the Baltic States' electricity systems under normal conditions, with the capacity deficit reaching up to 360 MW. The generation capacity development scenarios created by the TSOs indicate the need for new electricity and balancing resources development in the Baltic region to ensure the security and quality of electricity supply.

New balancing capacities are needed. The demand for balancing capacities in the energy system is expected to increase. Approximately 12–15 years ago, when the electricity market was introduced, transmission system operators faced the first increase in volatility. Interregional electricity trading flows became more unpredictable. The direction of flows was no longer influenced by transmission system operators but rather moved from regions with lower prices to regions with higher prices, as with any commodity where price is determined based on market principles. Six to eight years ago, when the rapid development of wind and solar power plants began, transmission system operators encountered a second increase in volatility. For several years now, similar to elsewhere in Europe, wind and solar power plants have dominated the newly commissioned generation capacity in the Baltics. Currently, energy system management is rapidly changing. There is an increase in the volatility of flows and energy balances in the energy system, making it more difficult to forecast the system's condition. Therefore, there is a growing need for additional balancing capacities to be used in energy system management.

Furthermore, it should be noted that currently, the Baltic electricity transmission system is integrated into the unified energy system BRELL, where the grid frequency is centrally regulated in Russia. Due to the planned switch of the Baltic transmission grid to synchronous operation with the continental European energy system, by 2025, Baltic transmission system operators will need to ensure the ability to participate in frequency regulation both under normal conditions and in the event of an incident following the disconnection of a large generator or interconnector line. Therefore, Baltic TSOs will need to maintain frequency regulation and balancing reserves as required by the synchronous operation agreement of continental Europe. Table 1.1 shows indicative volumes of the necessary reserves [54]. This poses a significant challenge for transmission system operators, as there is still a need to develop a fully-fledged balancing reserve market in the Baltics and create the necessary balancing resources.

Table 1.1

Indicative volumes of necessary reserves for Baltic TSOs after synchronization with the continental European power system in 2025 (MW)

Type of reserve products	**Baltic**
FCR	30
aFRR up	100
aFRR down	100
mFRR up	600
mFRR down	600

FCR – Frequency Containment Reserve (must be able to start within a few seconds after an incident and activate 100% of reserve capacity within 30 seconds).

aFRR – Automated Frequency Restoration Reserve (managed with centralized, automatic generation control; activated to full capacity within a few minutes after a system incident)

mFRR – Manual Frequency Restoration Reserve (activated manually, brought to full capacity within a few minutes)

1.5. WHAT TO DO?

Directions to promote adequacy of power supply and development of balancing capacity:

1. Promote generation development. Various promotion instruments are available, but primarily it is necessary to start by reducing existing barriers and avoiding the creation of new ones (including bureaucratic obstacles, permit acquisition, producer fees, etc.).
2. Invest in grid development. Grid development is necessary for connecting large-scale renewable energy generation and balancing the energy system. For example, this year, JSC "Augstsprieguma tīkls" commissioned the final section of the Kurzeme 330 kV

transmission line. Now, the transmission network in the western part of Latvia is capable of accommodating up to 800 MW of wind power.

3. Promote consumer response and aggregation. Currently, the potential for consumer response in Latvia and the Baltic region is not utilized for balancing the energy system. To achieve this, the first necessary step is to establish the necessary regulations for independent aggregators to enter the market, which is a prerequisite for the development of consumer response and aggregation. This would enable aggregator competition equivalent to producers, make the energy system more flexible and secure with lower investments in power plants, and simultaneously promote the development of new market products.
4. Develop the balancing market. Especially after the planned synchronization of the Baltic energy system with the Continental European grid in 2025, Latvia's transmission system operator will require additional and new types of balancing reserves. Therefore, it is necessary to continue to undertake the necessary activities to develop a balancing reserve market in Latvia, which involves integration into the broader European balancing market, serving as a commercial environment for the development and trading of balancing resources. It is crucial to ensure that the Baltic states, including Latvia, can join the MARI energy market platform by the end of 2024, followed by the PICASSO energy market platform in early 2025. This year will be significant not only because the Baltic states will be synchronized with Continental Europe but also because the balancing market model will change significantly as market participants gain access to the Baltic Balancing Reserve Capacity Auction. Given the activities that need to be carried out, they cannot be performed in isolation from the electricity market. The electricity market also requires changes to its market design, specifically the introduction of a 15-minute trading interval from the day-ahead market to the balancing market.

2. BALTIC POWER SYSTEM ADEQUACY FORECASTING

2.1. METHODOLOGY OF MODELING

A modelling platform for a comprehensive assessment of the energy balance of the Baltic power system (BPS) there is a need for a list of mathematical models. The dropped flowchart in Fig. 2. reflects the structure of the required models for analysing BPS energy balance.

As can be seen from Fig. 2.1., two different methods are applied for the BPS operating mode forecast:

- Assessment of recorded time-series impact on the BPS operating mode (historical data);
- The scenario approach; the primary objective is to forecast BPS power consumption, power generation, etc.

The scenario generator block, depicted in Fig. 2.1, operates with a relatively large amount of data for BPS modelling: power generation (P GEN) and consumption (P CON) in BPS, electricity market prices (Price EL) in neighbouring countries that have interconnections through transmission lines with BPS, etc.

The final step of BPS modelling provides an opportunity with an hourly discretisation step to analyse the power disbalance of the BPS, its energy import/export and energy prices.

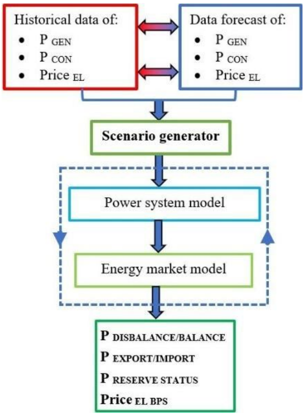


Fig. 2.1. The structure of the modelling platform.

2.2. MODEL OF BALTIC POWER SYSTEM

Baltic power system (BPS) Fig. 2.2. model includes separate comprehensive mathematical models (submodels) correspondingly to the existing and foreseeable energy sources: pumped storage hydropower plants [60] [59], hydropower plants (HPP) [59], [61]; small hydropower plants (sHPP); solar power plants (SPP); wind power plants (WPP); electric vehicles (EV); power reserve (PR (cogeneration power plants and thermal power plants)) [62]–[64]; bioenergy power plants (BPP); BPS electricity demand and interconnections between the Baltic power system and Finland, Sweden and Poland [66].

Furthermore, each submodel considers a wide range of specific features: technic-economic limitations as well as environmental constraints. BPS internal distribution network (330 kV) represents a simplified mathematical model excluding power losses and limitations of transmission line capacities.

The considered BPS mathematical model encompasses the interconnection potentials of Finland (Estonia–Finland), Sweden (Lithuania–Sweden), Poland (Lithuania–Poland). Environmental conditions have an impact on the transmission line features [66]. However, the thesis assumes corresponding capacities of transmission lines: 1 016 MW (Estonia– Finland), 700 MW (Lithuania–Sweden) and 1 700 MW (Lithuania–Poland). In that way, the mathematical model of the BPS provides an opportunity for analysing energy balance of the Baltic power system.

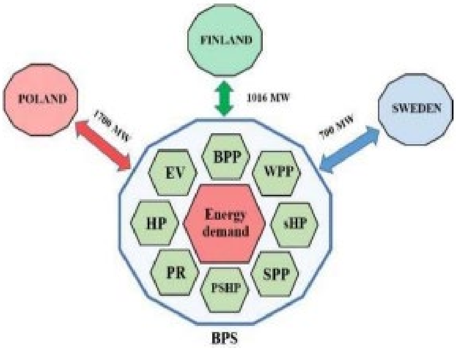


Fig. 2.2. The structure of the modelled BPS.

2.3. ENERGY MARKET MODEL

Another speculation of the article is that the plants' shareholders strive to increase their profitability and are forced to follow the technical and legal constraints established by the laws of the NordPool [68] day-ahead electricity market, the government and the networks. The final two steps of the modelling structure work together to achieve optimal power flows. The objective is to maximise the benefits of energy export while minimising expenses related to energy import and local power reserves.

Table 2.1 provides data of forecast total power consumption and power generation by source for Scenario 1 (BPS 2030), for Scenario 2 (BPS 2050) and for Scenario 3 (BPS 2050).

Table 2.2. presents the maximum values of the predicted power consumption and power generation by source for the BPS modelling scenarios under consideration [70]. The forecast Baltic power system consumption (BPSC) in 2030 is 37.86 TWh. The forecast BPS consumption in 2050 is 41.80 TWh [74]-[79].

Taking into account the development plans of the Baltic countries regarding the integration of EVs, the following assumptions are considered in the Thesis:

- The total number of EVs for 2030 and 2050 is EUR 1 million and 3 million, respectively.
- The average daily mileage is 15 km/day. The average energy consumption equals 0.3 kWh/km.
- The energy storage capacity of EV batteries is 90 kWh.

Also, all the cars will be charged evenly overnight, from 11 p.m. to 7 a.m. (for 8 hours) when the predicted market price will be lower than during business hours. An increasing trend in the installed capacities of renewable energy sources (RES) can be observed in the second part of

Table 2.1, in columns SPP and WPP, respectively. It has to be noted that in Scenario 2 and Scenario 3, the RES installed capacity differs twofold. Assessment of the impact of renewable energy sources on the BPS energy balance is a major reason for the difference of the above parameters. The capacity of the local power reserve is supported by conventional power plants that emit greenhouse gases into the atmosphere. The power reserve (PR) value summarises the capacities of thermal power plants (TPP) located in Estonia and fuelled by oil shale. Also, the PR includes existing and planned CHPPs in Latvia and Lithuania. In the long-term perspective, the capacity of fossil energy production is planned to be limited. For example, in the long term, the Estonian National Energy Sector Development Plan implies a reduction in CO2 emissions by reducing oil shale TPPs [67].

The last column of Table 2.2, titled “PR”, reflects a trend of conventional power plant capacity reduction. Thus, the hourly available PR capacity in 2030 is equal to 4 300 MWh (Scenario 1). Due to the policies of reducing CO2 emissions into the atmosphere, it is planned to reduce reserve power hourly capacity to the 1 500 MWh (Scenario 2 and Scenario 3). Capacity reduction of conventional power plants is a questionable development plan for the energy sector and more in-depth consideration and argumentation are required.

Table 2.1.

Power consumption and power generation data for modelling scenarios 1, 2 and 3

	BPSC TWh	SPP TWh	WPP TWh	HP TWh	sHP TWh	BPP TWh	PSHP TWh
1	37.86	1.74	11.66	1.9	0.34	3.52	2.85
2	41.8	2.19	17.64	1.9	0.34	3.52	2.85
3	41.8	4.52	34.57	1.9	0.34	3.52	2.85

Table 2.2.

Maximal power consumption and maximal power generation data for modelling scenarios 1, 2 and 3

	BPSC MW	SPP MW	WPP MW	HP MW	sHP MW	BPP MW	PSHP MW	PR MW
1	6 026	1 489	3 907	1 562	165	522	1 625	4 300
2	7 233	1 876	5 913	1 562	165	522	1 625	1 500
3	7 233	3 872	11 586	1 562	165	522	1 625	1 500

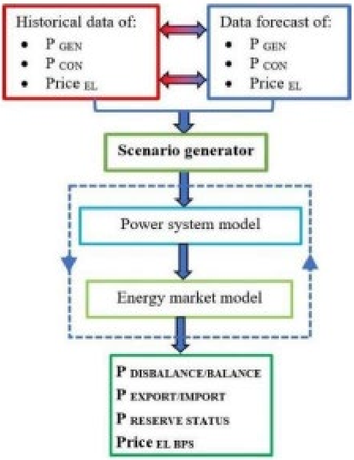


Fig. 2.3. Applied simplified structure of energy market model.

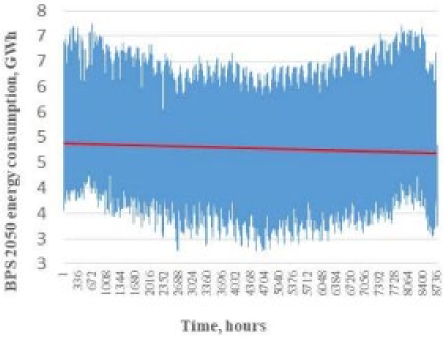


Fig. 2.4. BPS's 2050 hourly modelled energy consumption

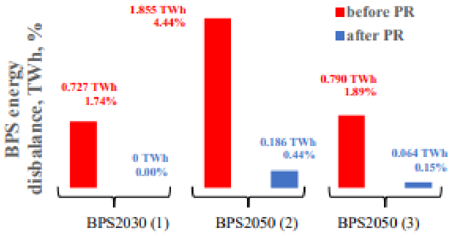


Fig. 2.5. The impact of the power reserve on the BPS energy balance.

The capacity of the local power reserve is supported by conventional power plants that emit greenhouse gas into the atmosphere. The power reserve (PR) value summarises the capacities of thermal power plants (TPP) located in Estonia and fuelled by oil shale. Also, the PR includes existing and planned CHPPs in Latvia and Lithuania.

2.4. ESTIMATION OF MINIMUM POWER RESERVE MAINTENANCE

The value of power reserve needed to terminate the BPS's energy deficit can vary in a sufficiently wide range. Thus, the maximum capacity of power reserve needed to compensate energy deficit in BPS 2030 equals 1 740 MWh (Fig. 2.6.). At the same time, frequency analysis of required PR activation for BPS 2030 energy deficit compensation shows that the above maximum value was applied only once during a whole year. However, to ensure the BPS 2030 energy balance, it is vital to maintain the required amount of power reserve. Accordingly, to the results of

Table 2.1, the power reserve capacity in 2030 will be 4 300 MWh. It can be noted that the maintained PR value covers the energy deficit in BPS 2030. The histogram in Fig. shows an opposite result. Here, the maximum capacity of energy deficit in 2050 is 2 890 MWh. As listed in Table 2.1, the planned power reserve capacity in 2050 is 1 500 MW. As a consequence of short-sighted energy sector development policies, the planned PR capacity cannot compensate the energy deficit. As a result, the maximum hourly energy deficit in BPS2050 remains equal to 1 390 MWh. It is expected that a significant number of RES will help in energy balancing. Fig. 2.8.shows a bar diagram of required capacities to balance the BPS 2050 energy deficit in Scenario 3. In contrast with the previous case of Scenario 2, where the maximum hourly energy deficit capacity was 2 890 MWh, the result of the twofold increase in the RES installed capacity led to a maximum hourly energy deficit of 2 756 MWh. As in the previous case, the planned amount of power reserve cannot cover the energy deficit and BPS 2050 continues to be unbalanced.

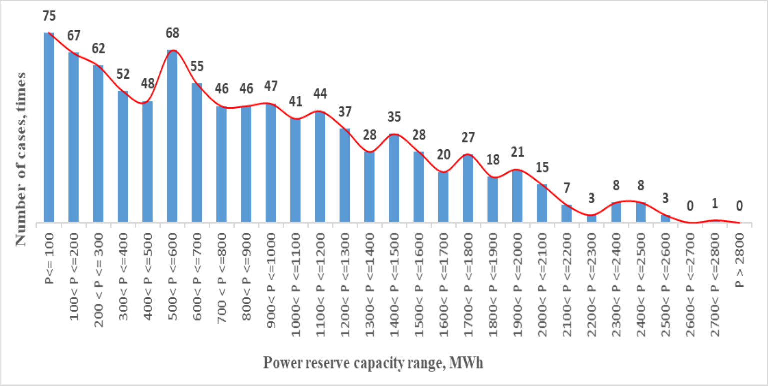


Fig. 2.6. Histogram of energy deficit in BTS2030 (scenario 1) after electricity import / export procedures.

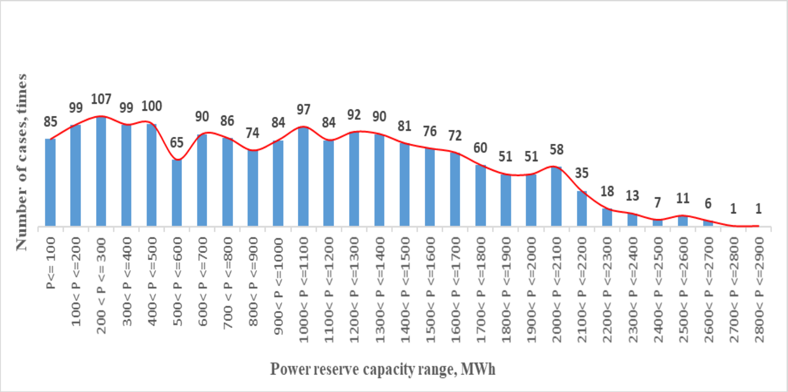


Fig. 2.7. Histogram of energy deficit in BTS2030 (scenario 2) after electricity import / export procedures.

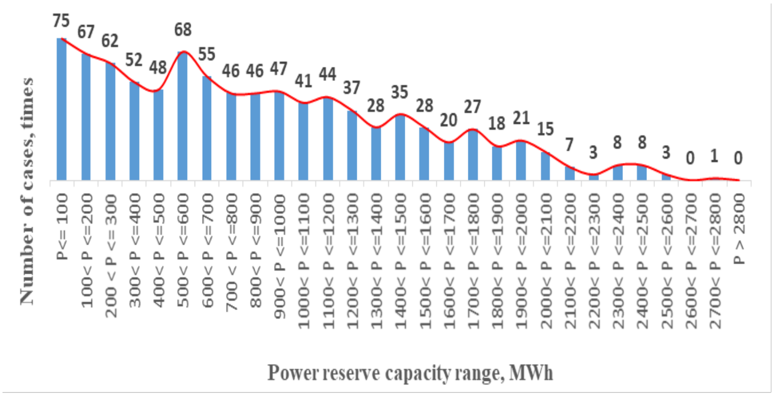


Fig. 2.8. Histogram of energy deficit in BTS2030 (scenario 3) after electricity import / export procedures.

2.5. MODELING THE ENERGY DEMAND OF EVs

This subchapter is devoted to the transport electrification problem.

When modelling the consumption of EVs [70]-[72], assumption are the following:

- The total number of EVs in Baltic States is 2 million. We accept that by 2050 all cars in region will be electric.
- The average daily mileage is known (we take 15 km/day). The average energy consumption is also known (0.3 kWh/km).
- Energy storage capacity of EV batteries is 90 kWh and all cars will be loaded evenly overnight, from 11 p.m. to 7 a.m. (during 8 hours).
- At night and in 2050 the price of energy will be lower than during business hours. Fig. 2.9.reflects the Baltic energy consumption in 2050.

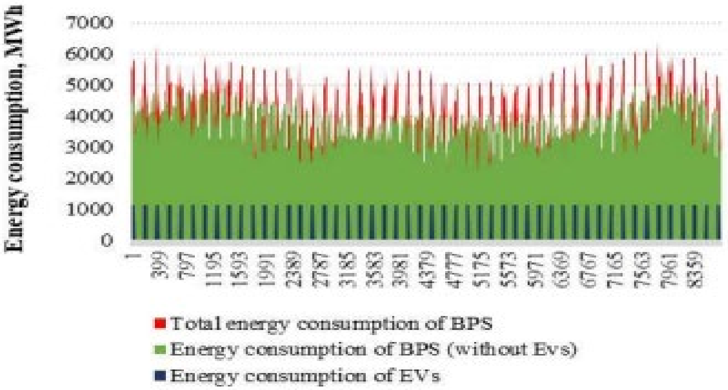


Fig. 2.9. BPS 2050 modelled energy consumption

It can be seen from the Fig. 2.9. that EVs consume about 10% of the energy consumed in the Baltics. This is a significant quantity that affects the operation of the power system.

2.6. CASE STUDY AND RESULTS

To demonstrate the impact of the electrification of transport on the self-sufficiency of the Baltic energy system and the need to exchange energy with neighbouring countries, we will consider two main cases:

Case 1 – the power system operates without EVs.

Case 2 – to the conditions of the model according to the first point, we add the energy of the car battery charge.

Case 1.

Figure. 2.10. demonstrates the imbalance of energy production/ consumption of the BPS in the situation when reserve stations using natural gas are not used.

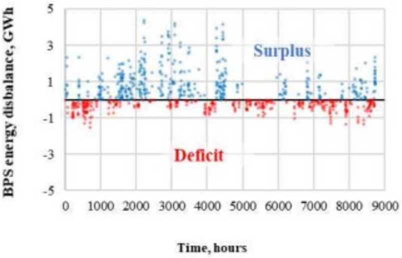


Fig. 2.10 BPS 2050 energy imbalance after energy import/export procedures (reserve stations are not used)

The graph shows the presence of time intervals when the energy balance is not ensured. The increase in imports is impossible due to the limited capacity of the lines. At the same time, there are periods of time when excess energy is generated. Surplus energy can be eliminated by turning off generators. However, the energy deficit is 0.13 TWh. The hourly frequency of energy deficit is 4.36%. Consequently, we see the need to use reserve power station capacities. Fig. 2.11.. demonstrates the imbalance of energy production/ consumption of the BPS in the event when reserve stations are used.

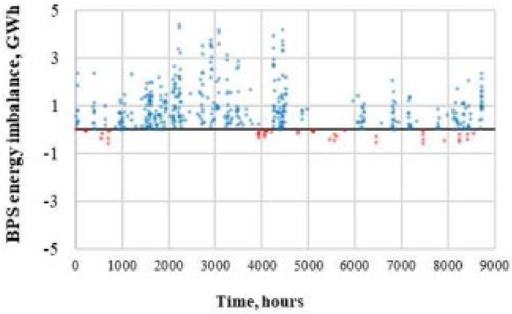


Fig. 2.11. 2050 energy imbalance after energy import/export procedures (reserve stations are used)

Analyzing the results of Fig. 2.11., it can be concluded that the use of reserve stations reduces the energy deficit to the level of 0.009 TWh, which is 0.03% of the energy consumption. The frequency of occurrence of the energy deficit also decreased to the level of 0.52%. The shortage of the named insignificant volume of energy could be eliminated, for example, by organizational measures (increase in tariffs or bonuses for reducing consumption. However, as will be shown below, electrification of cars will dramatically worsen the situation.

Fig. 2.12.. presents the imbalance of energy production/ consumption of the BPS corresponding to the use of EVs. Fig. 2.12.BPS 2050 energy imbalance after energy export procedure (reserve stations are not used, 2 mil. EVs are used) The graph shows the situation corresponding to the power supply of two million EVs. Analysing this graph, it can be stated that the the frequency of power deficit occurrence equals to the 65.57 % during 2050 (when in Case 1 it is equal to 61.66%). The graph allows us to draw a conclusion about the inability of the power system of the structure under consideration to meet the demand for energy (without reserve plants).

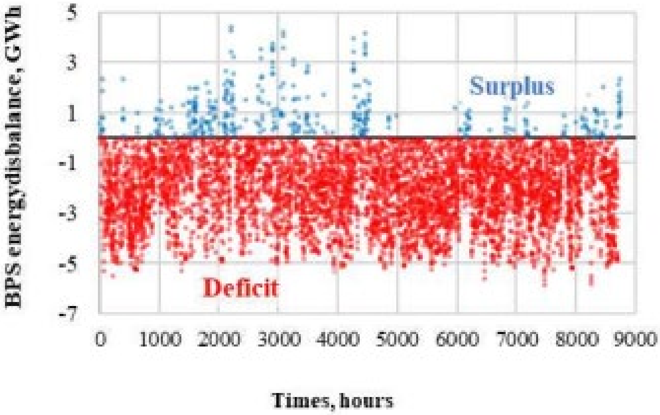


Fig. 2.12. BPS 2050 energy imbalance after energy export procedure (reserve stations are not used, 2 mil. EVs are used).

Either additional electricity generators or additional stations capable of storing energy are required, or stronger ties with neighbouring countries. Energy import in BPS 2050 practically reduces the energy deficit by up to 12.19% (Fig. 2.13.). However, this value of the deficit is not acceptable either.

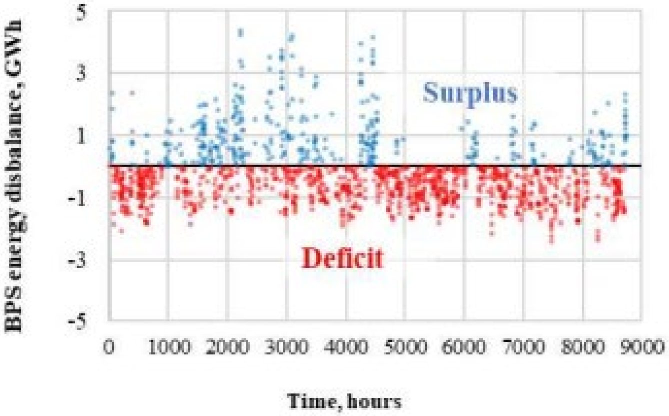


Fig. 2.13.BPS 2050 energy imbalance after energy import/export procedures (reserve stations are not used, 2 mil. EVs are used).

Figure 2.14 presents the electricity imbalance of BPS 2050 when the reserve energy power plants are used.

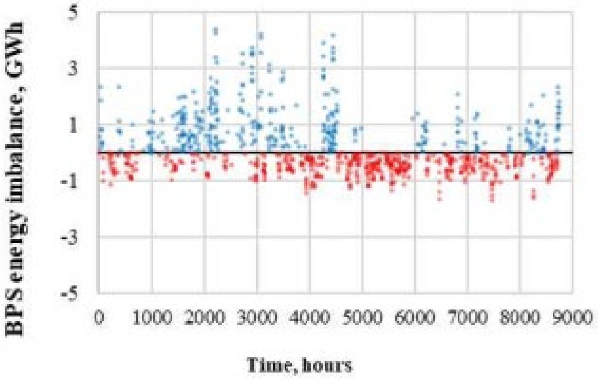


Fig. 2.14. BPS 2050 energy imbalance after energy import/export procedures (reserve stations are used, 2 mil. EVs are used)

The energy reserve activation led to the electricity deficit appearing frequency diminishing to 6.08 %, which is much higher than in Case 1. When comparing the energy imbalance in the BPS between Case 1 and Case 2, a significant issue of energy deficit becomes apparent.

2.7. CONCLUSIONS

To achieve the above-set goal and to stop climate change, the global and European energy development plans propose applying several strategies, at least two of which significantly affect the structure of energy systems: Strategy 1 – a precipitous increase in the capacity of power plants operating on renewable energy sources; Strategy 2 – reducing the capacity, suspending or shutting down power plants that use fossil fuels. It is a well-known fact that the production of electricity from RES is an unpredictable and volatile process. As a result, there is a problem related to manageable energy production and ensuring the power balance of any energy system. Sometimes, to entirely compensate for the power deficit by energy import from neighbouring countries is an impossible issue due to the limited capacity of transmission lines. Thus, the last opportunity to mitigate the energy deficit is to activate the local power reserve. The BPS 2030 energy development plan provides for a reserve capacity of 4 300 MW. As a result, the energy deficit of BPS 2030 is completely covered and the energy balance is maintained. The above strategies (Strategies 1 and 2) of the energy development plan are implemented in BPS 2050 (Scenario 2). Hence, the simulation results of BPS 2050 (Scenario 2) argue that attempts to ensure energy balance by power import and to compensate for the energy deficit by increasing the installed capacity of RES do not lead to success. At the same time, the reduced capacity of reserved power plants does not allow getting rid of the power deficit. A nearly twofold increase in the installed capacity of wind and solar power sources is considered in BPS 2050 (Scenario 3). However, the above-described power generation potential is not a panacea and the BPS 2050 system remains in energy deficit.

The electrification of cars will significantly worsen the Baltic power system’s capacity balancing situation. To meet the demand for electricity, it will be necessary to build additional stations that can generate energy in the absence of sun and wind or create new transborder transmission lines and long-term energy storage capacities.

The results prove that the adequacy of BPS needs a more detailed assessment and analysis. The developed mathematical model allows determining the minimal value of power reserve needed to be maintained for ensuring energy balance to the BPS. Only a rational, reasonable and timely selection of the operation mode of the BPS’s power plants, as well as a carefully thought-out development strategy is the only way to form a sustainable and balanced energy system of the future.

3. BENEFITS OF REGIONAL BALANCING AREAS

3.1. INTRODUCTION

This chapter provides an analysis of the operation of the common balancing area based on a case study of the Baltic common balancing energy market model, which was launched on the 1st of January 2018. The manual frequency restoration reserve (mFRR) helps to stabilize the frequency of the electricity grid. In most countries, the TSO (Transmission System Operator) is in control of its finding and activation. The mFRR (also tertiary reserve) helps to restore the required grid frequency of 50 Hz. The objectives of the development of the common Baltic balancing market were to increase balancing efficiency, to increase availability of balancing resources, and to reduce the costs of power system balancing. Establishing the common Baltic balancing market required harmonization of balancing market frameworks of the three Baltic States, including the settlement rules between market parties, the introduction of a coordinated balance control on a regional level and the introduction of a common balancing IT platform. This chapter analyses operational indicators assessing the performance of the new balancing system, including changes in area control error, changes in market liquidity and diversity, and changes in balancing costs for market participants. This chapter also analyses changes in balancing energy price dynamics in the Baltic states, including price volatility and price correlation, to understand how imbalance prices could motivate balanced steering of the balanced responsible parties. Proposals for further balancing market model development are also provided in the chapter. Multiple indicators are utilized to evaluate the performance of the new balancing system, encompassing alterations in area control error (indicative of balance management quality), shifts in market liquidity and diversity, and changes in balancing costs for market participants. Additionally, this chapter analyses variations in imbalance energy price dynamics within the Baltic states, including price volatility and correlation.

Utilizing data from 2017 and 2018 (see Fig. 3.1.) covering a complete year of operation under the new model, facilitates a comparison between the old and new approaches. This enables the identification of trends stemming from the introduction of the Common Baltic Balancing market and offers insights into potential improvements for subsequent operational periods. Furthermore, the experience gained serves as valuable knowledge for other regions undertaking similar initiatives.

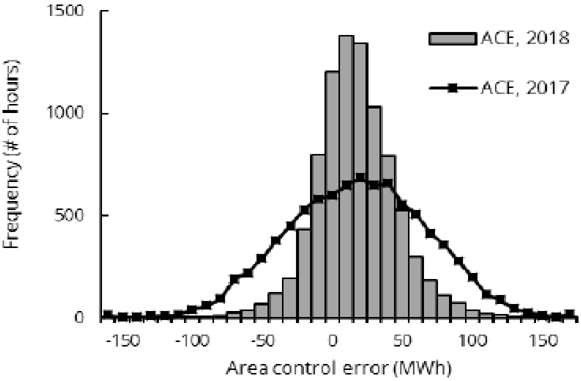


Fig. 3.1. Baltic Area control error (ACE)

From 2017 till 2018 there was visible significant impact on main balancing market performance characteristics.

3.2. CREATING COMMON BALANCING MARKET

The goal of the common Baltic balancing market is to increase transmission system operation reliability, foster the availability of balancing resources, and reduce the costs of system balancing. A common balancing market creates competition between balancing service providers which reduces the costs of balancing responsible parties.

The main objectives for the common Baltic balancing market are:

- increased reliance on local balancing resources and improved balancing market liquidity;
- levelling playing field and establishing incentivizing price signals that promote BRP's self-balancing;
- harmonized settlement procedures to remove market entry barriers;
- improved data transparency.

The following features were introduced with Baltic CoBA:

- common balancing towards Russia;
- TSO-TSO imbalance netting;

- common centralized mFRR activation model with shared merit order list;
- Nordic-Baltic mFRR exchange;
- harmonized BRP balance management model and imbalance pricing methodology

3.3. IMPACT ON BALTICS'S AREA CONTROL ERROR

Baltic’s area control error (ACE) means the Baltic’s not netted imbalance towards Russia.

Successful cooperation models among TSOs for balance control and imbalance netting has been in place for some time, and one of successful examples is Grid Control Cooperation (GCC) between German TSOs [95], that has grown to pan-European imbalance netting project involving 24 countries. Introducing similar principles to common Baltic balancing area enables optimization of balancing effort. As each country is not balanced separately it is possible to avoid counter-activation by netting "long" and "short" positions and as a result there is higher availability of mFRR reserves for minimization of Baltic’s Area Control Error (ACE).

The advantages and challenges of imbalance netting are widely discussed; [96] emphasizes the importance of TSO-TSO settlement to maintain financial neutrality, thus all TSOs benefit from imbalance netting.

The analysis of historical data on Baltic CoBA performance revealed that the centralized balancing market approach led to a significant decrease in Baltic ACE. Average ACE decreased by 43 %, from 42 MWh to 24 MWh per imbalance settlement period (ISP) in 2018 compared to the year 2017. Similarly, improved results on maintaining ACE close to 0 MWh were observed. In 2018, ACE was within the 50 MWh range at 89 % of operational hours compared to 65 % in 2017.

The trend of monthly acumulated ACE "Fig. 3.7" indicates that ACE could continue decrease even further as we gain experience in choosing and ordering the optimal amount of balancing energy. Improvements in ACE forecasting will also contribute to ACE reduction.

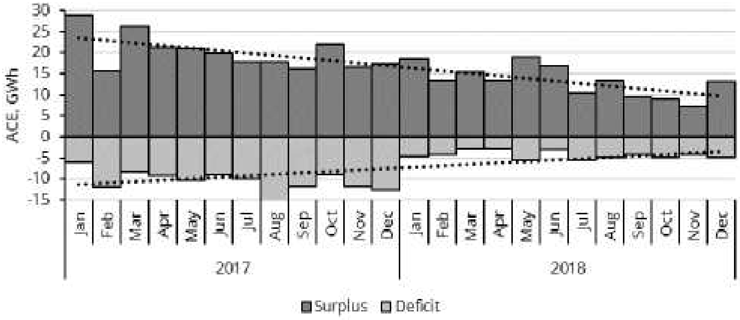
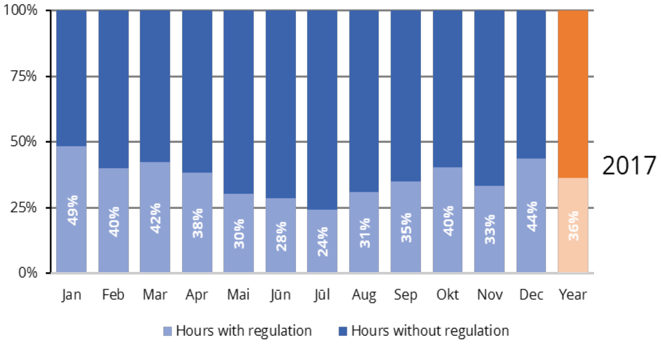


Fig. 3.6 Monthly acumulated ACE.

3.4. MARKET LIQUIDITY

More active balancing of CoBA with the goal to minimizing the Baltic ACE increased the frequency of use of balancing energy bids. In 2018 Baltic TSOs ordered mFRR products in 79% of hours, which is twice as much as in 2017 (36% of hours), Fig. 3.



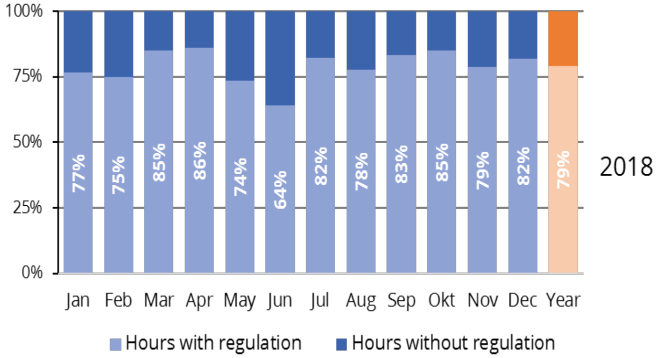


Fig. 3.3. Share of hours with regulation.

This higher demand for balancing resources increased balancing market liquidity and made it more attractive to local generation. Therefore, the amount of used balancing energy in 2018 tripled compared to 2017 "Fig.3.4.", while at the same time share of local balancing resources stayed at the level of 66%.

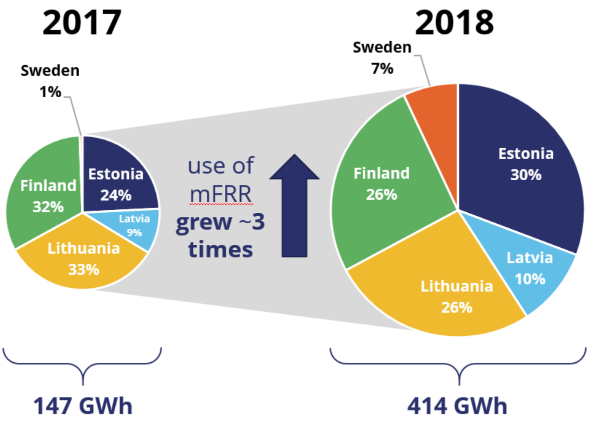


Fig.3.4. Use of balancing energy

3.5. IMBALANCE PRICING

The major change is seen not only by balancing service providers but also by balancing responsible parties – introduction of single pricing for BRPs regardless of their imbalance position. Until 2018, settlement procedures were country-based; imbalance prices included country-specific components. Harmonization of settlement procedure and introduction of single imbalance price model (previously – dual price model) led to almost full convergence of imbalance prices in the Baltic counties in 2018. Hourly imbalance prices were equal "Fig. 3.5." in Latvia, Estonia and Lithuania in 97% of hours in 2018.

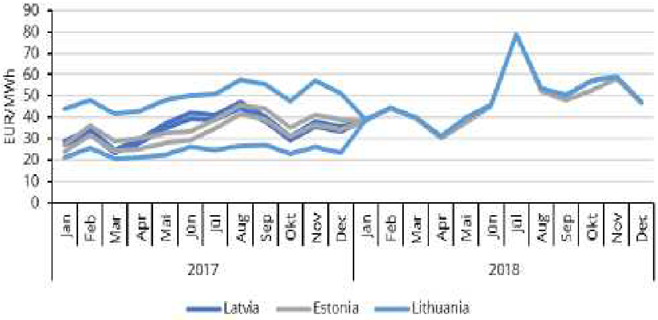


Fig. 3.5. Imbalance price.

The imbalance price in 2018, compared to the day-ahead market for Baltic countries, shows that 43 % of hours have had a higher imbalance price than the day-ahead price. In addition to that, there are continuous periods of up to 88 hours long with an imbalance price difference in one direction (smaller or larger) compared to a day-ahead price. Long periods of price difference in one direction may create motivation for BRPs to plan for intended imbalance with "long" or "short" positions. This effect should be further monitored and analysed to understand if it does not create counterproductive behaviour at the system level.

Changes in the imbalance pricing system created a more level playing field for pan-Baltic BRPs and BSPs. Total Baltic BRP balancing costs decreased from EUR 19.9 M in 2017 to EUR15.1 M in 2018. To evaluate the impact of changes in the imbalance pricing model on pan-Baltic BRP's imbalance costs, we simulated the BRP's portfolio.

Pan-Baltic BRP was created with an average hourly planned consumption of 100 MWh in each country. Hourly consumption was profiled according to the Baltic weekly average consumption profile. To create multiple scenarios with randomized imbalances towards the planned schedule, the actual position was randomly generated for each hour from the planned value. Randomization was made with normal distribution and standard deviation of 5 MW to get, on average, a 4 % imbalance (no leaning towards surplus or deficit). As a result, the cost/profit was calculated from the bought/sold imbalance volume. Average yearly cost/profit of imbalance MWh (300 scenarios) is shown in

Fig.3.6 and Fig. 3.7.. It is visible that the cost of simulated BRP reduced significantly compared to 2017 to 2018 and that BRP can benefit from netting its imbalances between Baltic countries, therefore reducing the cost of balancing.

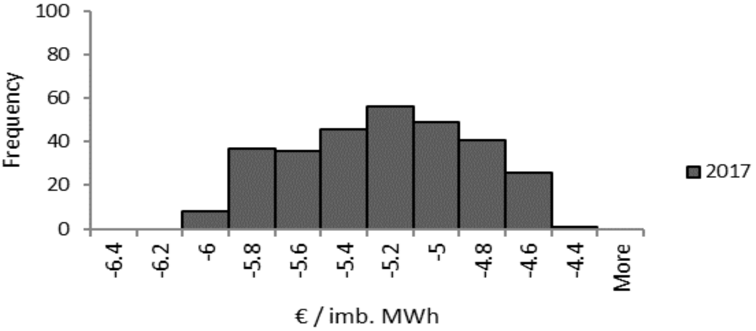


Fig.3.6 BRP imbalance costs in 2017

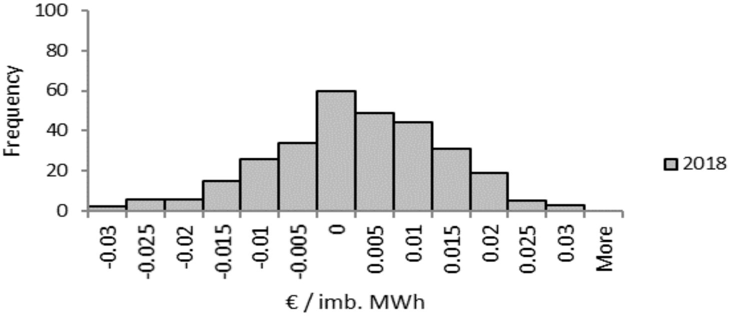


Fig. 3.7. BRP imbalance costs in 2018

Trend of monthly acumulated ACE (Fig. 3.8) indicates that ACE could continue decrease even further from gaining experience in choosing and ordering optimal amount of balancing energy. Improvements in ACE forecasting will also add to reduction of ACE.

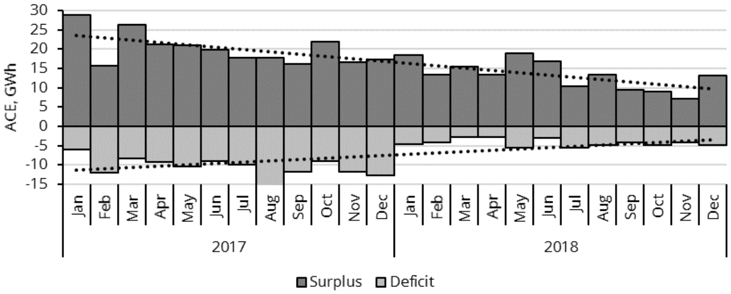


Fig. 3.7. Monthly accumulated ACE.

3.6. CONCLUSIONS

Analysis of performance indicators of the Baltic balancing system indicates clear benefits of common balancing areas and coordinated balance management. Market players, including balancing service providers and balanced responsible parties, benefited from the introduction of a single price and single portfolio model. Considering that in 2018, 97 % of hours imbalance prices were similar in all three Baltic states, the balanced responsible parties are able to exercise imbalance netting and substantially reduce balancing costs that are passed onto end-users. The analysis shows that the introduction of a common balancing area and centralized balance management at a regional level has improved the efficiency of system balancing, reduced ACE, improved the availability of balancing resources, and thus improved the security of supply.

The model presented in this chapter is not yet ready to ensure active real-time balancing from the BRP side because imbalance and balancing prices are published after real time, and that is an issue which requires further study.

4. MARKET-BASED STORAGE MANAGEMENT STRATEGY FOR FCR PROVIDER

4.1. INTRODUCTION

The focus of this chapter was publication [83] which presents a market-based storage state of charge management strategy for primary frequency control providers with limited energy reservoirs such as battery energy storage systems. The frequency containment reserve (FCR), also known as the primary control reserve*,* is the first reaction to frequency disturbances. If a deviation occurs, the automatic frequency restoration (aFRR) gets involved automatically within seconds to restore the rated frequency and the balance between supply and demand. The strategy is the result of research work motivated by relatively recent regulatory condition updates in continental Europe, which stipulate that frequency containment reserve providers cannot rely on dead-band utilization and delivery over fulfilment to manage their reservoirs. In addition, we show how the devised strategy allows an appropriately sized battery system to withstand the realization of a worst-case scenario, even if the unit is providing multiple reserve products at once and is allowed to recover its state of charge only via the intraday market.

In order to both facilitate and regulate the integration of storage systems in ancillary service markets, especially for the provision of **frequency containment reserve** (FCR), the EU System Operation Guideline [85] stipulates specific rules applicable to **limited energy reservoirs (LERs)**, i.e. storage units that can be depleted within two hours of operation. Namely, the minimum activation period (Tmin LER criterion) to be ensured by FCR providers qualified as LERs is 15–30 min during the system alert state with a specific value to be proposed by all TSOs of each synchronous area. While the continental Europe (CE) TSOs lean towards a 30-min Tmin LER at least for newly installed storage power plants, the final proposal is still under development.

LERs as FCR and frequency restoration reserve (FRR) providers are of particular interest for the Baltic power system, which is scheduled to desynchronize from IPS/UPS and connect to the CE synchronous area by 2025 [86]. By this time, the Baltic TSOs ought to be able to cover their FCR and FRR needs themselves while historically the primary frequency control has been ensured by the neighboring Russian power system [87] ,[88]. Hence, large-scale battery energy storage system (BESS) projects are under development in the Baltics to ensure FCR and FRR adequacy [88]-[91]. The outlined EU-level developments and regional challenges around the Baltic synchronization project have motivated the research question of this study: develop efficient market-based BESS operational management strategy subject to a set of technical and regulatory constraints related to ancillary service markets and specific reserve products as well as to electricity wholesale markets for storage recovery.

4.2. SOC MANAGEMENT STRATEGY

The main goal of the strategy is to prepare ID bids while delivering the reserves in order to assure a sufficient SOC level in line with the undertaken reserve (FCR and/or FRR) obligations. The overall philosophy of the strategy envisions a robust approach, i.e. the BESS must strive to be prepared for the realization of a worst-case scenario at any future point in time..

Assumptions and Simplifications.

We assume that the FCR provider is a single BESS with a LER which can only use market-based mechanisms for restoring the energy content of its reservoir (i.e. no alternative generation or load neither in the reserve provider's portfolio nor contracted bilaterally which could be used to charge/discharge the BESS; intentional imbalance to manage storage disallowed). Ultimately, this means that the BESS can manage its SOC only by participating in the ID market as it has a much shorter lead time than the DA market and thus allows for more flexibility. To achieve the most effective storage management under the laid out conditions, the optimum decision-making time on whether an ID trade offer needs to be submitted would be at the last possible moment before the GCT. However, for the sake of robustness, a certain bid preparation time should be added before each ID GCT by which the decision is made. The relationship between various time-related variables employed in the management strategy is explained in Fig. 4.1., where tID, decision – moment in time for ID offer decision; tID, GCT, next – the closest ID GCT; tID, start and tID, end – the start and end time of the ID trading period with the closest GCT; Δtprepare – user-selectable time period for bid preparation (expressed in minutes before GCT, e.g. 5 min); ΔtID, GCT – ID GCT (in minutes before delivery start, e.g. 60 min in Baltics[92]); ΔtMTU – market time unit duration (assumed 15 min [87]).

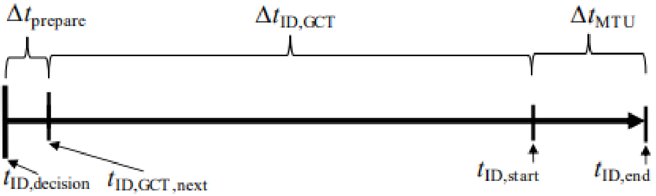


Fig. 4.1. Relationship between the time-related variables

Relationship between the time-related variables to minimize over-correction risks, ID trades are prepared only for the shortest possible delivery periods, i.e. at each decision time only one potential MTU is considered for delivery. On the other hand, this means that the need for corrective trade has to be evaluated before each ID GCT; with a 15-min MTU this equals to 96 decisions a day.

Based on analysis of the EU regulatory framework, we derive the following main requirements for the SOC management strategy of a BESS to provide FCR with a LER qualification:

- Capability to provide a prolonged full FCR activation at least until the TminLER criterion is satisfied during the system alert state.

- Capability to provide uninterrupted prolonged FCR up to 25% of the total committed reserve power in one direction during the system normal state.

- Recovery of sufficient storage level to be able to fulfill the TminLER criterion no later than 2 hours after the end of a prior system alert state.

- The previous three requirements need to be met also when the BESS provides FRR alongside FCR. However, the committed FRR must be able to be fully activated at any given time for any duration regardless of the TminLER criterion and post-alert state recovery status. This is because there are no special properties defined or exemptions allowed for an FRR provider with a LER.

4.3. ALGORITHM

The main steps of the devised algorithm are generalized in Figure 4.2.and detailed explained in prepared annex paper [83],

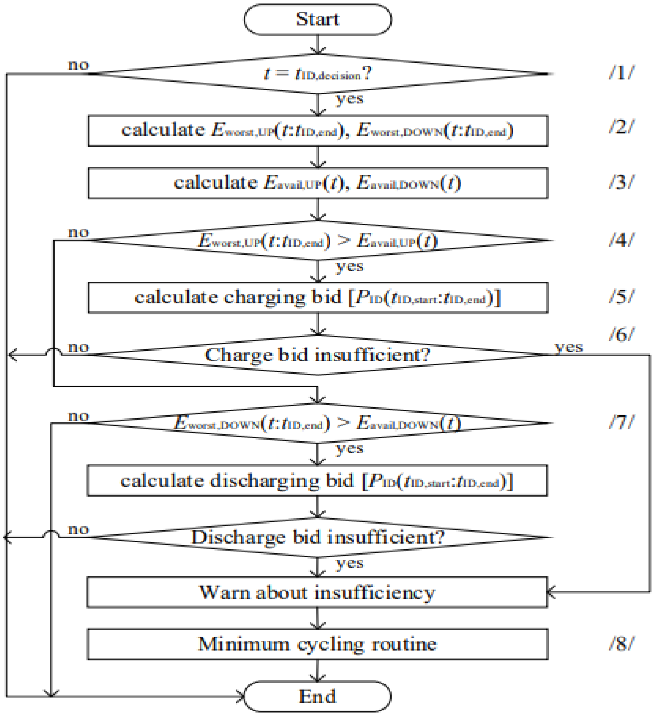


Figure 4.2. Main steps of the energy recovery algorithm [83].

The mathematical model developed to simulate and validate the outlined strategy, could be used in future work to study the impact of BESS technical parameters on their reserve provision capabilities as well as the impact of market regulations on BESS performance.

4.4. VALIDATION

A model for algorithm validation was created in publication [83] a BESS with 80 MW charge/discharge capacity, 160 MWh rated storage, 0.95 charge and discharge efficiencies and reservoir limits 10% and 90%. The BESS has to provide 8 MW of FCR and 32 MW of FRR in each direction. The selected parameters have been derived from the estimated reserve needs in the Latvian power system after desynchronization from the IPS/UPS in 2025 and from the specification of BESS that is being discussed for installation in Latvia [84]. In terms of reserve activations, for FCR we assume a sixhour frequency deviation profile as depicted by the brown line / right axis in Fig. 4.9 (NB: FCR providers observe a ±10 mHz dead-band followed by a proportional response reaching a full activation at ±200 mHz deviation). This profile is entirely artificial as its only purpose is to demonstrate that the devised BESS management strategy can ensure the reserves as expected. The FRR activations are likewise simulated to enforce a worst-case scenario realization (i.e. full activation for the entire six hours).

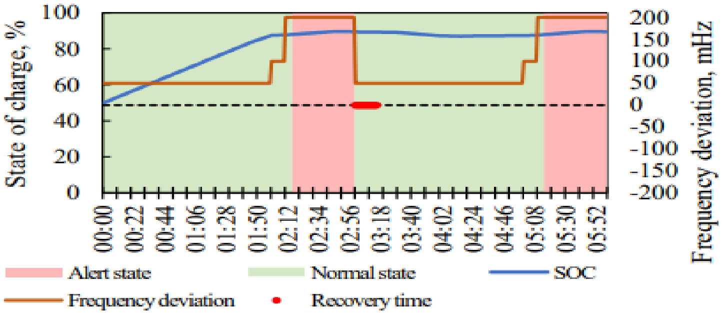


Fig. 4.8. Simulated frequency deviation and LER SOC evolution.

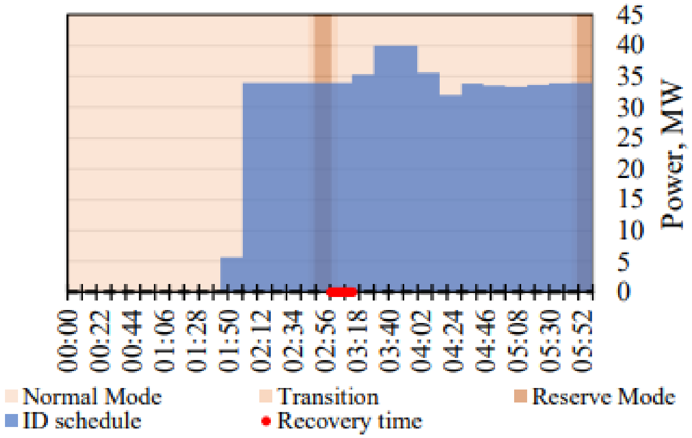


Fig. 4.4. The schedule of corrective ID trades and FCR provision mode.

In the simulated scenario, the BESS is able to continuously provide a 25% FCR activation during the normal state of the power system together with a full FRR activation without any issues. At 2:15 an alert state is declared due to frequency deviation exceeding 50 mHz for 15 minutes and 100 mHz for 5 minutes. The LER starts transition to Reserve Mode only at 2:44 when the 30 minute TminLER criterion has been fulfilled. At 3:00 the alert state ends due to the frequency deviation dropping slightly below 50 mHz, at which point the 2-hour countdown for LER recovery starts. However, the LER already completes the recovery at 3:16, which means that it only required 16 min to be completed. This is due to the robust nature of the storage management algorithm. It is also partly because of the fact that scheduled future ID deliveries are taken into account when evaluating the recovery conditions, provided that there is no risk of violating the SOC constraints at any point in the considered future time horizon. At 5:15 another alert state is declared and again the LER only starts transition to the Reserve Mode once 30 min of full activation have been endured. From Fig. 4.9 it can be seen how the SOC trajectory approaches the upper constraint of 90% but does not violate it, instead remaining near it. Moreover, thanks to the scheduled ID deliveries (Fig. 4.4.), the LER can even guarantee continued capability to provide the required FCR and FRR despite the SOC presently being close to the constraint.

4.5. CONCLUSION

The validated market-based BESS SOC management strategy enables robust and reliable LER participation in FCR provision, meeting all the additional properties and regulatory provisions that FCR providers with LERs are subjected to in continental Europe. It is also suitable for LERs providing both FCR and FRR. The devised strategy can be applied to prospective BESS installations in the Baltic power system after synchronization with CE and also elsewhere in the EU as it follows the most recent regulations to be adopted by the Member States. Moreover, the tool allows testing the impact of important technical parameters and market settings to aid in decision-making. The crux of the offered approach is anticipating and preparing for the emergence of a worst-case scenario. Due to the limitations of chapter size, only a part of the overall BESS operational management strategy has been presented, which, among other aspects, also manages the LER's transition between normal/reserve mode and estimates the voluntary FRR energy bids. Hence, the elaboration of the additional model components and features remains a topic for future work. Furthermore, the mathematical model developed to simulate and validate the outlined strategy could be used in future research to study the impact of BESS technical parameters on their reserve provision capabilities as well as the impact of market regulations on BESS performance. The potential topics of future studies include BESS and reserve sizing, pros and cons of qualification as an LER, duration of the Tmin LER criterion, recovery duration, market lead time, etc. Moreover, the model can be extended to also consider diverse economic criteria to ultimately provide a comprehensive cost-benefit assessment of a LER-qualified BESS with varied control strategies.

CONCLUSIONS OF SECTIONS AND FUTURE WORK

The main preconditions for the Baltic States mentioned in Chapter 1 on the transformation of the energy sector in the Baltic States to promote adequacy of power supply and development of balancing capacity are:

1. Promote generation development.
2. Invest in grid development.
3. Promote consumer response and aggregation and
4. Develop the balancing market, especially after the planned synchronization of the Baltic energy system with the continental European grid in 2025.

Chapter 2 highlights that the global and European energy development plans propose applying several strategies, at least two of which significantly affect the structure of energy systems.

Strategy 1: A precipitous increase in the capacity of power plants operating on renewable energy sources.

Strategy 2: Reducing the capacity, suspending or shutting down power plants that use fossil fuels.

It is a well-known fact that electricity production from RES is an unpredictable and volatile process. As a result, there is a problem related to manageable energy production and ensuring the power balance of any energy system. Sometimes, to entirely compensate power deficit by energy import from neighbouring countries is an impossible issue due to the limited capacity of transmission lines.

The simulation results of all BPS 2050 scenarios show that attempts to ensure energy balance through power import and to compensate for the energy deficit by increasing the installed capacity of RES do not lead to success.

Additionally, car electrification will significantly worsen the Baltic power systems’ capacity balancing situation. To meet the demand for electricity, it will be necessary to build additional stations that can generate energy in the absence of sun and wind or create new interconnection transmission lines and long-term energy storage capacities.

Conclusions of Chapter 3 based on analysis of performance indicators of the Baltic balancing system indicate clear benefits of common balancing areas and coordinated balance management. Market players, including balancing service providers and balanced responsible parties, benefited from the introduction of a single price and single portfolio model. Considering that in 2018, 97 % of hours imbalance prices were similar in all three Baltic states, balanced responsible parties are able to exercise imbalance netting and substantially reduce balancing costs that are passed onto end-users.

Analysis shows that the introduction of a common balancing area and centralized balance management at a regional level has improved the efficiency of system balancing, reduced ACE, improved availability of balancing resources and thus improved security of supply.

The model presented in this chapter is not yet ready to ensure active real-time balancing from the BRP side because imbalance and balancing prices are published in real time, and that is an issue that requires further study.

Conclusions of Chapter 4 based on the validated market-based BESS SOC management strategy enable robust and reliable LER participation in FCR provision, meeting all the additional properties and regulatory provisions that FCR providers with LERs are subjected to in continental Europe. It is also suitable for LERs providing both FCR and FRR. The devised strategy can be applied to prospective BESS installations in the Baltic power system after synchronization with CE and also elsewhere in the EU as it follows the most recent regulations to be adopted by the Member States. Moreover, the tool allows testing the impact of important technical parameters and market settings to aid in decision-making. The crux of the offered approach is anticipating and preparing for the emergence of a worst-case scenario. Due to the limitations of chapter size, only a part of the overall BESS operational management strategy has been presented, which, among other aspects, also manages the LER's transition between normal/reserve mode and estimates the voluntary FRR energy bids. Hence, the elaboration of the additional model components and features remains a topic for future work. The mathematical model developed to simulate and validate the outlined strategy, could be used in future work to study the impact of BESS technical parameters on their reserve provision capabilities as well as the impact of market regulations on BESS performance. The potential topics of future studies include BESS and reserve sizing, pros and cons of qualification as an LER, duration of the Tmin LER criterion, recovery duration, market lead time, etc. Moreover, the model can be extended to also consider diverse economic criteria to ultimately provide a comprehensive cost-benefit assessment of an LER-qualified BESS with varied control strategies.

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ANNEXES

Annexes 1.

Baltijā ilgtermiņa pārvades tiesību izsoles nepaplašinās

2017. gada maijā pēc padziļinātas izpētes un publiskām konsultācijām ar tirgus dalībniekiem Igaunijas, Latvijas, Lietuvas, Somijas, Zviedrijas un Polijas nacionālie regulatori pieņēma koordinētus lēmumus neieviest jaunas ilgtermiņa pārvades tiesību izsoles uz starpvalstu robežām Baltijas tirgū. Tas nozīmē, ka tuvākajos gados nozīmīgas izmaiņas Baltijas elektroenerģijas finanšu tirgus modelī nav gaidāmas.

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Valentīns Lavrinovičs, AS "Augstsprieguma tīkls" projektu vadītājs
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Nolemj nepaplašināt pārvades tiesību izsoles Baltijā

2016. gada 17. oktobrī stājās spēkā Eiropas Komisijas regula, kas nosaka vadlīnijas attiecībā uz cenu risku ierobežošanas instrumentu pilnveidi Eiropas tirgū. Regula uzdod pārvades sistēmas operatoriem ieviest uz visām tirdzniecības zonu robežām ilgtermiņa pārvades tiesību izsoles, izņemot gadījumus, ja regulatori sešu mēnešu laikā kopš regulas stāšanās spēkā koordinēti pieņemtu lēmumu par ilgtermiņa pārvades tiesību izsoļu neieviešanu. Pirms lēmuma pieņemšanas regulatori izvērtēja, vai attiecīgajās cenu zonās tirgū ir pietiekami pieejami cenu risku ierobežošanas instrumenti. Novērtējums ietvēra konsultācijas ar tirgus dalībniekiem par instrumentu nepieciešamību, kā arī tika analizēta tirgū jau piedāvāto instrumentu vai to kombināciju efektivitāte. Pieejamo instrumentu efektivitāte tika vērtēta pēc tādiem parametriem kā likviditāte, pirkšanas-pārdošanas cenu starpība, tirdzniecības apjoma (*open interest*) attiecība pret fizisko patēriņu u.c. 1. attēlā parādīts nacionālo regulatoru koordinēti pieņemto lēmumu kopsavilkums Baltijā. Kopumā regulatori ir vienojušies neprasīt pārvades tiesību izsoļu ieviešanu uz Baltijas valstu robežām.

Svarīgi uzsvērt, ka regulatori pieņēma koordinētus lēmumus, lai Baltijas reģionā veidotos homogēns, efektīvs tirgus modelis. Tāpēc, pieņemot lēmumu par savā pārraudzībā esošajām robežām, regulatori ņēma vērā arī citu regulatoru viedokli.

Igaunijas un Somijas regulatori nolēma, ka ilgtermiņa pārvades tiesību vai citu produktu ieviešana nav nepieciešama

Igaunijas un Latvijas regulatori nolēma, ka ilgtermiņa pārvades tiesību vai citu produktu ieviešana nav nepieciešama

Lietuvas un Latvijas regulatori nolēma, ka ilgtermiņa pārvades tiesību ieviešana nav nepieciešama; Lietuvas un Latvijas PSO ir jāgādā, lai tirgū būtu pieejami citi produkti

Zviedrijas un Lietuvas regulatori nolēma, ka ilgtermiņa pārvades tiesību ieviešana nav nepieciešama; Zviedrijas un Lietuvas PSO ir jāgādā, lai tirgū būtu pieejami citi produkti

Polijas un Lietuvas regulatori nolēma, ka ilgtermiņa pārvades tiesību ieviešana nav nepieciešama; Polijas un Lietuvas PSO ir jāgādā, lai tirgū būtu pieejami citi produkti

1. attēls. Regulatoru lēmumi par Baltijas pārrobežu risku vadības instrumentiem

Somijas-Igaunijas robeža

Balstoties uz elektroenerģijas vairumtirgus novērtējumu, Somijas (FI) un Igaunijas (EE) regulatori vienojās, ka Somijas un Igaunijas tirdzniecības zonās pastāv pietiekami cenu risku ierobežošanas instrumenti, ar kuriem pārvaldīt cenu riskus uz FI-EE tirdzniecības zonu robežas. 2016. gada statistika rāda, ka starp Somijas un Igaunijas elektroenerģijas biržas cenām ir salīdzinoši maza starpība (vidēji 0,7 EUR/MWh) un ļoti augsta korelācija (0,97). Tas dod iespēju Igaunijas tirgus dalībniekiem cenu risku ierobežošanai izmantot Somijas tirdzniecības zonas finanšu instrumentus (EPAD). Somijas EPAD instrumenti ir vieni no likvīdākajiem Skandināvijas finanšu instrumentiem (sk. 3. att.). Tāpēc Somijas un Igaunijas regulatori vienojās nepieprasīt Somijas un Igaunijas pārvades sistēmu operatoriem ieviest pārvades tiesību izsoles uz Somijas-Igaunijas robežas.

Igaunijas-Latvijas robeža

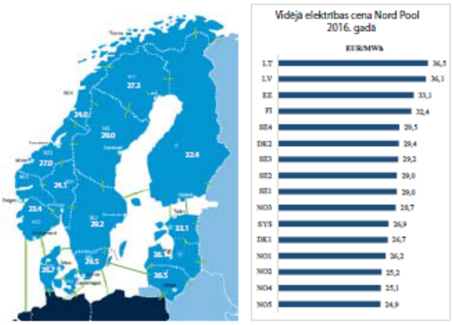
Balstoties uz elektroenerģijas vairumtirgus novērtējumu, Igaunijas un Latvijas (LV) regulatori vienojās, ka gan Igaunijas, gan Latvijas tirdzniecības zonās pastāv pietiekami cenu risku ierobežošanas instrumenti. Kopš 2014. gada Igaunijas un Latvijas pārvades sistēmu operatori izsola pārvades tiesības uz EE-LV tirdzniecības zonu robežas virzienā uz Latviju, ko kombinācijā ar Skandināvijas finanšu instrumentiem var izmantot Latvijas tirgus cenas svārstību risku ierobežošanai. Savukārt pārvades ierobežojumi uz EE-LV robežas virzienā uz Igauniju praksē nepastāv. Tāpēc Igaunijas un Latvijas regulatori vienojās nepieprasīt attiecīgajiem pārvades sistēmu operatoriem ieviest pārvades tiesību izsoles uz EE-LV robežas virzienā uz Igauniju.

Latvijas-Lietuvas robeža

Pēc vairumtirgus novērtējuma Latvijas un Lietuvas (LT) regulatori secinājuši, ka Latvijas tirdzniecības zonā ir pietiekami pieejami instrumenti cenu risku ierobežošanai, bet Lietuvas tirdzniecības zonā – ne. Latvijas un Lietuvas cenu starpība ir ļoti neliela (2016. gadā vidēji 0,4 EUR/MWh) un abu tirdzniecības zonu cenu korelācija ļoti augsta (0,97), tāpēc var pieņemt, ka Lietuvas cenu svārstību risku ierobežošanai ir praktiski pielietojami tie paši instrumenti, kas tiek izmantoti Latvijas tirdzniecības zonā. Tomēr jāņem vērā, ka izsolītais pārvades tiesību apjoms uz EE-LV robežas līdzinās aptuveni ceturtajai daļai no Latvijas un Lietuvas kopējā elektroenerģijas pieprasījuma un tāpēc nav pietiekams, lai apmierinātu visu tirgus dalībnieku pieprasījumu. Tāpēc uz LV-LT robežas ir nepieciešami cenu risku ierobežošanas instrumenti. Latvijas un Lietuvas regulatori pieņēma lēmumu nepieprasīt pārvades sistēmas operatoriem izsolīt ilgtermiņa pārvades tiesības uz LV-LT tirdzniecības zonu robežas, bet uzdeva nodrošināt cita veida cenu risku ierobežošanas instrumentu pieejamību. Pārvades sistēmu operatoriem sešu mēnešu laikā ir jāsagatavo priekšlikums par alternatīviem instrumentiem un tas jāiesniedz regulatoriem apstiprināšanai.

Lietuvas-Zviedrijas robeža

Pēc vairumtirgus analīzes Zviedrijas un Lietuvas regulatori secināja, ka Zviedrijas tirdzniecības apgabalā SE4 ir pietiekami pieejami cenu riskus ierobežojoši instrumenti, bet Lietuvā – ne. Zviedrijas SE4 un Lietuvas tirdzniecības zonu cenām ir salīdzinoši liela starpība: 2016. gadā vidēji 7 EUR/MWh. Tomēr jāņem vērā, ka 2016. gadā *NordBalt* kabelis nebija pieejams 38% no plānotā darbības laika, kas paaugstināja cenu starpību. Taču arī stundās, kad *NordBalt* bija pieejams, vidējā cenu starpība bija vērā ņemama – 3,46 EUR/MWh. Zviedrijas un Lietuvas regulatori pieņēma lēmumu nepieprasīt pārvades sistēmas operatoriem ieviest ilgtermiņa pārvades tiesību izsoles uz SE4-LT tirdzniecības zonu robežas, bet uzdeva pārvades sistēmas operatoriem nodrošināt, ka ir pieejami cita veida instrumenti cenu risku ie-



2. attēls. Elektroenerģijas vidējās gada cenas *Nord Pool* biržā (2016).
Avots: *Nord Pool*

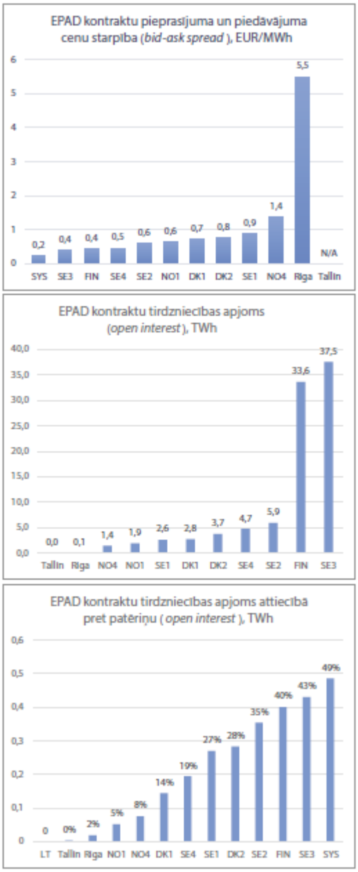
Tabula. Korelācijas koeficienti starp dažādu *Nord Pool* apgabalu *spot* stundu cenām 2016. gadā.

	FI	SE4	EE	LV	LT
SYS	0,79	0,88	0,76	0,56	0,54
FI		0,88	0,97	0,78	0,72
SE4			0,85	0,62	0,61
EE				0,74	0,78
LV					0,97

robežošanai, lai atbalstītu elektroenerģijas vairumtirgus funkcionēšanu uz minētās robežas. Pārvades sistēmu operatoriem sešu mēnešu laikā ir jāsagatavo priekšlikums par alternatīviem instrumentiem un tas jāiesniedz regulatoriem apstiprināšanai.

Polijas-Lietuvas robeža

Izvērtējot elektroenerģijas vairumtirgu, Polijas (PL) un Lietuvas regulatori secināja, ka Polijā ir pietiekama cenu risku ierobežojošo instrumentu pieejamība, bet Lietuvā – ne. Vidējā elektroenerģijas vairumtirgus cena Polijā 2016. gadā bija 36,48 EUR/MWh (avots: SKM), Lietuvā – 36,54 EUR/MWh, tātad vidējā vairumtirgus cenu starpība – 0,06 EUR/MWh. Tajā pašā laikā ikstundu cenu atšķirības gada laikā bija vērā ņemamas, tādēļ starpvalstu tirdzniecībai bija ekonomisks pamats. Tomēr nozīmīgs šķērslis pārvades tiesību izsoļu ieviešanai uz PL-LT robežas būtu nepastāvīgā, ierobežotā *LitPol* starpsavienojuma jaudas pieejamība Polijas pārvades sistēmas operatora regulāri noteikto ierobežojumu dēļ. 2016. gadā *LitPol* tirdzniecībai pieejamā jauda virzienā uz Lietuvu bija vidēji 30% no *LitPol* uzstādītās pārvades jaudas, bet virzienā uz Poliju – 62%. Savukārt faktiskā vidējā *LitPol* noslodze ar tirdzniecības plūsmām virzienā uz Lietuvu bija 10% no *LitPol* uzstādītās pārvades jaudas, bet virzienā uz Poliju – 24%.



3. attēls. Tirgus dati.
* Visu attiecīgās cenu zonas *Nasdaq OMX* tirgoto finanšu kontraktu apjoms periodā no 2015. gada jūnija līdz 2016. gada beigām.
Avots: SKM

Pārvades tiesību izsoles uz Igaunijas-Latvijas robežas tiks turpinātas

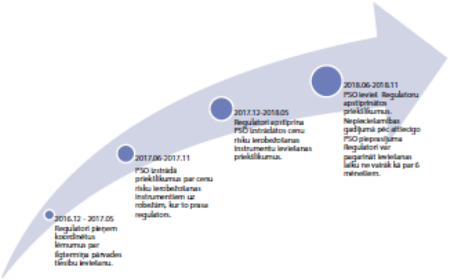
Atbildot uz tirgus dalībnieku atkārtotām prasībām ieviest cenu risku ierobežošanas instrumentus, Latvijas un Igaunijas pārvades sistēmas operatori ar nacionālo regulatoru atļauju kopš 2014. gada veic ilgtermiņa pārvades tiesību izsoles (*PTR-Limited*) uz Igaunijas-Latvijas robežas virzienā uz Latviju. Igaunijas un Latvijas pārvades sistēmas operatoru trīs gadu pieredze ar pārvades tiesību izsolēm liecina, ka šāds finanšu instruments Baltijas tirgum ir piemērots un ļoti nepieciešams. Šajā laikā veiktajās izsolēs gan mēnešu, gan ceturkšņu, gan gadu PTR-L instrumenti pilnībā izpirkti, pieprasījumam vairākkārt pārsniedzot piedāvājumu. Piemēram, 2016. gada septembrī notikušajā izsolē, kurā tika izsolīti 300 MW PTR-L 2017. gadam, pieprasījums pārsniedza piedāvājumu turpat piecas reizes, pārvades tiesību cenai noslēdzoties pie 2,53 EUR/MW. Arī izsoļu dalībnieku skaits no gada uz gadu ir pieaudzis, un šobrīd ir 12 aktīvi izsoļu dalībnieki.

Attiecībā uz esošajām PTR-L izsolēm uz Igaunijas-Latvijas robežas regulatori nepieņēma nekādus lēmumus, tāpēc patlaban izsoles tiks turpinātas.

Pārvades sistēmas operatori pētīs alternatīvus cenu risku ierobežošanas instrumentus

Saskaņā ar nacionālo regulatoru pieņemtajiem lēmumiem attiecīgajiem pārvades sistēmas operatoriem sešu mēnešu laikā (līdz 2017. gada novembrim) jāsagatavo priekšlikumi tam, kādus cenu risku ierobežošanas instrumentus ieviest uz Latvijas-Lietuvas, Zviedrijas-Lietuvas un Polijas-Lietuvas tirdzniecības zonu robežām. Izstrādātos priekšlikumus ir jāiesniedz regulatoriem apstiprināšanai. Šo priekšlikumu ieviešana notiek ne vēlāk kā sešus mēnešus pēc regulatoru apstiprinājuma. Saskaņā ar Eiropas Komisijas vadlīnijām pēc attiecīgo PSO pieprasījuma regulatori var ieviešanas laiku pagarināt, bet ne vairāk par sešiem mēnešiem (sk. 4. att.).

Priekšlikumu sagatavošanā viens no jautājumiem, uz kuru pārvades sistēmas operatoriem nāksies atbildēt, ir jautājums par pārvades sistēmas operatoru iesaisti finanšu instrumentu tirdzniecībā, jo no tā ir atkarīgs iespējamo alternatīvo finanšu instrumentu klāsts. Par pārvades sistēmas operatoru izstrādāto priekšlikumu tiks organizēta sabiedriskā apspriešana, kuras ietvaros visas ieinteresētās puses varēs izteikt savu viedokli un sniegt komentārus.



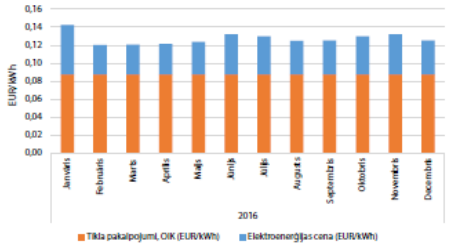
4. attēls. Nākamie soļi cenu risku ierobežošanas instrumentu ieviešanā saskaņā ar Regulu 2016/1719, ar ko izveido nākotnes jaudas piešķiršanas vadlīnijas.

Elektroenerģijas finanšu tirgus loma nākotnē varētu mazināties

Elektroenerģijas tirgus dalībnieki izmanto finanšu instrumentus, lai nodrošinātos pret finanšu riskiem, ko varētu radīt elektroenerģijas cenas svārstības nākotnē. Visaktīvākā finanšu instrumentu tirdzniecība parasti notiek līdz trīs gadu periodam nākotnē, kad elektroenerģijas ražotāji "fiksē" elektroenerģijas pārdošanas cenu (ieņēmumu līmeni), bet elektroenerģijas patērētāji "fiksē" elektroenerģijas pirkšanas cenu (izdevumu līmeni). Tas ir būtiski, lai tirgus dalībnieks pasargātu sevi no neplānota nozīmīga finanšu stāvokļa pasliktināšanās. Tomēr elektroenerģijas finanšu tirgus loma nākotnē pakāpeniski varētu mazināties un pat zust.

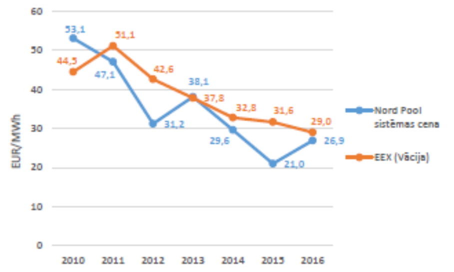
Viens no iemesliem ir arvien pieaugošais to elektroenerģijas patērētāju skaits, kuri izvēlas pirkt elektroenerģiju par cenu, kas piesaistīta elektroenerģijas biržas cenai. Ļoti tipisks arguments, kāpēc patērētājs izvēlas pirkt elektrību par fiksētu cenu, ir vēlme izvairīties no neplānota cenu lēciena, pat ja biržas cenai piesaistītais elektrības tarifs varētu būt zemāks par fiksēto cenu. Taču patērētāji bieži izdara šo izvēli, neiedziļinoties, cik patiesībā mainīgs var būt biržas cenai piesaistītais tarifs. 5. attēlā redzamas tarifa izmaiņas pa mēnešiem mājsaimniecības patērētājam 2016. gadā. Biržas cenai piesaistītā elektrības cena mainās no mēneša uz mēnesi, bet, tā kā 2/3 no elektrības tarifa veido nemainīgas komponentes – tīkla pakalpojuma tarifs un obligātā iepirkumu komponente, bet elektrības cena veido tikai 1/3 no elektroenerģijas rēķina, tad elektrības cenas svārstībām ir ierobežota ietekme uz kopējā tarifa svārstībām. Tāpēc arvien pieaug to patērētāju loks, kuri izvēlas pirkt elektrību par biržas cenai piesaistītu elektrības tarifu. Piemēram, Igaunijā šobrīd teju 30% no visiem patērētājiem pērk elektrību par cenu, kas piesaistīta *Nord Pool* biržas cenai.

Otrs iemesls, kāpēc nākotnē elektroenerģijas finanšu (forvardu) tirgus nozīme samazināsies, ir elektroenerģijas cenas pakāpeniska samazināšanās, ko rada vispārējas ģenerācijas struktūras pārmaiņas energosistēmā. Energosistēmā gadu no gada strauji attīstās vēja un saules elektrostacijas, kur ražošanas izmaksu struktūrā īstermiņa (mainīgās) ražošanas izmaksas ir tuvas vai līdzinās nullei. Šis ir viens no iemesliem, kāpēc pēdējos gados ar izteiktu tendenci samazinās elektroenerģijas cena. 6. attēlā redzams, kā pēdējos gados samazinās elektroenerģijas cena Skandināvijas biržā *Nord Pool* un Vācijas biržā *EEX*. To, cik strauji šī tendence turpināsies nākotnē, var prognozēt dažādi, taču šobrīd viss liecina par to, ka vēja un saules elektrostaciju īpatsvars energosistēmā nākotnē tikai palielināsies.



Pieņēmumi: mājsaimniecība ar mēneša patēriņu 300 kWh/mēn;
pieslēguma jauda 3 fāzes 25 A; elektrības cena pieņemta vienāda ar
mēnešu vidējo *Nord Pool* Latvijas cenu ar 10% mazumtirdzniecības uzcenojumu.

5. attēls. Mājsaimniecības patērētāja tarifa struktūra ar elektrības cenu, kas piesaistīta *Nord Pool* cenai (bez PVN).



6. attēls. Gada vidējās elektroenerģijas cenas izmaiņas biržās Skandināvijā un Vācijā.

Ceļā uz vienotu iekšējo elektroenerģijas tirgu – progress Eiropas Savienības tīkla kodeksu ieviešanā

Alnis Bāliņš, AS "Augstsprieguma tīkls" Elektroenerģijas tirgus integrācijas un attīstības daļas vadītājs

Aigars Sīlis, AS "Augstsprieguma tīkls" Elektroenerģijas tirgus integrācijas un attīstības daļas projektu vadītājs

Kristīne Mārciņa, AS "Augstsprieguma tīkls" Elektroenerģijas tirgus integrācijas un attīstības daļas projektu vadītāja

Laikposmā no 2015. līdz 2017. gadam tika izstrādāti un stājās spēkā trīs uz elektroenerģijas tirgus darbību attiecināmi elektroenerģijas tīkla kodeksi – noteikumu kopums, kas Eiropas līmenī un ar regulu spēku nosaka elektroenerģijas tirgus darbību Eiropas Savienības iekšējā elektroenerģijas tirgū. Šie tirgus tīkla kodeksi nosaka pārvades jaudas aprēķināšanas un piešķiršanas kārtību, nākamās dienas un tekošās dienas tirgu darbību, tirgus dalībnieku tirdzniecības risku vadību un balansēšanas jautājumu risināšanu, tā kopumā nodrošinot iespēju tirgot elektroenerģiju pāri valstu robežām Eiropas mērogā, pilnveidot un nostiprināt efektīvi strādājošu Eiropas vienoto iekšējo elektroenerģijas tirgu.

Šī raksta autori iepriekš (2015., 2016. un 2017. gadā) jau publicējuši atziņas par izmaiņām, kas ES iekšējā elektroenerģijas tirgū sagaidāmas pēc jauno tīkla kodeksu apstiprināšanas. Turpinot iesākto un atskatoties uz laika periodu kopš tirgus tīkla kodeksu apstiprināšanas, šajā reizē izklāstīsim, kas ir paveikts un kādus labumus guvuši elektroenerģijas tirgus dalībnieki līdz ar šajos tīkla kodeksos noteikto prasību ieviešanu.

Eiropas Savienība (ES) ir izstrādājusi un politiski apstiprinājusi Eiropas vienotā iekšējā elektroenerģijas tirgus modeli. Tas iekļauj ES kopējos noteikumus par efektīvu pārrobežu pārvades jaudu izmantošanu un Eiropas vairumtirdzniecības tirgus harmonizēšanas kārtību. Vienotā ES tirgus modeļa prasības tiešā veidā atspoguļojas arī trijos apstiprinātajos uz tirgu vērstajos tīkla kodeksos (vadlīnijās). Šie trīs tirgus tīkla kodeksi aptver visas elektroenerģijas tirgus darbības jomas – sākot ar nākotnes un beidzot ar tekošo tirgus darbības periodu (1. att.).

Šie trīs tirgus tīkla kodeksi ļaus harmonizēt pārrobežu tirgu darbību visos tirgus darbības laika posmos, nodrošinot stabilāku elektroenerģijas tirgus darbību un ļaujot visiem tirgus dalībniekiem bez ierobežojumiem darboties ES vienotajā iekšējā elektroenerģijas tirgū.

1. attēls. Eiropas iekšējā elektroenerģijas tirgus modelis

Tīkla kodeksu prasību izstrādē un ieviešanā ir iesaistījušies visi ES dalībvalstu pārvades sistēmas operatori (PSO) un, piekritīgi jautājumu lokam, arī visi ES nominētie elektroenerģijas tirgus operatori (NETO) jeb elektroenerģijas biržas. Tīkla kodeksu prasības katrai dalībnieku kategorijai ir gan atsevišķas, gan arī kopīgas.

Tīkla kodeksu ieviešana notiek arī reģionāli un nacionāli, atbilstoši tīkla kodeksu izvirzītajām prasībām par reģionālajiem un nacionālajiem vai sinhrono zonu nodevumiem. Kā pirmais nodevums tika veikta ES sadalīšana reģionos atbilstoši visu PSO kopīgam piedāvājumam, ko 2016. gada 17. novembrī apstiprināja Energoregulatoru sadarbības aģentūra (ACER). Tā rezultātā tika izveidoti 10 reģioni, kas tiek saukti par "jaudas aprēķina reģioniem" (JAR). Šo reģionu izveides pamatā ir esošo sinhrono zonu iedalījums un līdzstrāvas starpsavienojumi starp dažādiem reģioniem un ES valstīm (2. att.).

Baltijas jaudas aprēķina reģions ietver ES valstu iekšējās robežas – Igauniju, Latviju, Lietuvu, Poliju (*LitPol Link* – līdzstrāvas starpsavienojums), Zviedrijas 4. tirgus zonu (*NordBalt* – līdzstrāvas starpsavienojums) un Somiju (*Estlink I* un *Estlink II* – līdzstrāvas starpsavienojumi). Līdz ar to visu ES tīkla kodeksu prasību ieviešanu reģionāli ir jākoordinē attiecībās starp minēto sešu valstu PSO un nacionālajiem regulatoriem. Šis ir labs un pozitīvs piemērs Baltijas valstu energosistēmas un tirgus dziļākai integrācijai ES iekšējā elektroenerģijas tirgū.

Turpmāk izklāstīsim konkrētos būtiskos nodevumus, ko PSO atsevišķi vai kopdarbā ar NETO ir izdevies izpildīt un kas var demonstrēt jau konkrētus vai sagaidāmus ieguvumus no kopējā vienotā ES iekšējā elektroenerģijas tirgus integrācijas.

Nākotnes jaudas piešķiršanas tīkla kodekss[1]

Nākotnes jaudas sadales tirgus pamatfunkcija ir sniegt iespēju tirgus dalībniekiem vadīt savus pārrobežu elektroenerģijas tirdzniecības riskus. Tīkla kodekss nosaka principus, kā tirgus dalībnieki var iegādāties ilgtermiņa pārvades tiesības, kuras tiem ļauj ierobežot riskus saistībā ar elektroenerģijas cenu izmaiņām nākamās dienas elektroenerģijas tirgos atsevišķās tirdzniecības zonās.

Vienotā piešķiršanas platforma

Elektroenerģijas biržas cenas dažādos elektroenerģijas tirdzniecības apgabalos var atšķirties nepietiekamo pārvades jaudu, ražošanas avotu struktūras un tirgus piedāvājuma un pieprasījuma attiecību dēļ. Pārvades sistēmas operatoriem ir pienākums nodrošināt nepieciešamo elektroenerģijas pārvadi pieprasītajā apjomā un līdztekus – energosistēmas līdzsvaru tekošā laika momentā. Saskaņā ar ES elektroenerģijas tirgus modeli elektroenerģija no lētākiem elektroenerģijas apgabaliem plūst uz dārgākiem elektroenerģijas apgabaliem. Ja starpvalstu savienojumu caurlaides spējas jeb līniju pārvades jaudas nav pietiekamas, lai visa elektroenerģija no lētākā reģiona nosegtu pieprasījumu reģionā, kur cena ir augstāka, tad veidojas sastrēgumi. Tieši sastrēgumu dēļ cenas blakus esošajos apgabalos atšķiras.

Avots: ENTSO-E [illegible]

2. attēls. Eiropas Savienības jaudas aprēķina reģioni

Sastrēgumu gadījumā, kad izveidojas atšķirīgas cenas tirdzniecības apgabalu robežas abās pusēs, operatori gūst tā saucamos "sastrēgumu vadības ieņēmumus", elektroenerģijas cenu starpību sadalot starp abu elektroenerģijas tirdzniecības apgabalu operatoriem. Šos ieņēmumus saskaņā ar ES Regulu Nr.714/2009 var izlietot sastrēgumu mazināšanai (jaunu līniju būvniecībai – šaurās vietas likvidēšanai) vai pārvades tarifa samazināšanai saskaņā ar regulējošo institūciju lēmumiem.

Elektroenerģijas cenu ilgtermiņa riska samazināšanas ("hedžēšanas") instrumentu attīstība Baltijā un virzība uz vienotu izsoles platformu

Saskaņā ar Regulā Nr. 714/2009 noteikto 2013. gada 3. decembrī Baltijas valstu nacionālo regulatori vēstulē (*"Long-term risks hedging instruments"*) visiem Baltijas valstu elektroenerģijas pārvades sistēmas operatoriem izteica kopīgu pieprasījumu ieviest elektroenerģijas cenu ilgtermiņa riska samazināšanas ("hedžēšanas") instrumentus Baltijas valstu elektroenerģijas tirgū.

Ievērojot Baltijas valstu nacionālo regulatīvo iestāžu pieprasījumu un Latvijas un Igaunijas elektroenerģijas tirgus dalībnieku lūgumus, sākot no 2014. gada 1. janvāra AS "Augstsprieguma tīkls" kopīgi ar Igaunijas pārvades sistēmas operatoru AS "Elering" nodrošina starpvalstu savienojuma jaudas piešķiršanu uz Igaunijas-Latvijas tirdzniecības zonas robežas, organizējot ierobežotu fizisko pārvades tiesību ar atpakaļpārdevuma pienākumu izsoles uz Igaunijas-Latvijas tirdzniecības zonas robežas virzienā uz Latviju (turpmāk – izsoles).

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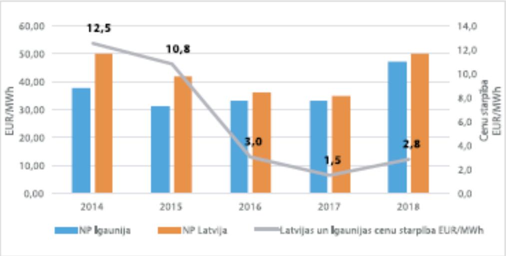
[1] http://networkcodes.entsoe.eu/wp-content/uploads/2013/08/131001-NC-FCA-final.pdf



3. attēls. Gada vidējā elektroenerģijas cenu starpība Latvijas un Igaunijas tirdzniecības apgabalos *Nord Pool* biržā

Viens no galvenajiem iemesliem, kāpēc pieprasījums pēc izsolēm nāca no Latvijas un Igaunijas elektroenerģijas tirgus dalībniekiem, bija esošā starpsavienojuma jaudas uz Igaunijas-Latvijas robežas nepietiekama pieejamība, kā rezultātā pastāvēja cenu atšķirības abos tirdzniecības apgabalos (3. att.), kas veicināja cenu svārstību risku.

Reģionālās piešķiršanas platformas attīstība ar mērķi iekļauties vienotā piešķiršanas platformā

Piedaloties izsolē un iegādājoties nosolīto jaudu (*Limited* formā), elektroenerģijas tirgus dalībniekiem ir iespēja ierobežot cenu svārstību risku, proti, saņemt naudu no operatoru sastrēgumu vadības ieņēmumiem vai pilnīgi vai daļēji samaksāt nosolīto cenu par iegādāto jaudu, ja atpakaļpārdevuma cena (cenu starpība starp Latvijas un Igaunijas tirdzniecības apgabaliem) ir mazāka nekā nosolītā summa vai vienāda ar to.

Norēķini starp vienoto piešķiršanas platformu un izsoles dalībnieku notiek ieskaita veidā, salīdzinot nosolīto cenu, kuru izsoles dalībnieks apņemas samaksāt par nosolītās jaudas iegādi, un atpakaļpirkuma cenu:

- izsoles rīkotājiem ir pienākums maksāt izsoles dalībniekam atpakaļpārdevuma cenas un nosolītās cenas starpību, ja atpakaļpārdevuma cena ir lielāka par nosolīto cenu;
- izsoles dalībniekam ir pienākums maksāt izsoles rīkotājiem nosolītās cenas un atpakaļpārdevuma cenas starpību, ja nosolītā cena ir lielāka par atpakaļpārdevuma cenu;
- izsoles dalībniekam ir pienākums maksāt izsoles rīkotājiem pilnu nosolīto cenu, ja atpakaļpirkuma cena ir vienāda ar 0 jeb Latvijas un Igaunijas tirdzniecības apgabalos elektroenerģijas cenas neatšķiras;
- nevienai pusei nav savstarpēju maksājuma saistību, ja nosolītā cena un atpakaļpārdevuma cena ir vienādas.

Nosolītā jauda (*FTR-option* formā) nepiešķir izsoles dalībniekam tiesības to izmantot elektroenerģijas fiziskai pārvadei.

Regulas 2016/1719 48. panta 1. punktā ir paredzēta vienotās piešķiršanas platformas (*single allocation platform*) izveide. Tādējādi saskaņā ar Regulas 2016/1719 prasībām reģionālā izsoles platforma ir jānodod vienotai piešķiršanas platformai.

Vienotās piešķiršanas platformas priekšlikuma izstrādē piedalījās visi PSO, kuri ierosināja nozīmēt *Joint Allocation Office S.A.* (turpmāk – JAO) par vienotās piešķiršanas platformas operatoru šādu iemeslu dēļ:

1) PSO kompetencē ir nākotnes jaudas piešķiršana, un tādēļ šī uzdevuma veikšanai ir izveidots kopējs PSO uzņēmums – JAO;

2) JAO ir radies, saplūstot CASC.EU S.A. un CAO *Central Allocation Office GmbH*, kuriem bija pieredze ilgtermiņa izsoļu rīkošanā. Tādējādi jau patlaban JAO organizē ilgtermiņa izsoles lielākajai daļai PSO, kuriem šis pienākums izriet no Regulas 2016/1719;

3) JAO jau ir pielāgojis savus rīkus un programmatūras, lai atbilstu ilgtermiņa pārvades tiesību saskaņotiem piešķiršanas noteikumiem saskaņā ar Regulas 2016/1719 51. pantu (turpmāk arī – HAR)), ko ir izstrādājuši atbilstošie PSO un apstiprinājušas atbilstošās nacionālās regulatīvās iestādes, sākotnēji ieviešot Regulu 2016/1719;

4) JAO patlaban ir sadarbības partneris lielākajai daļai tirgus dalībnieku, kas piemēro HAR un aptver lielāko daļu tirdzniecības zonu robežu, kur piemērojama nākotnes jaudas piešķiršana.

Ņemot vērā Regulā uzliktos pienākumus, Eiropas pārvades sistēmas operatoriem bija liels izaicinājums ieviest visas izmaiņas, kuras paredzēja Regula. Tā rezultātā tika optimizēti un automatizēti procesi, kas ne vien saglabāja elektroenerģijas tirgus dalībnieku ieinteresētību piedalīties reģionālās izsoles platformā, bet arī radīja interesi par dalību vienotā izsoles platformā.

Kā apliecinājums tam, ka visu Eiropas regulatoru pieņemtais lēmums bijis pareizs, ir 2018. un 2019. gada janvāra mēneša izsoles rezultātu salīdzinājums. Saskaņā ar AST[2] un JAO[3] interneta vietnē pieejamo informāciju izsoļu dalībnieku skaits pieauga par 110%, jo 2018. gada janvāra izolē piedalījās 9 tirgus dalībnieki no Baltijas, bet 2019. gada janvārī – jau 19 no visas Eiropas (4. att.).

Baltijas elektroenerģijas tirgus ir interesants ne tikai Baltijas valstu tirgotājiem, bet arī pārējiem ES tirgus dalībniekiem, par ko liecina lielais izsoles dalībnieku skaits.

Būtiski norādīt, ka, sākot ar 2019. gadu, vienotā izsoles platforma ir vienīgā un galvenā platforma, kurā var notikt tirdzniecība ar finanšu instrumentiem, kuri paredzēti Eiropas tirgum un darbojas pēc ES HAR.

Pārvades sistēmas operatori, kuri ir iesaistīti vienotajā jaudas izsoles platformā: *50Hertz* (Vācija), *Amprion* (Vācija), AS "Augstsprieguma tīkls" (Latvija), *Austrian Power Grid*

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[2] http://www.ast.lv/sites/default/files/editor/PTR-2018/Publishing%20results_January.pdf

[3] http://www.jao.eu/marketdata/monthlyauctions

	Reģionālās izsoles platformas rezultāti par 2018. gada janvāra izsoli uz Igaunijas-Latvijas robežas	Vienotās piešķiršanas platformas rezultāti par 2019. gada janvāra izsoli uz Igaunijas-Latvijas robežas
Piedāvātā jauda MW (*Offered capacity*)	150	150
Pieprasītā jauda MW (*Requested capacity*)	694	1200
Dalībnieku skaits (*Number of participants who placed bids*)	9	19
Dalīdnieki, kuri ieguva jaudu (*Number of successful participants*)	8	13
Izsolītā jauda MW (*Sold capacity*)	150	150
Cena EUR/MWh (*Marginal Price per hour*)	0.4	0.91

4. attēls. Reģionālās izsoles platformas rezultāti par 2018. gada janvāra izsoli un vienotās piešķiršanas platformas rezultāti par 2019. gada janvāra izsoli

(Austrija), *Creos* (Luksemburga), *Elering* (Igaunija), *Elia* (Beļģija), *Energinet.dk* (Dānija), *Fingrid* (Somija), *Litgrid* (Lietuva), *National Grid Interconnectors* (*Britned* un IFA, Apvienotā Karaliste), REE (Spānija), REN (Portugāle), RTE (Francija), *Statnett* (Norvēģija), *Svenska kraftnät* (Zviedrija), *TenneT* TSO B.V. (Nīderlande), *TenneT* TSO GmbH (Vācija) un *Transnet-BW* (Vācija).

Jaudas piešķiršanas un pārslodzes vadības tīkla kodekss[4]

Jaudas piešķiršanas un pārslodzes vadības tīkla kodeksa pamatfunkcija ir noteikt Eiropas Savienībā vienotus noteikumus pārrobežu (starpzonu) elektroenerģijas tirdzniecībai. Šis tīkla kodekss nosaka principus un prasības jaudas piešķiršanai – pieejamo pārrobežu pārvades jaudu piešķiršanai nākamās dienas un tekošās dienas elektroenerģijas tirdzniecībā, kā arī nosaka veidu, kā jāveic aprēķini elektroenerģijas tirdzniecībai piešķiramajai pārrobežu (starpzonu) pārvades jaudai dažādiem laika periodiem. Tīkla kodekss nosaka arī noteikumus pārslodzes vadībai un ierobežoto pārvades jaudu sadalei starp tirgus dalībniekiem – šo pārvades jaudu pieprasītājiem.

Jaudas sadales un pārslodzes vadības tīkla kodekss ir veidots, pamatojoties uz Eiropas Savienības vienotā iekšējā elektroenerģijas tirgus modeļa noteiktajiem principiem.

Lai nodrošinātu šo divu augstāk minēto tirgu darbību un tirgu savienošanu (*market coupling*), šis tīkla kodekss nosaka arī principus, kā reģionālie tirgi var tikt savienoti, izveidojot vienotu Eiropas iekšējo elektroenerģijas tirgu, kā un kādas prasības tiek izvirzītas pārvades sistēmas operatoriem un nominētajiem elektroenerģijas tirgus operatoriem (NETO; jeb elektroenerģijas biržām), izstrādājot algoritmus un metodikas.

Laika periodā no CACM apstiprināšanas līdz šodienai ENTSO-E sadarbībā ar NETO ir izstrādājusi, nostiprinājusi un nodrošina darbību šo algoritmu – un attiecīgi nākamās dienas un tekošās dienas tirgu – savienošanai un darbībai. Rezultātā patlaban strādā visu Eiropu iekļaujošs vienotais nākamās dienas tirgus, ko sauc par "reģionu cenu savienošanas tirgu" (*price coupling of the regions* – PCR), un gandrīz visu Eiropu iekļaujošs vienotais tekošās dienas tirgus, ko sauc par "pārrobežu tekošās dienas nepārtrauktas tirdzniecības tirgu" (XBID). Latvija – ar AS "Augstsprieguma tīkls" un Latvijas tirdzniecības zonā strādājošo nominēto elektroenerģijas tirgus operatoru *Nord Pool* tiešu iesaisti – ir pilnībā integrēta šajos abos tirgos, nodrošinot visiem Latvijas un Baltijas tirgus dalībniekiem piekļuvi plašajam vienotajam ES iekšējam elektroenerģijas tirgum.

PCR ir nākamās dienas tirgus savienošanas platforma, kuras izstrādē, uzturēšanā un darbībā piedalās 8 Eiropas NETO, 25 ES valstu PSO. Tās pamatā ir *Euphemia* algoritms, kas nodrošina vienotu nākamās dienas elektroenerģijas cenas aprēķinu visās ES tirdzniecības zonās, kurās strādā šie NETO un PSO. Integrētais vienotais ES elektroenerģijas nākamās dienas tirgus ir izdevīgs visiem dalībniekiem, jo tas nodrošina tirgus palielinātu likviditāti, cenas noteikšanas atklātību, pārvades jaudu izmantošanas palielinātu efektivitāti un kopumā – sociālekonomisko labklājību visiem sistēmā iesaistītajiem tirgiem un to dalībniekiem.

XBID ir tekošās dienas tirgus savienošanas nepārtrauktas tirdzniecības platforma, kuras izstrādē, uzturēšanā un darbībā šobrīd jau piedalās praktiski visi Eiropas NETO un PSO. Tā darbība tika uzsākta 2018. gada 12. jūnijā.

XBID sākās kā 11 valstu elektroenerģijas biržu un pārvades sistēmas operatoru kopīgs projekts, izpildot sagaidāmās CACM prasības attiecībā uz nepārtrauktas tekošās dienas tirdzniecības platformas izveidi, un tas šobrīd jau ir atzīts kā ES vienota tekošās dienas tirgus sasaistīšanas risinājums. Pārrobežu tekošās dienas elektroenerģijas tirdzniecības risinājums (XBID) uzsāka darbu 2018. gada 12. jūnijā, sākotnēji iekļaujot 15 dalībvalstis, tajā skaitā arī Baltijas valstis. Turpmāk XBID projektā iesaistīsies vēl vairākas valstis, kas iekļausies otrajā pieslēgšanās posmā, kas pašlaik tiek plānots uz 2019. gada nogali (5. att.).

XBID ir balstīts uz vienotu IT sistēmu, kura sastāv no: vienotas Kopīgās tirdzniecības rīkojumu grāmatas (*Shared Order Book* – SOB), Jaudas vadības moduļa (*Capacity Management Module* – CMM) un Sūtījumu izpildes moduļa (*Shipping Module* – SM). Tas nozīmē, ka tirdzniecības rīkojumi, ko iesniedz tirgus dalībnieki vienā XBID darbības valstī (tirdzniecības zonā), var tikt savienoti ar līdzīgiem tirdzniecības rīkojumiem, ko iesnieguši tirgus dalībnieki jebkurā citā darbības valstī (tirdzniecības zonā), ar nosacījumu, ka ir pieejama atbilstoša pārvades jauda. XBID mērķis ir palielināt kopējo tekošās dienas tirdzniecības efektivitāti.

XBID sistēma ir uzbūvēta, paredzot, ka tirgus dalībnieku visi tirdzniecības rīkojumi tiek centralizēti vienotajā SOB caur NETO lokālajām tirdzniecības sistēmām. Tirdzniecības

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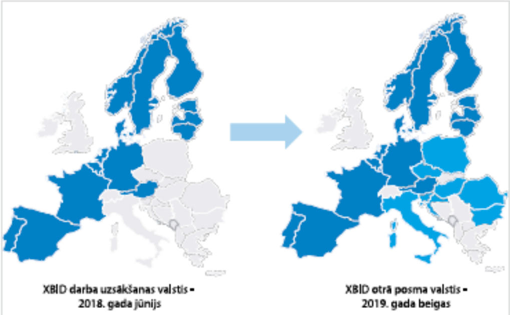
[4] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2015.197.01.0024.01.ENG



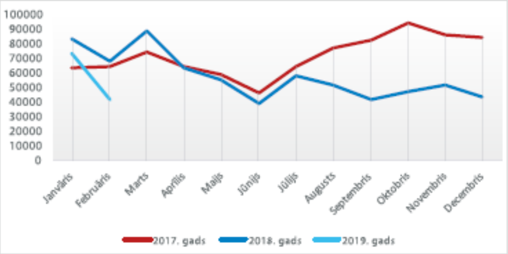
Avots: XBID

5. attēls. XBID sākotnējā un nākamā pievienošanās viļņa valstis

		Vācijas PSO apgabali	Austrija	Francija	Nīderlande, Beļģija	Ziemeļvalstis, Baltija	Spānija, Portugāle
Apjoms		Min. apjoma pieaugums 0,1 MW					
Cenu atzīme		EUR 0,01 par MWh					
Cenu intervāls		-9 999 €/MWh līdz 9 999 €/MWh					
Produkti	15 min.	X	X				
	30 min.	X		X			
	Stundas	X	X	X	X	X	X
	Lietotāja definēti bloki*	X	X	X	X	X	

* Stundas bloki (nevis 15 vai 30 min. bloki)

6. attēls. Specifiskie produkti, kas pieejami tirdzniecības zonās



7. attēls. Baltijas tekošās dienas tirgus attīstība (2017 – 2019)

rīkojumu izpildei pieejamās pārvades jaudas tiek vadītas ar CMM palīdzību, un tās tiek pārrēķinātas pēc katra tirdzniecības rīkojuma izpildes. Pašlaik XBID atļauj šādu (6. att.) tirdzniecības produktu pārrobežu realizāciju konkrētajos tirdzniecības reģionos.

XBID savu darbību ir uzsācis ļoti veiksmīgi. Tajā iesniegto, apstrādāto un izpildīto tirdzniecības rīkojumu skaits pieaug ar katru mēnesi. Patlaban XBID strādā jau gandrīz 10 mēnešus. Tirdzniecības darījumu skaitam ik mēnesi gandrīz dubultojoties, kopējais platformā notikušo tirdzniecības darījumu skaits pārsniedz jau 10 miljonus. Analizējot to, kādu iespaidu uz Baltijas tekošās dienas elektroenerģijas tirgu ir atstājusi XBID darbības uzsākšana, jāsecina, ka Baltijas tirgus dalībnieki nepietiekami aktīvi izmanto jaunās iespējas. Salīdzinot tirdzniecības datus par 2017. un 2018. gadu un 2019. gada pirmajiem mēnešiem, nav redzams, ka tekošās dienas tirdzniecības apjoms Baltijā pieaugtu.

Multi-NEMO kārtība

Jaudas piešķiršanas un pārslodzes vadības tīkla kodekss aplūko jaunus Eiropas iekšējā vienotā elektroenerģijas tirgus aspektus, ar kuriem, ES kontekstā, tirgus dalībnieki iepriekš nebija saskārušies. Līdz šim Eiropas Savienībā darbojās nacionālie un reģionālie elektroenerģijas tirgi, kuru darbību nodrošināja reģionālas vai nacionālas elektroenerģijas biržas. Piemēram, Baltijas valstis ir integrētas kopējā tirgū ar Ziemeļvalstīm: tirgus darbību nodrošina *Nord Pool*, kas šajā tirgū līdz šim darbojies kā monopolistisks elektroenerģijas biržas pakalpojumu sniedzējs. Jaudas piešķiršanas un pārslodzes vadības tīkla kodekss paver iespēju savstarpēji konkurēt arī elektroenerģijas biržām.

Tā rezultātā ES valstīs, kurās nav noteikts biržu darbības monopols (piem., Baltijas valstis, Ziemeļvalstis, Vācija, Polija) ir jānodrošina vide, kas atļauj strādāt vairāk nekā vienam NETO vienā tirdzniecības zonā. Baltijas valstīs, līdztekus Ziemeļvalstīm, savu darbību ir pieteikuši vismaz divi NETO – *Nord Pool* un EPEX. Visos ES reģionos tiek strādāts pie tā, lai nodrošinātu, ka līdz 2019. gada beigām ir veikti visi priekšdarbi, kas ļaus uzsākt darbu vairākiem konkurējošiem NETO vienā tirdzniecības zonā. Arī Baltijas valstu PSO kopīgi ar *Nord Pool* un EPEX strādā pie šo prasību izpildes.

Elektroenerģijas balansēšanas tīkla kodekss[5]

Elektroenerģijas balansēšanas tīkla kodekss stājās spēkā kā viens no pēdējiem, proti, 2017. gada 18. decembrī, līdz ar to 2018. gadā lielākoties tika attīstītas metodikas, kas iezīmē kopējā Eiropas balansēšanas tirgus satvaru. Šī tīkla kodeksa

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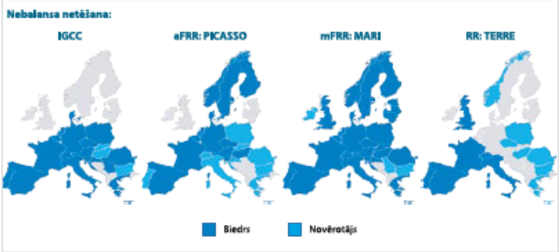
[5] https://eur-lex.europa.eu/legal-content/LV/TXT/HTML/?uri=CELEX:32017R2195&from=EN

mērķis ir nodrošināt Eiropas elektroenerģijas pārvades sistēmas optimālu pārvaldību un koordinētu darbību un izveidot ES mēroga tehniskos, darbības un tirgus noteikumus, ar ko regulē elektroenerģijas balansēšanas tirgu darbību. Tas arī paredz saskaņotu metodiku izstrādi, tādējādi palielinot balansēšanas tirgu likviditāti, paplašinot pārrobežu tirdzniecību un efektīvāk izmantojot esošo tīklu balansēšanas nolūkiem.

Tā kā Regula paredz sekmēt balansēšanas elektroenerģijas tirgu ar kopīgu Eiropas platformu starpniecību, paredzams, ka katram balansēšanas produktam tiks izveidota vienota Eiropas platforma, kas koordinēs pārvades sistēmas operatoru balansēšanas elektroenerģijas aktivizēšanas pieprasījumus un ļaus apmainīties ar balansēšanas elektroenerģiju. Eiropas platformā tiks pielietots PSO-PSO modelis, tāpēc aktivizēšanas pieprasījumi un komunikācija ar nacionālajiem balansēšanas pakalpojumu sniedzējiem (BPS) paliks katra pārvades sistēmas operatora pārziņā.



8. attēls. Balansēšanas platformu ieviešanas projektu statuss un dalībnieki

9. attēls. Vispārējais balansēšanas platformas darbības princips

Eiropā balansēšanas procesā var būt līdz pieciem soļiem:
- frekvences noturēšanas rezerves (*Frequency containment reserve* – FCR);
- nebalansa netēšana (*Imbalance netting* – IN);
- frekvences atjaunošanas rezerves ar automātisku aktivēšanu (*Frequency restoration reserves with automatic activation* – aFRR);
- frekvences atjaunošanas rezerves ar manuālu aktivēšanu (*Frequency restoration reserves with manual activation* – mFRR);
- aizvietošanas rezerves (*Replacement reserves* – RR).

Elektroenerģijas balansēšanas tīkla kodekss paredz ieviest kopējas Eiropas platformas, tādējādi harmonizējot Eiropas balansēšanas tirgus procesus. Tā kā katram no procesiem (izņemot FCR) tīkla kodekss paredz izveidot Eiropas platformu, Eiropas PSO ir izveidojuši šādus ieviešanas projektus (8. att.):
- IGCC (*International Grid Control Cooperation*) – nebalansa netēšanas procesam;
- PICASSO (*Platform for the International Coordination of Automated Frequency Restoration and Stable System Operation*) – aFRR procesam;
- MARI (*Manually Activated Reserves Initiative*) – mFRR procesam;
- TERRE (*Trans-European Restoration Reserves Exchange*) – RR procesam.

2018. gadā tika izstrādātas vairākas metodikas un PSO priekšlikumi, kas iezīmē turpmākā Eiropas balansēšanas tirgus satvaru un darbības pamatprincipus, harmonizē balansēšanas tirgus produktus un cenošanas principus. Savukārt 2019. gads iezīmēs sākumu pašu platformu izstrādē un ieviešanā. Eiropas platformu pamatā būs aktivizēšanas optimizēšanas funkcija, kas apstrādās visu ienākošo un izejošo informāciju – tostarp apkopos visus iesūtītos soļījumus, apvienojot tos ar PSO balansēšanas enerģijas pieprasījumu, kā arī optimizācijas rezultātā ieteiks nepieciešamās aktivizēšanas darbības, ko pārvades sistēmas operatori tālāk nodos balansēšanas pakalpojumu sniedzējiem. Vispārējais balansēšanas platformas darbības princips ilustrēts 9. attēlā.

Baltijas valstīs šobrīd no nosauktajiem procesiem tiek izmantots mFRR produkts, līdz ar to tās ir iesaistītas MARI projektā. Saistībā ar Baltijas valstu plānoto sinhronizāciju ar Centrāleiropu, nākotnē būs nepieciešami papildu balansēšanas produkti, līdz ar to paredzēta iesaiste arī pārējos projektos.

Vienots Baltijas balansēšanas tirgus

Baltijas PSO, veicinot reģionālo sadarbību ENTSO-E elektroenerģijas balansēšanas tīkla kodeksa agrīnās ieviešanas pilotprojekta ietvaros, jau ir izveidojuši (no 2018. gada 1. janvāra) vienotu Baltijas valstu elektroenerģijas balansēšanas tirgu. Lai optimizētu balansēšanas elektroenerģijas apjomu un veicinātu konkurenci elektroenerģijas balansēšanas tirgū, Baltijas balansēšanas tirgū tiek centralizēti aktivizēta balansēšanas enerģija (standartizēts produkts), ņemot vērā visas Baltijas sistēmas nebalansu (novirzi).

Papildus tam, 2018. gadā tika izstrādāta un ieviesta IT platforma Baltijas balansēšanas tirgus vadībai, kas nodrošina ātrāku un efektīvāku balansēšanas tirgus darbību, kā arī kalpo par pamatu turpmākai šī tirgus attīstībai un integrācijai ar Eiropu. E&P

Annexes 3.

elektroenerģijas tirgus

Latvijas integrācija Eiropas elektroenerģijas tirgū

Latvijas pārvades sistēmas operatora mērķi, atbilstoši Eiropas kopējās enerģētikas politikas pamatnostādnēm, ir nodrošināt stabilu elektroenerģijas pārvades sistēmas darbu un drošu elektroapgādi patērētājiem. Tajā pašā laikā pārvades sistēmas operatoram ir jāveicina elektroenerģijas tirgus darbība un jāpalīdz elektroenerģijas ražošanas industrijai pakāpeniski pāriet uz videi draudzīgāku elektroenerģijas ražošanu. Lai Latvija sasniegtu šos mērķus, būtiska ir integrācija vienotajā Eiropas elektroenerģijas tirgū.

Dr. sc. ing. **Gatis Junghāns**,
RTU asoc. prof., AS "Augstsprieguma tīkls" valdes loceklis

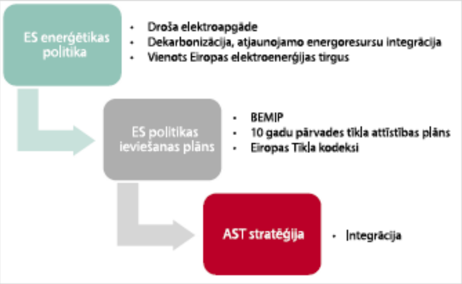
Mg. oec. **Aigars Sīlis**,
AS "Augstsprieguma tīkls" elektroenerģijas tirgus uzraudzības speciālists

26 ENERĢIJA UN PASAULE 2017/6

Eiropas enerģētikas politika nosaka pārvades sistēmas operatora stratēģiju

Eiropas Savienības (ES) enerģētikas politikas trīs galvenie mērķi ir šādi (1. att.):

- droša elektroapgāde;
- energosistēmas dekarbonizācija un atjaunojamās enerģijas izmantošanas palielināšana enerģijas ražošanā;
- vienota Eiropas elektroenerģijas tirgus izveide.



1. attēls. Eiropas Savienības enerģētikas politikas ietekme uz pārvades sistēmas operatora stratēģiju

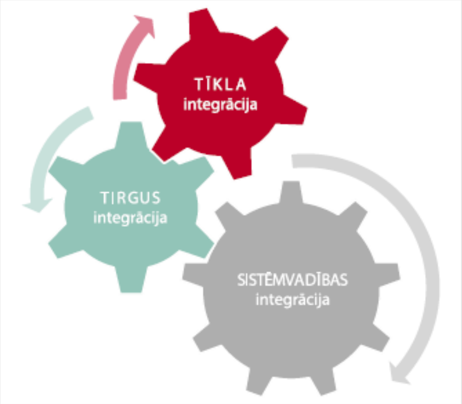
ES enerģētikas politikas mērķu sasniegšanai nepieciešamais rīcības plāns ir iestrādāts dažādos dokumentos. Latvijai būtiskākie ir trīs rīcības plāna dokumenti:

- Baltijas jūras reģiona valstu valdību pārstāvju apstiprinātais Baltijas enerģijas tirgus starpsavienojumu plāns **BEMIP** – reģionālas sadarbības rīcības plāns ar mērķi ieviest vairākus enerģijas infrastruktūras un tirgus integrācijas projektus;
- Latvijas **elektroenerģijas pārvades sistēmas 10 gadu attīstības plāns**, kuru izstrādā AS "Augstsprieguma tīkls" (AST) un apstiprina LR Sabiedrisko pakalpojumu regulēšanas komisija;
- Eiropas elektroenerģijas **tīkla kodeksi**. Patlaban tiek izstrādāti un ieviesti astoņi Eiropas elektroenerģijas tīkla kodeksi. Šie tīkla kodeksi ir vispusīgs vadlīniju kopums, kā organizēt elektroenerģijas sektora darbību Eiropas Ekonomiskās zonas dalībvalstīs.

Integrācijas trīs pamatvirzieni

Integrācijas trīs pamatvirzieni ir šādi (2. att.):

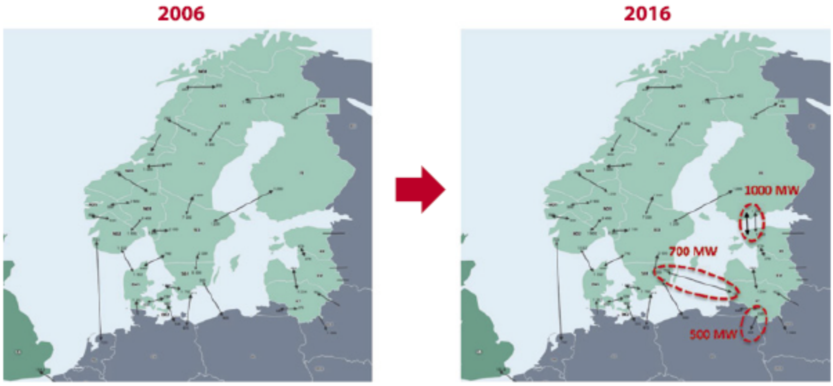
- **tīkla integrācija**. Latvijas pārvades tīkla integrācija ar Eiropas pārvades tīklu tiek nodrošināta, izbūvējot jaunus starpsavienojumus gan Baltijas iekšienē, gan starp Baltijas un Eiropas pārvades sistēmām, lai nodrošinātu infrastruktūru elektroenerģijas apmaiņai starp Eiropas valstīm;
- **tirgus integrācija**. Lai veicinātu konkurenci Eiropas līmenī, Latvijā, līdzīgi kā pārējās Eiropas dalībvalstīs, tiek ieviests vienots tirgus modelis, kura mērķis ir nodrošināt brīvu starpvalstu elektroenerģijas tirdzniecību un augstu konkurenci;
- **sistēmvadības integrācija**. Pieaugot vēja, saules un izkliedētās ģenerācijas īpatsvaram energosistēmā, arvien vairāk pārvades sistēmas darbu vienā valstī ietekmē procesi kaimiņvalstu pārvades sistēmās. Līdz ar to arvien aktuālāka kļūst pārvades sistēmas operatoru savstarpēja sistēmvadības koordinācija reģionālā līmenī.



2. attēls. Integrācijas stratēģijas trīs pamatelementi

Pieaug starpsavienojumu nozīme Baltijas elektroapgādes nodrošināšanā

Latvijas elektroenerģijas tirgus ir salīdzinoši mazs – no elektroenerģijas patēriņa skatpunkta Latvijas tirgus apmērs ir nepilni 2% no kopējā Skandināvijas-Baltijas tirgus jeb aptuveni 0,25% no kopējā Eiropas elektroenerģijas tirgus. Latvijai elektroapgādes un drošuma pašpietiekamības nodrošināšana izmaksātu ļoti dārgi. Tāpēc Latvijai ir kritiski svarīgi nodrošināt integrāciju vienotajā Eiropas elektroenerģijas tirgū. Baltijas valstu pārvades sistēmas operatori pēdējo desmit gadu laikā ir neatlaidīgi strādājuši pie Baltijas energosistēmas integrācijas Eiropas tirgū. Pirmais starpsavienojums starp Baltijas un Skandināvijas pārvades sistēmām tika nodots ekspluatācijā 2007. gada sākumā, un tā uzstādītā jauda bija 350 MW (Igaunija-Somija). Patlaban ir nodoti ekspluatācijā jau četri starpsavienojumi starp Baltijas un Eiropas pārvades sistēmām ar kopējo uzstādīto jaudu



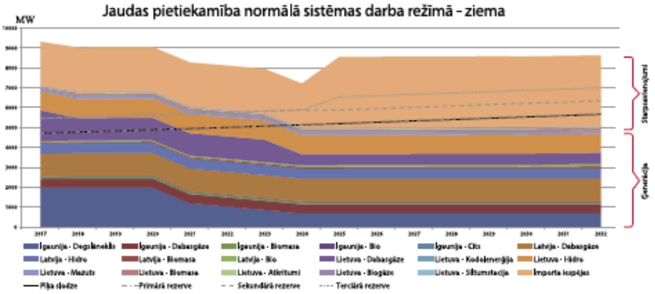
3. attēls. Baltijas starpsavienojumi ar Eiropas pārvades sistēmu

2200 MW (3. att.) jeb aptuveni 50% no Baltijas elektroenerģijas patēriņa maksimuma. Starpsavienojumu izbūve ir būtiski paaugstinājusi elektroapgādes drošumu Baltijā un nodrošinājusi Baltijas iekļaušanu Eiropas elektroenerģijas tirgū.

Baltijā sagaidāms ražošanas jaudu samazinājums

Šobrīd Baltijas valstu elektrostacijās uzstādīto jaudu summa sasniedz ap 9000 MW, kas aptuveni divas reizes pārsniedz Baltijas patēriņa maksimumu. Tajā skaitā ap 5000 MW uzstādītās jaudas ir lielajām termoelektrostacijām (pamatā ar gāzes un degakmens kurināmo). Baltijas pārvades sistēmas operatoru veiktais jaudu pietiekamības novērtējums nākamajiem desmit gadiem paredz būtisku ražošanas jaudu samazinājumu pēc 2020. gada, kad no tirgus izstāsies vecākās gāzes un degakmens elektrostacijas. Līdz 2030. gadam Baltijā varētu tikt slēgtas ražošanas jaudas kopumā ap 2300 MW jeb turpat puse no lielo termoelektrostaciju esošās jaudas. Samazinoties ražošanas jaudām Baltijā, elektroapgādes nodrošināšanā pieaugs starpsavienojumu nozīme (4. att.). Starpsavienojumi nodrošinās gan elektroenerģijas, gan pārvades sistēmas drošumam nepieciešamo sistēmas pakalpojumu (rezerves) starpvalstu tirdzniecību.

Uz atjaunojamiem energoresursiem balstītu ražošanas tehnoloģiju izmaksas pasaulē strauji samazinās. Sagaidāms, ka nākotnē Baltijā turpinās attīstīties izkliedētā ģenerācija un uz atjaunojamiem energoresursiem balstītā ģenerācija. Šobrīd Baltijā jau darbojas ap 5500 izkliedētās ģenerācijas vienību, un nākotnē sagaidāma tās turpmāka attīstība. Baltijā uzstādītā vēja elektrostaciju kopējā jauda patlaban jau pārsniedz 900 MW, kas līdzinās aptuveni 20% no Baltijas pīķa patēriņa. Ņemot vērā vēja ģenerācijas konkurētspējīgās izmaksas, salīdzinot ar citiem ģenerācijas veidiem, ir sagaidāma šī ģenerācijas veida turpmāka attīstība Baltijā. Baltijas pārvades tīkla stiprināšana un integrēšana ar Eiropas pārvades tīklu ir priekšnosacījums, lai būtu iespējama liela apjoma atjaunojamo energoresursu elektrostaciju turpmāka pieslēgšana Baltijas energosistēmā.



4. attēls. Ražošanas un starpsavienojumu jaudu pietiekamības novērtējums.
Avots: AST, *Elering*, *Litgrid*

Līdz 2025. gadam tiks realizēti nozīmīgi Baltijas pārvades tīkla pastiprināšanas projekti

Līdztekus Baltijas starpsavienojumu ar Eiropas pārvades sistēmām izbūvei Baltijas pārvades sistēmas operatori pastiprina Baltijas pārvades tīklu. 5. attēlā redzami Baltijas 330 kV pārvades tīkla nozīmīgākie attīstības projekti.

Latvijas elektroenerģijas pārvades sistēmas attīstības plānā paredzētas 445 milj. eiro investīcijas laikposmā no 2018. līdz 2027. gadam. Pieciem projektiem, kuru investīcijas 10 gadu periodā tiek lēstas 224 milj. eiro apmērā, ir piesaistīts vai tiek plānots piesaistīt arī ES līdzfinansējumu. Patlaban līdzfinansējums ir piešķirts trim projektiem – "Kurzemes loka" 3. kārtas elektrolīnijas un apakšstaciju būvniecībai (ES līdzfinansējums – 55 milj. eiro, kopējās investīcijas – 128 milj. eiro), Latvijas-Igaunijas trešā starpsavienojuma elektrolīnijas būvei un apakšstacijas paplašināšanai (ES līdzfinansējums – 63 milj. eiro, kopējās investīcijas – 102 milj. eiro), kā arī jaunas 330 kV elektropārvades līnijas, kas savienos Rīgas TEC-2 ar Rīgas HES, būvniecībai (ES līdzfinansējums – 10 milj. eiro, kopējās investīcijas – 20 milj. eiro).

5. attēls. Baltijas 330 kV pārvades tīkla nozīmīgākie attīstības projekti

Turpinās Baltijas elektroenerģijas tirgus harmonizēšana ar vienoto Eiropas tirgu

Lai izveidotu vienotu reģionālu elektroenerģijas tirgu, nepietiek tikai ar starpsavienojumu izbūvi. Atšķirīgi tirgus modeļi var būtiski ierobežot vai pat bloķēt starpvalstu tirdzniecību, pat neskatoties uz fizisku starpsavienojumu esamību. Tāpēc, balstoties uz Eiropas elektroenerģijas tīkla kodeksiem, ES dalībvalstu pārvades sistēmas operatori katrs savā valstī ievieš vienotu tirgus modeli, lai panāktu, ka elektroenerģijas tirgus Eiropā faktiski darbojas kā vienots veselums.

Eiropas elektroenerģijas tirgus modelis sastāv no četrām daļām (6. att.).

Nākamās dienas tirgus patlaban pēc pirktās un pārdotās elektroenerģijas apjoma ir galvenais tirgus, kurā tiek slēgti standartizētas piegādes darījumi nākamajai dienai pa stundām. Eiropas tīkla kodekss nosaka noteikumus Eiropas koordinēta nākamās dienas tirgus izveidei. Tāpēc ES dalībvalstu pārvades sistēmas operatori sadarbībā ar elektroenerģijas biržām ievieš Eiropas tirgus integrācijas projektu (*multiregional coupling*), kura galvenais princips ir vienota platforma, vienots cenu un starpvalstu plūsmu noteikšanas algoritms. Šis sarežģītais projekts, kas ir lielākais šāda veida projekts ES praksē, tiek sekmīgi ieviests, un šobrīd jau 75% no visa Eiropas elektroenerģijas tirgus, tajā skaitā Latvija un pārējās Baltijas valstis, ir integrēti caur centralizēto platformu.

Tekošās dienas tirgus arī ir fizisko piegāžu tirgus, kas atveras uzreiz pēc nākamās dienas tirgus slēgšanas, un tajā iespējams slēgt piegāžu darījumus līdz pat vienai stundai pirms reālā laika stundas. Palielinoties nepastāvīgai un izkliedētai ģenerācijai, tirgus dalībniekiem kļūst arvien izaicinošāk sabalansēt piegādes un patēriņu nākamās dienas tirgū, tāpēc tekošās dienas tirgū dalībnieki var veikt papildu darījumus, lai sabalansētu piegādes. Eiropas elektroenerģijas tīkla kodeksi nosaka prasības Eiropas koordinēta

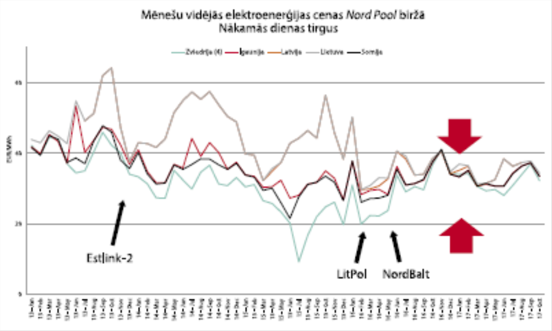
6. attēls. Baltijas elektroenerģijas tirgus struktūra tekošās dienas tirgus izveidei. Tāpēc Eiropas pārvades sistēmas operatori sadarbībā ar biržām strādā pie vienotas Eiropas tekošās dienas tirgus platformas izveides (XBID projekts). 2018. gada pirmajā ceturksnī tiks ieviests šā apjomīgā projekta pirmais posms, un pirmā daļa no ES dalībvalstīm, tajā skaitā Baltijas valstis, sāks organizēt tekošās dienas tirgu caur vienoto Eiropas XBID platformu.

Balansēšanas tirgus ir svarīgs instruments pārvades sistēmas operatoriem, lai izpildītu vienu no svarīgākajām funkcijām – nodrošināt nepārtrauktu elektroenerģijas līdzsvaru sistēmā, kur strauji pieaug nepastāvīgā un izkliedētā ģenerācija. Balansēšanas tirgū tirgus dalībnieki pārdod pārvades sistēmas operatoriem manuāli aktivizējamas frekvences regulēšanas rezerves reālās stundas laikā (piemēram, elektrostaciju ģenerācijas palielināšana vai samazināšana pēc sistēmas operatora pieprasījuma). Lai ieviestu vienotu Eiropas balansēšanas tirgu, kas balstīts uz vienotas Eiropas balansēšanas tirgus platformas, patlaban jau vairāk nekā 20 Eiropas pārvades sistēmas operatori, tajā skaitā no visām trim Baltijas valstīm, strādā pie vienotas balansēšanas tirgus platformas projekta (MARI projekts). MARI projektu plānots pabeigt 2020–2022. gadā, un Baltijā tas aizstās Baltijas reģionālo balansēšanas tirgus platformu.

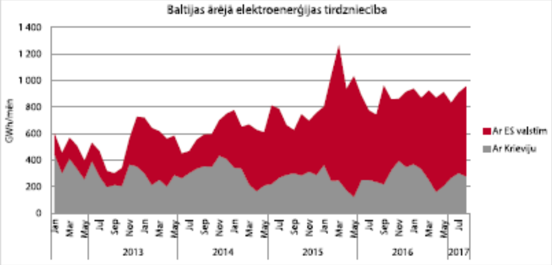
Baltijas elektroenerģijas tirgū pieaug konkurence un samazinās cenas

Pateicoties pārvades sistēmas operatoru īstenotajiem integrācijas projektiem, pēdējos gados elektroenerģijas tirgus darbība Baltijā ir nozīmīgi uzlabojusies. Par to liecina cenu tendences un tirdzniecības apjoma izmaiņas.

Viens no svarīgākajiem indikatoriem tirgus darbības novērtēšanai ir elektroenerģijas cenu līmenis biržā. Pēdējo četru gadu laikā elektroenerģijas cenu līmenis *Nord Pool* biržā Latvijā ir samazinājies turpat par 30%. Vidējā elektroenerģijas tirgus cena 2014. gadā Latvijā bija 52,12 EUR/MWh, bet 2016. gadā – 36,09 EUR/MWh (samazinājums par 30%). Savukārt 2017. gada 10 mēnešos vidējā elektroenerģijas cena bija 34,93 EUR/MWh (7. att.).



7. attēls. Vidējās elektroenerģijas cenas *Nord Pool* biržā pa mēnešiem. Nākamās dienas tirgus.
Avots: *Nord Pool*



8. attēls. Baltijas ārējās elektroenerģijas tirdzniecības dinamika.
Avots: *Nord Pool*

Svarīgs tirgus kvalitātes rādītājs ir arī cenu starpība starp dažādām cenu zonām reģionā – līdzīgākas cenas liecina par augstāku konkurenci reģionālajā tirgū. Ja 2014. gadā elektroenerģijas cenas *Nord Pool* biržā Igaunijā un Latvijā bija vienādas tikai 30% no laika, tad 2016. gadā cenas Igaunijā un Latvijā bija identiskas jau 70% no laika. Arī cenu starpība starp cenu zonām ir samazinājusies. Ja 2014. gadā Latvijas cenas bija augstākas par Igaunijas cenām vidēji par 12,51 EUR/MWh, tad 2016. gadā šī starpība samazinājās līdz 3,03 EUR/MWh, bet 2017. gada 10 mēnešos jau tikai 1,64 EUR/MWh. Stundās, kad elektroenerģijas cenas reģionā izlīdzinās, konkurence starp tirgus dalībniekiem ir visaugstākā, jo šādos apstākļos nepastāv pārvades ierobežojumi un elektroenerģijas ražotāji konkurē plašākā reģionā.

Pateicoties jaunajiem starpsavienojumiem, Baltijas kopējais ārējās elektroenerģijas tirdzniecības apjoms (t.sk. ar Krieviju un Eiropas tirgu) pēdējo četru gadu laikā ir dubultojies, bet ar Eiropas tirgu – turpat četrkāršojies (8. att.). Tas liecina par tirgus likviditātes uzlabošanos un konkurences paaugstināšanos. Latvijā elektroenerģijas pircējiem tas nodrošina iespēju pirkt elektroenerģiju par konkurētspējīgākām cenām. Savukārt Latvijas elektroenerģijas ražotājiem tiek nodrošināta piekļuve plašākam, likvīdākam starptautiskam tirgum. E&P

Latvijas elektroenerģijas sistēmas attīstības pamats –

ikgadējais pārvades sistēmas operatora AS "Augstsprieguma tīkls" novērtējuma ziņojums

Ansis Žbanovs, AS "Augstsprieguma tīkls" Starptautisko attīstības projektu dienesta elektroinženieris
Aigars Sīlis, AS "Augstsprieguma tīkls" Elektroenerģijas tirgus uzraudzības un attīstības daļas tirgus uzraudzības speciālists
Antons Kutjuns, AS "Augstsprieguma tīkls" Starptautisko attīstības projektu dienesta vadītājs

Jau kopš 2006. gada – līdz ar Latvijas integrāciju Eiropas Savienībā un tās regulu ieviešanu, AS "Augstsprieguma tīkls" kļūstot par neatkarīgu pārvades sistēmas operatoru (PSO), viens no tās pienākumiem ir nozares attīstības dokumentu veidošana, plānošana un koordinēšana, apkopojot informāciju vienotā novērtējuma ziņojumā sistēmas attīstībai.

Vēsturiski gan Latvijā, gan Eiropā elektroenerģijas sistēmu attīstību ir lielā mērā noteikušas energokompānijas ar nedaudziem lieliem ģenerācijas avotiem, taču līdz ar Trešās enerģētikas paketes (Eiropas Parlamenta 2009. gadā apstiprināts Eiropas enerģētikas sistēmas liberalizācijas plāns) aso vēršanos pret monopoliem būtiski pieaugusi Eiropas valstu elektroenerģijas pārvades sistēmas operatoru nozīme pārvades tīklu un sistēmu attīstībā, dodot brīvu pieeju tirgum arī mazākām kompānijām uz vienlīdzīgiem nosacījumiem ar enerģētikas milžiem. Tomēr vienlīdzīgi nosacījumi lieliem un maziem ģenerācijas avotiem – ņemot vērā, ka daudzi mazie ģeneratori izmanto atjaunīgos energoresursus (vējš, saule, ūdens, biomasa un biogāze) un ir atkarīgi no laikapstākļiem un pieejamā dabas resursa,– ir liels izaicinājums arī pārvades sistēmas operatoriem, kam jāspēj sabalansēt ģenerāciju ar patēriņu, nepieciešamības gadījumā nodrošinot enerģijas izdošanu un uzņemšanu katra pārvades sistēmas operatora atbildības zonā, un vienlaikus nodrošināt nepieciešamās jaudas rezerves regulēšanas un avārijas gadījumiem, lai apmierinātu pieprasījumu lielu ģenerējošo jaudu vai starpsavienojumu neplānotu atslēgumu gadījumos.

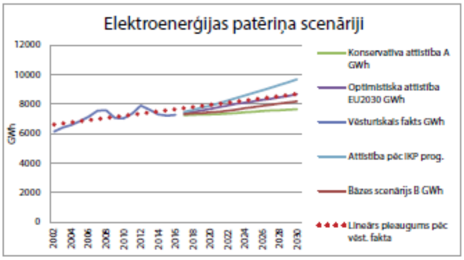
Līdz ar atjaunīgo energoresursu straujāku attīstību, ko sekmē gan Eiropas Savienības politika, gan arī Latvijas valsts ilgtermiņa attīstības stratēģija, pārvades sistēmas operatora sagatavotais ikgadējais novērtējuma ziņojums ir nozīmīgs dokuments Latvijas elektroenerģijas sistēmas attīstībai, jo izvirza un aplūko vairākus iespējamos ģenerāciju attīstības scenārijus, analizē patēriņu un pīķa slodzes, apskata elektroenerģijas bilanci 10 gadu intervālam un informē par pieejamajām jaudām diennakts slodzes segšanai tuvākajā nākotnē. Pamatojoties uz šo ziņojumu, kā arī AS "Augstsprieguma tīkls" izstrādāto desmit gadu attīstības plānu, tiek izstrādāts Elektroenerģijas pārvades sistēmas operatoru apvienības (ENTSO-E) Eiropas pārvades tīkla desmit gadu attīstības plāns (TYNDP), kas savukārt ir viens no pamatdokumentiem, uz kuru pamata iespējams piesaistīt Eiropas Savienības līdzfinansējumu elektroenerģijas sistēmas attīstībai un tirgus integrācijai. Tāpat ziņojumā ir iekļauta aktuāla informācija visiem elektroenerģijas sistēmas lietotājiem, kas palīdz izprast elektroenerģijas sistēmas attīstības tendences un pārvades tīkla attīstības virzienu, bet komersantiem plānot jaunu ģenerāciju attīstību, pamatojoties uz tirgus tendencēm un pieprasījumu. Pārvades sistēmas operatora ikgadējais novērtējuma ziņojums pamatojas uz Latvijas Republikas Ministru kabineta noteikumiem Nr. 322 "Noteikumi par pārvades sistēmas operatora ikgadējo novērtējuma ziņojumu" un ir brīvi pieejams AS "Augstsprieguma tīkls" interneta vietnē www.ast.lv. Pārvades sistēmas operatora ikgadējais novērtējuma ziņojums ir izstrādāts, ņemot vērā Latvijas Republikas Ministru kabineta apstiprinātās enerģētikas pamatnostādnes analizētajam laika intervālam, Latvijas enerģētikas ilgtermiņa stratēģiju 2030, Eiropas Komisijas regulas saistībā ar enerģētikas attīstību ilgtermiņā. Pārvades sistēmas operators šobrīd strādā pie jaunākās ziņojuma redakcijas, kas tiks apspriesta un publicēta šā gada oktobra sākumā.

Ģenerāciju attīstība saskaņā ar dažādiem attīstības scenārijiem

Novērtējuma ziņojums ietver informāciju par elektroenerģijas sistēmas aktuālo stāvokli, un uz tā pamata var prognozēt iespējamo nākotnes scenāriju attīstību un elektroenerģijas sistēmas patēriņa attīstību, analizēt pīķa slodzes pieauguma tempu un raksturot elektroenerģijas sistēmas dinamiku attiecībā pret iepriekšējiem gadiem. Elektroenerģijas sistēmas stāvokļa pārskats atspoguļo elektroenerģijas sistēmas kopējo patēriņu, fiksēto pīķa slodzi un sistēmas minimālo slodzi pārskata periodā, detalizētu diennakts slodzes grafiku. Esošās elektroenerģijas sistēmas apzināšana ļauj izstrādāt iespējamos nākotnes scenārijus. Pārvades sistēmas operators izskata trīs iespējamos ģenerāciju attīstības scenārijus:

- konservatīva attīstība (A);
- bāzes scenārijs (B);
- optimistiska attīstība (EU).

Iespējamie nākotnes scenāriji ir veidoti, pamatojoties uz Ekonomikas ministrijas sniegto informāciju par iekšzemes kopprodukta attīstības (IKP) tempiem, enerģētikas nozares attīstības tempiem, elektroenerģijas sistēmas lietotāju sniegto informāciju par viņu attīstības plāniem, kā arī regulatīvajiem normatīviem. Konstruējot iespējamos attīstības scenārijus, PSO ņem vērā visu sistēmas lietotāju intereses un vajadzības, lai sagatavotu ilgtspējīgu un drošu elektroenerģijas sistēmas prognozi un tādējādi pilnveidotu elektropārvades sistēmu un spētu nodrošināt tās drošu darbību jebkura iespējamā nākotnes scenārija gadījumā.



1. attēls. Elektroenerģijas patēriņa scenāriji līdz 2030. gadam

Jaudas pietiekamība un elektroenerģijas plānotais patēriņš – vieni no svarīgākajiem sistēmas raksturlielumiem

Šī PSO ikgadējā novērtējuma ziņojuma sadaļa ietver detalizētu scenāriju raksturojumu un skaidrojumu, būtiskāko Latvijas elektroenerģijas sistēmas elementu skaidrojumu un parametru/pieņēmumu fiksēšanu, lai atbilstoši katram scenārijam varētu veikt jaudas bilances novērtējumu turpmākajiem 10 gadiem. Jaudas bilances novērtējums iekļauj Latvijas elektroenerģijas sistēmas uzstādīto neto jaudu (jauda, kas pieejama elektroenerģijas sistēmai un kas neietver elektrostaciju pašpatēriņu jaudu) un pieejamās jaudas slodzes maksimuma segšanai. Jaudas bilances novērtējums tiek sniegts katram scenārijam – tas ļauj sagatavot elastīgu elektroenerģijas sistēmu, lai nodrošinātu jaudas bilanci jebkura scenārija īstenošanas gadījumā. Jaudas bilances novērtēšanai atsevišķi tiek izdalītas lieljaudas elektrostacijas (ar uzstādīto jaudu virs 40 MW) un mazās elektrostacijas (līdz 40 MW), kas ir izkliedētas visā Latvijas teritorijā. Pieejamo jaudu novērtējumā ņem vērā elektroenerģijas sistēmas avārijas rezervi un regulēšanas rezervi, lai parādītu nepieciešamās jaudas rezerves sistēmai pa gadiem. Atsevišķi ziņojumā informāciju par jaudas rezervju izmantošanu pārvades sistēmas operators sniedz par pārskata gadu, norādot maksimālo nepieciešamo rezervi, pieejamo rezervi un izmantoto avārijas rezerves apjomu gan savas, gan kaimiņvalstu elektroenerģijas sistēmas vajadzībām. Papildus jaudas bilances novērtējumam tiek apskatīts elektroenerģijas bilances novērtējums 10 gadu periodam. Elektroenerģijas bilance dota dažādiem attīstības scenārijiem un ļauj izvērtēt iespējamo elektroenerģijas importa vai eksporta apjomu atkarībā no Latvijas elektrostaciju izstrādes. Elektroenerģijas bilances prognozei ir svarīgi ņemt vērā, ka katru gadu aptuveni 500 GWh elektroenerģijas, kas saražota Daugavas HES, tiek eksportēta uz kaimiņvalstu elektroenerģijas sistēmām, jo Latvijas patēriņš nespēj aptvert visu pavasara plūdu laikā saražotās elektroenerģijas apjomu.

Elektroenerģijas sistēmas importu vai eksportu nosaka pieejamie ģenerācijas avoti ziemas maksimuma un vasaras minimuma slodzes segšanai

Pārvades sistēmas operators sagatavo diennakts slodzes grafikus vasaras (slodzes minimums) un ziemas (slodzes maksimums) periodiem ar detalizētu elektrostaciju izstrādi diennaktī pēc galvenajiem ģenerācijas avotiem. Elektroenerģijas sistēmai ziemas maksimuma periodā ir jāspēj saražot nepieciešamo

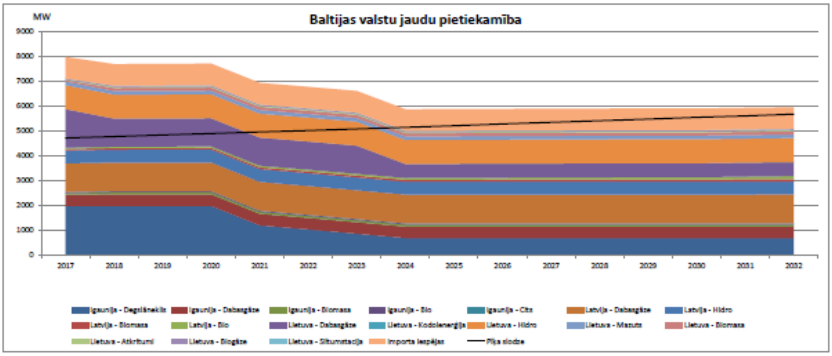
	Elektroenerģijas tirdzniecības apjoms 2015 (MWh)	Elektroenerģijas tirdzniecības apjoms 2016 (MWh)
Imports	5 245 938	4 828 354
Eksports	3 424 478	3 794 883

jaudu pīķa slodzes segšanai, bet vasarā minimuma slodzes segšanai – izdot atjaunīgo (vēja, saules, ūdens, biomasas un biogāzes) energoresursu saražoto elektroenerģijas pārpalikumu uz kaimiņvalstu elektroenerģijas sistēmām. Šādi tiek maksimāli izmantoti atjaunīgie energoresursi un veicināta to attīstība, bet fosilā kurināmā elektrostacijas saglabājas kā regulējošās stacijas, kas vitāli svarīgas pie slodzes maksimumiem. Elektroenerģijas bilanci raksturojošais lielums gada griezumā ir kopējais sistēmas imports un eksports: pēdējo gadu tendences liecina, ka Latvijas elektroenerģijas sistēmas eksports ir mazāks nekā imports un Latvijas elektroenerģijas sistēma strādā ar 1–2 TWh lielu deficītu gada griezumā. Tas norāda, ka ir nepieciešama jaunu ģenerāciju attīstība Latvijā, lai elektroenerģijas bilance būtu pozitīva (sk. tabulu).

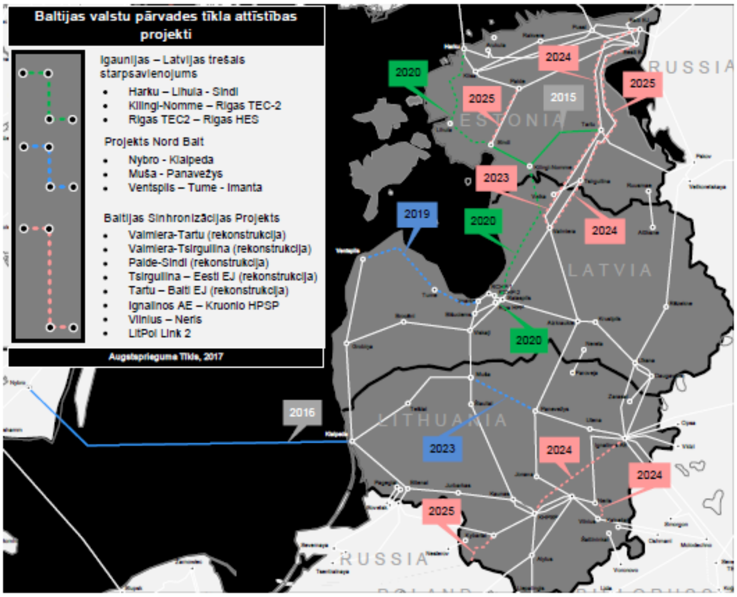
Pārvades sistēmas operators izdara secinājumus par elektroenerģijas sistēmas attīstības virzieniem un izvērtē iespējamās darbības jaudas bilances nodrošināšanai un elektroenerģijas patēriņa segšanai. Strauji attīstoties atjaunīgajiem energoresursiem (AER), jaudu pietiekamība ir jāizvērtē reģionālā līmenī: pie mazām slodzēm un lieliem AER ražošanas apjomiem ir svarīgi no AER saražoto elektroenerģiju eksportēt no ģenerācijas vietām uz galvenajiem patēriņa centriem un pie jaudas deficīta caur pārrobežu starpsavienojumiem ir iespējams saņemt trūkstošās jaudas no kaimiņvalstu elektroenerģijas sistēmām. Šāda reģionāla kooperēšanās ļauj sasniegt plašāku AER elektroenerģijas izmantošanu, tā samazinot gan nepieciešamību pēc fosilā kurināmā elektrostaciju darbības, gan siltumnīcefekta gāzu izmešus.

Reģionāla jaudas pietiekamības novērtējuma nozīme pārvades sistēmas attīstībā

2015. gadā Baltijas valstu PSO vienojās izveidot kopēju elektroenerģijas sistēmu datu apmaiņas platformu, kas nodrošina jaudas pietiekamības novērtējuma analīzi Baltijas reģiona līmenī. Arī AS "Augstsprieguma tīkls" daļu no reģionālā pētījuma rezultātiem atspoguļo savā *Pārvades sistēmas operatora ikgadējā novērtējuma ziņojumā*. Jaudas bilances novērtējums tiek sagatavots vairākiem iespējamajiem attīstības scenārijiem ziemas un vasaras periodam, kā arī tiek izskatīti divi elektroenerģijas sistēmas darba režīmi – normāls darba režīms (N-0), kad visi elektroenerģijas sistēmas elementi ir darbā, un avārijas režīms, kad vienlaicīgi atslēdzas divi lielākie sistēmas elementi (N-2, atslēdzas *NordBalt* 700 MW un *Estlink 2* 650 MW). Šāds reģionāls jaudas pietiekamības novērtējums norāda uz to, ka, sākot no 2024. gada, aktualizēsies jautājums par jaudas pietiekamību: ja netiks veiktas investīcijas jaunu jaudu attīstībā, var rasties problēmas ar slodzes segšanu un elektroenerģijas cenas varētu pieaugt. Attīstot papildu starpsavienojumus uz Ziemeļvalstīm vai Poliju, varam samazināt riskus, kas saistīti ar jaudas pietiekamību reģionā (sk. 2. att.). Jaudas pietiekamības novērtējumā netiek ņemtas vērā elektropārvades līniju jaudas savienojumos ar Krieviju un Baltkrieviju, jo nav zināms pieejamo jaudu apmērs no trešajām valstīm un nenotiek sadarbība šajos jautājumos ar austrumu elektroenerģijas sistēmām.



2. attēls. Baltijas valstu pieejamās jaudas novērtējums *NordBalt* (700 MW) un *Estlink 2* (650 MW) atslēguma gadījumā



3. attēls. Baltijas valstu elektroenerģijas sistēmas attīstības projekti saskaņā ar Eiropas desmit gadu attīstības plānu

Nozīmīgākie pārvades tīkla attīstības projekti sistēmas darba drošuma nodrošināšanai

Analizējot jaudas pietiekamību dažādos scenārijos turpmāko 10 gadu periodā, PSO izvērtē jaunu starpsavienojumu būvniecību un iekšējā pārvades tīkla 110 kV un 330 kV pastiprināšanu. Pārvades tīkla attīstībā izmanto tirgus un tīkla modeļus: pēc vairāku indikatoru izvērtēšanas pārvades sistēmas operators izstrādā projektus un iekļauj tos nacionālajā 10 gadu attīstības plānā. Visi turpmāk minētie projekti ir vitāli svarīgi, lai sekmētu Latvijas valsts integrāciju ar kaimiņvalstu elektroenerģijas sistēmām, izlīdzinātu elektroenerģijas cenas ar tās cenām kaimiņvalstīs, sekmējot Latvijas valsts ekonomisko izaugsmi, un nodrošinātu jaudu pārvades drošumu dažādos elektroenerģijas sistēmas darba režīmos (sk. 3. att.).

Latvijas elektropārvades sistēmas attīstības aktuālie projekti, kas saņēmuši līdzfinansējumu no Eiropas infrastruktūras savienošanas instrumenta līdzekļiem:

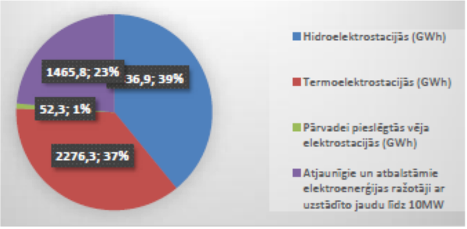
1. Kurzemes loka 3. etaps, 330 kV, "Ventspils-Tume-Imanta", kas iekļauts Kopīgu interešu projektu (KIP) sarakstā un Eiropas 10 gadu attīstības plānā *NordBalt* projekta ietvaros. Saņemtais ES līdzfinansējums 55,059 MEuro;

2. Igaunijas-Latvijas trešais starpsavienojums, kas iekļauts KIP sarakstā un Eiropas 10 gadu attīstības plānā. Saņemtais ES līdzfinansējums 63,38 MEuro;

3. elektropārvades tīkla savienojums "Rīgas TEC-2 – Rīgas HES", kas iekļauts KIP sarakstā un Eiropas 10 gadu attīstības plāna Igaunijas-Latvijas trešā starpsavienojuma projekta ietvaros. Saņemtais ES līdzfinansējums 9,99 MEuro.

Pēdējo gadu aktuālākais projekts, kura nozīme tiek uzsvērta gan pārrunās starp Baltijas valstīm, gan Eiropas Komisijā, ir Baltijas valstu energosistēmu sinhronizācija ar Eiropas elektropārvades tīkliem. Projekts tika aizsākts 2007. gadā ar Baltijas valstu premjerministru kopīgu Komunikē prasību izpildi, un tā īstenošanai aizvadīto10 gadu laikā ir veiktas vairākas ekonomiskās un tehniskās izpētes (Eiropas desmit gadu attīstības plāns, konsultanta *Ghotia Power* sinhronas darbības priekšizpēte: Baltijas valstu integrācija Eiropas iekšējā elektroenerģijas tirgū un EK Apvienotā pētniecības centra pētījums par Baltijas valstu integrāciju Eiropas elektroenerģijas sistēmā: tehniskā un ekonomiskā analīze). Projekta izmaksas lēšamas no 600 milj. EUR līdz pat vienam miljardam EUR atkarībā no izvēlētā sinhronizācijas scenārija. Projekts ietver jaunu pārvades līniju attīstību un esošo līniju rekonstrukciju, lai paaugstinātu elektroenerģijas sistēmas drošumu. Šobrīd notiek projekta tālāka virzība, un lēmumu pieņēmējiem jāizvēlas labākais iespējamais sinhronizācijas scenārijs, lai realizētu projektu ieplānotajā laikposmā līdz 2025. gadam.

Elektroenerģijas tirgus apskati sabiedrības un tirgus dalībnieku informēšanai par elektroenerģijas tirgus datiem īstermiņā



4. attēls. Latvijā saražotās elektroenerģijas apjoms 2016. gadā

Lai sabiedrībai un tirgus dalībniekiem sniegtu aktuālu, ticamu un precīzu informāciju par elektroenerģijas tirgus datiem, AS "Augstsprieguma tīkls" kopš 2015. gada publicē ikmēneša elektroenerģijas tirgus apskatus (pieejami interneta vietnē www.ast.lv). Atšķirībā no pārvades sistēmas operatora ikgadējā novērtējuma ziņojuma, kas paredzēts sistēmas jaudas pietiekamības plānošanai ilgtermiņā, elektroenerģijas tirgus apskats ir instruments sabiedrības informēšanai par situāciju elektroenerģijas tirgū pārskata periodā. Šī informācija tiek sagatavota, balstoties uz iepriekšējā gada statistikas datiem un ļauj tirgus dalībniekiem savlaicīgi un pašu spēkiem veikt datu analīzi. Pārvades sistēmas operatoram ir jābūt neatkarīgam, tāpēc AS "Augstsprieguma tīkls" nav tiesīga izteikt prognozes vai iezīmēt cenu attīstības tendences ne ilgtermiņā, nedz arī īstermiņā – pretstatā elektroenerģijas tirgotājiem un ražotājiem, kuri to dažkārt dara mārketinga nolūkos.

Viens no sabiedrībai aktuāliem jautājumiem skar Latvijas valsts spēju nosegt savu elektroenerģijas patēriņu, izmantojot vietējās ģenerācijas jaudas. Izvērtējot Latvijas jaudas bilanci, var secināt, ka nepieciešamības gadījumā ir iespējams nosegt valsts elektroenerģijas patēriņu, izmantojot tikai vietējās ģenerācijas vienības. Ir svarīgi saprast, ka katrai elektroenerģijas ģenerācijas vienībai ir sava cena, pie kuras tā tiek aktivizēta: elektroenerģijas tirgus darbojas pēc principa, ka lētākā elektroenerģijas ģenerācijas vienība tiek izmantota pirmā un tikai pēc tam tiek aktivizēta dārgākā. Latvijā visa saražotā elektroenerģija tiek tirgota elektroenerģijas biržā un visa nepieciešamā elektroenerģija tiek iepirkta no biržas. Vietējās ģenerācijas vienības pieejamība ir viens no instrumentiem, kas ļauj nodrošināt energoapgādes drošību, cenu ierobežošanu un sistēmas stabilitāti, ņemot vērā gan gaidāmo AER lomas pieaugumu, gan sinhronizāciju ar ES valstīm.

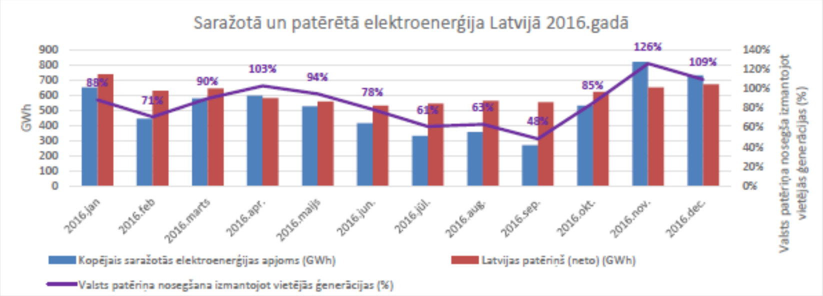
Pamatojoties uz publicētajiem datiem par 2016. gadu, var secināt, ka Latvijā saražotās elektroenerģijas apjoms bijis 6231,3 GWh – pietiekami, lai nosegtu Latvijas gada patēriņu vidēji par 86 %, izmantojot vietējās ģenerācijas jaudas (trūkstošā elektroenerģija tika importēta), kas ir par 11 procentpunktiem vairāk nekā 2015. gadā (75 %).

AS "Augstsprieguma tīkls" savos apskatos vietējās ģenerācijas vienības, kuras veido Latvijas jaudas bilanci, iedala šādi:

- Daugavas hidroelektrostacijas – Pļaviņu HES, Ķeguma HES un Rīgas HES;
- termoelektrostacijas – Rīgas TEC-1, Rīgas TEC-2;
- pārvadei pieslēgtās vēja elektrostacijas un atjaunīgie un atbalstāmie elektroenerģijas ražotāji ar uzstādīto jaudu līdz 10 MW (koģenerācijas, biomasas, biogāzes, vēja, ūdens un saules elektrostacijas).

Analizējot 2016. gada datus, var secināt, ka būtiska loma elektroenerģijas ģenerācijā Latvijā ir Daugavas hidroelektrostacijām un termoelektrostacijām (sk. 4. att.).

Analizējot datus par Latvijā saražotās un patērētās elektroenerģijas apjomu 2016. gadā, var secināt, ka spēja nosegt valsts elektroenerģijas patēriņu svārstās no 48% līdz 126% – šo procentuālo atšķirību galvenokārt nosaka sezonāli faktori, kas ietekmē hidroelektrostaciju un termoelektrostaciju darbību. Lai arī lielākoties Latvija ir elektroenerģijas importētāja, tomēr katru gadu vienā vai vairākos mēnešos Latvija spēj būtiski ietekmēt cenu Baltijas reģionā, kļūstot par izteiktu elektroenerģijas eksportētāju, jo ģenerācija pārsniedz patēriņu (sk. 5. att.).



5. attēls. Latvijā saražotā un patērētā elektroenerģija

Benefits of Electricity Industry Switching from Fixed to Spot-linked End-user Prices

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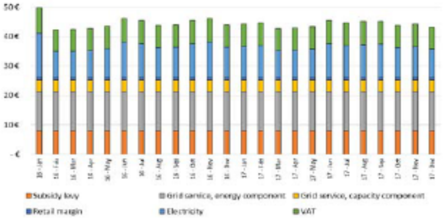
***Abstract* — Electricity prices in the wholesale market reflect the inherently volatile nature of electricity. The volatility is not expected to decrease in the future due to increased shares of intermittent resources such as wind and distributed generation. In efficient market, electricity price becomes the link that connects the necessary decisions of market participants and system operators, and makes the sector work with as little frictions as possible. One of the challenges is to organize market in which market players directly receive price signals and can react to them. The share of intermittent generation resources is steadily growing in the power system, and so is the demand for flexibility in the power system. Demand response is hugely untapped flexibility resource. This happens partially because price signals do not reach end-users, most of whom purchase electricity at a fixed price. In this paper, we present arguments, why end-users and electricity industry in general would gain significant economic benefits, if most of the end-users would switch from fixed price to dynamic, spot-linked electricity price. We analyze Nordic and Baltic market data to obtain deeper insight of end-users' price formation in fixed and spot-linked tariffs. The results show that spot-linked price contracts provide lower margins and lower end-user prices.**

***Index Terms* — demand response, dynamic electricity tariffs, electricity market, electricity price, power system balancing**

I. INTRODUCTION

The functioning of the electricity market is based on consumer rights and the ability to choose electricity supplier and terms of supply agreement. One of the key decisions is the choice between a fixed and a dynamic price. In this publication, the "dynamic price" refers to the consumer's retail electricity price, the value of which is tied to an hourly variable wholesale price on the electricity exchange. Electricity exchange has been in operation in the Baltics since 2010, however, only a relatively small number of consumers have so far opted to purchase electricity at a dynamic price. In some countries, consumers are choosing dynamic prices more often. For example, in Estonia at the beginning of 2018 38%, in Sweden about 47% and in Norway about 72% of consumers were buying electricity at a dynamic price.

The reasons, why consumers choose a fixed price tariff, are quite different. One of the reasons is the concern about possible larger fluctuations in electricity billing when choosing a dynamic price. Often this concern is groundless, and wrong choices are made due to the lack of information. Figure 1 illustrates how electricity bill would change over a two-year period to a Latvian household with constant consumption of 300 kWh per month and a dynamic electricity tariff. Data shows that changes in electricity prices in practice have minor impact on changes in monthly electricity bills.



Note: For households with a 3 phase 20 A grid connection and. The calculation is based on the network service tariffs and subsidy structure in force in 2017.

Figure 1. Electricity bill components, EUR with VAT.

This publication discusses six key benefits of moving from fixed to dynamic prices for both the power industry and consumers (Section II):

A. Increased demand response;
B. Increased security of electricity supply;
C. Increased competition between producers;
D. Lower electricity price;
E. Lower retail mark-ups;
F. Greater competition between retailers.

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We conclude with Section III.

The main contribution of this paper is the analysis of price formation in fixed and spot-linked tariffs for end-users in Latvia and Estonia. Following the findings of [1], such evidence of benefits of dynamic prices as presented in this paper, might be used to inform end-users on importance of choosing spot-linked tariffs for electricity industry.

II. ANALYSIS OF DYNAMIC PRICE BENEFITS

A. *Facilitation of demand response*

Historically, balancing electricity demand and generation in the power grid was done by regulating the large scale, easily controllable power plants, adapting instantaneous generation volume to demand. Demand is not elastic because making changes in demand is often technically complicated [2] and consumers are reluctant to change their consumption habits [3] (see Fig. 2). However, circumstances are changing. Technology development in the field of IT & T, automation and batteries allow consumers with flexible demand to compete commercially with electricity generators. Existence of such technologies is also a prerequisite for small consumers to participate in demand response [4].

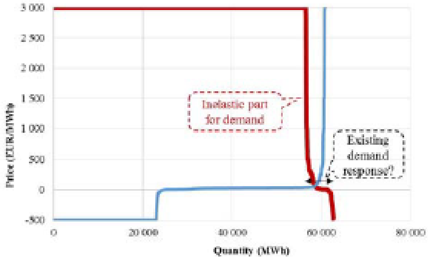

Figure 2. Electricity demand and supply curves at Nord Pool (16.01.2017, 09:00-10:00).

Demand response is determined by the economic choice between the benefits of using electricity at a convenient time and the benefits from the use of electricity at other times and/or a decrease in demand [4]. However, in a market dominated by tariffs with a fixed electricity price, most consumers do not have such an economic choice, and for such customers, efforts to reduce electricity bills are based only on supplier switching [5].

In order for the consumer to be economically motivated to change the profile of consumption, it is necessary that electricity tariff is linked to the variable wholesale price in Nord Pool exchange. By choosing a spot price linked electricity tariff and by changing the profile of consumption, the consumer will gain greater ability to control its electricity costs.

The European Commission (EC) is seeking a new legislative initiative to promote incentives for electricity supply companies to offer consumers spot-linked dynamic tariffs starting from 2020. This will improve ability of consumers to reduce their electricity bills. According to European Commission estimates [6], the transition to flexible prices in the European Union (EU) Member States could reduce the average household electricity bill by EUR 400 per year.

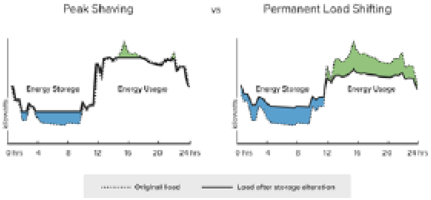

Figure 3. Using electricity demand response to cover peak loads (left) and level out load profile (right). Source: North American Clean Energy, 2017[1]

B. *Increased security of supply*

One of the main tasks of the Transmission System Operators (TSOs) is to ensure a continuous balance between supply and demand of electricity in the grid. Bigger deviations from balance can cause system instability and even disconnection of consumers. Balance management in the Baltic power grid is becoming more and more challenging for two reasons. First, the power of easily regulated conventional, large power plants is decreasing in the Baltics, but less controllable, less predictable and distributed generation such as wind power is increasing. During the next decade, approximately 50% of the current thermal power plant capacities are expected to decommission (see Fig 4). Secondly, the Baltic States are planning to desynchronize from the Russian unified power system by 2025, which will create the need for additional flexibility sources in order to ensure the balance of electricity in both normal and extraordinary circumstances.

Currently Russian power system provides substantial amount of balancing capacity, including primary control of frequency.

Possibly that the greatest power system flexibility potential lies in demand response. Therefore, in order to promote flexibility in the power grid, it is necessary to achieve that real electricity price reach electricity consumers, thus involving

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[1] "Grocery Stores Go Beyond Batteries with Thermal Energy Storage," [Online]. Available: http://www.nacleanenergy.com/articles/26591/grocery-stores-go-beyond-batteries-with-thermal-energy-storage

consumers in ensuring the power balance in the Baltic power system [7]-[9]. Electricity prices become a "glue" connecting the power system operation process with motivated decisions of market participants, thus contributing to the security of power system [10].

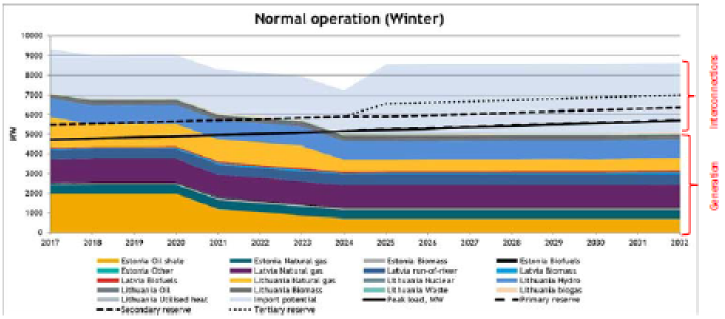

Figure 4. Forecasted available electricity supply capacity in the Baltic region in winter. Source: Baltic TSOs.

C. *Increased competition between electricity producers*

Flexible consumers can compete with producers in the market for both electricity and various system services, contributing to a reduction in overall electricity costs. As the intermittent and distributed generation expands rapidly in the system and at the same time the total capacity of conventional power plants decreases, role of demand response is increasing notably in provision of different system services in the European market, incl. frequency regulation and balancing.

By motivating consumers to choose spot-linked tariffs, demand response and consumer competition with electricity producers is encouraged, which has a positive effect on the formation of electricity prices in the market (Fig. 5).

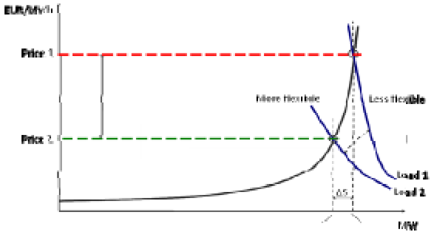

Figure 5. Flexible demand competition with generators and impact on market price cuts.

D. *Lower electricity price*

When purchasing electricity at a tariff linked to hourly spot price in exchange, the electricity user always pays for electricity at a price that is formed on the exchange in the actual circumstances of the power system during the period of electricity consumption. In turn, when choosing a fixed-price tariff, the fixed price in the supply contract between consumer and retailer is normally based on the wholesale electricity price forecast at the time of conclusion of the contract for the expected delivery period (for example, 12 months). The forecasted price never matches the actual price [11]. Consequently, the interesting question is: which type of supply contract offers the lowest average electricity price in the long run?

We will not give any forecasts about possible future price trends. However, we can look at the statistical price trends in the market. Within the framework of the analysis, the price comparison of the Nordic system spot prices and forward prices over a period of several years was carried out. The electricity spot price source is the Nord Pool exchange, while the source of electricity forward prices is the Nasdaq OMX Commodities. Similarly to [12] and [13], we apply ex-post forward risk premium methodology. We use the last closing prices before the start of the supply period for monthly, quarterly, and yearly forward contracts. Statistical data show (Fig. 6), for example, that yearly system price has been on average 8% higher than the average spot price during the 20-year period (1996-2016). As shown in Table 1, the monthly and quarterly forward prices have been higher than the spot prices, albeit to a lesser extent than the yearly forward prices.

Of course, it is not possible to say with certainty whether in future forward prices will be higher than spot prices. This work provides an overview of publicly available information on electricity prices and, based on this information, each electricity user can draw conclusions and further assumptions when it comes to choosing between fixed and dynamic prices. However, in order for market participants to make informed decisions, it is necessary to make such information accessible for the public.

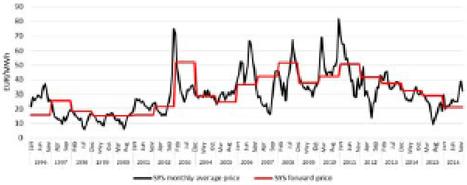

Figure 6. Price of Nordic system price forwards and Nordic system spot price. Source: SKM, authors' calculations.

TABLE I. FORWARD CONTRACTS' EX-POST RISK PREMIUM

Type of forward contract	Monthly	Quarterly	Yearly
Ex-post risk premium	3%	4%	8%

Note: Statistics of monthly and quarterly forward prices for taken from the period 2003 to 2016, but yearly forward prices from the period 1996 to 2016.

E. *Lower retail margins*

Publicly available electricity supply offers indicate that retail mark-ups in fixed price offers tend to be higher than in dynamic price offers. Table 2 shows a comparison of publicly available retail markups for fixed and dynamic price offers for households in Estonia and Latvia for 2018. This data show that in Latvia retail mark-ups in spot linked prices are on average two times smaller than in fixed price offers, but in Estonia the retail margin in spot linked prices is even nine times smaller. It should be emphasized that this analysis is based on publicly available bids, which may be changed in some cases during the negotiations between a consumer and supplier. It should be noted that the closing price of electricity financial contracts used to calculate the mark-up varies day by day. However, overall, the result of an analysis indicates the general trend of retail margins being smaller in spot linked price offers than in fixed price offers. The reasons for that may be quite different. For example, sale of electricity at a fixed price result in a higher financial risk for a retailer due to price spot volatility, and administrative costs associated with hedging.

TABLE II. COMPARISON OF ELECTRICITY RETAIL MARK-UPS (EUR/MWH) FOR FIXED AND VARIABLE PRICES

	Forward price[a]	Weighted forward price[b]	Fixed retail price[c]	Retail margin in fixed price[d]	Retail margin in spot-linked price[e]
Estonia	34.1	35.8	43.7	7.9	0.9
Latvia	36.9	38.7	45.2	6.5	3.0

a. yearly system forward prices of 2018 traded on the Nasdaq OMX Commodities exchange and the closing price (CP) of the respective EPAD financial contract (Tallinn or Riga) on 20.12.2017;

b. CP of financial contracts increased by 5% to account for the consumption profile;

c. the average of the five cheapest electricity supply retail offers at fixed prices at public sites www.elektroenergija.lv and www.energiaturg.ee on 20.12.2017;

d. the difference between fixed retail price and wholesale price (weighted forward price);

e. the average of the five cheapest spot linked electricity retail offers mark-ups on public websites www.elektroenergija.lv and www.energiaturg.ee on 20.12.2017.

F. *Higher competition among electricity suppliers*

The price of electricity on the wholesale market varies every hour, therefore retail of electricity at a fixed price creates additional financial risks which should be managed. Price risk management requires additional resources and competence. For new suppliers, these costs form part of the costs associated with entering the market. In addition, hedging of price risks involves not only additional administrative costs but also the cost of purchasing financial instruments, which are significantly higher in the Baltics than in the Nordic market due to low liquidity (Table 3).

TABLE III. MARKET DATA FOR DIFFERENT FINANCIAL CONTRACTS

Contract type	Bid-Ask spread (EUR/MWh)	Open interest (TWh)	Open interest relative to contract's local electricity demand (%)
Nord Pool System	0.23	187.8	48.6
EPAD SE3	0.41	37.5	43.0
EPAD FI	0.45	33.6	40.0
EPAD SE4	0.46	4.7	19.4
EPAD SE2	0.59	5.9	35.4
EPAD NO1	0.63	1.9	5.1
EPAD DK1	0.74	2.8	14.4
EPAD DK2	0.77	3.7	28.3
EPAD SE1	0.90	2.6	26.9
EPAD NO4	1.37	1.4	7.5
EPAD LV	5.50	0.1	1.8
EPAD EE	N/A	0.0	0.0

Note: The volume of all traded financial contracts of the respective price areas at Nasdaq OMX Commodities exchange over the period from June 2015 until the end of 2016.

The issue of low liquidity in trade with financial instruments is becoming more relevant not only in the Baltics, but also in the Nordic market. The turnover of Nordic electricity financial contracts traded in the Nasdaq OMX exchange in 2017 (total amount - 1059 TWh) decreased by 26% compared to the previous year and was the lowest in the last 18 years (Fig. 7).

The turnover has been steadily declining since the global financial crisis in 2008, when it reached 2535 TWh. Some of the reasons for such rapid decline could be the EU's additional regulatory requirements for financial market participants, decreasing electricity spot prices and low spot price volatility, as well as fragmentary markets with many price areas.

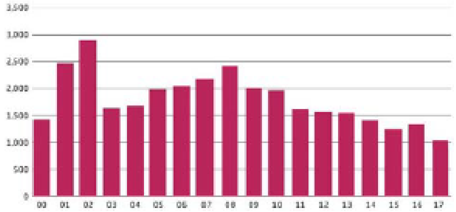

Figure 7. Nordic financial power trading volumes traded and cleared at Nasdaq (2000-2017), TWh. Source: Montel.

In any case, additional financial risk and the need for additional resources and competencies do not arise when the retailer sells electricity at spot-linked retail prices. Consequently, it is relatively easier and cheaper for new electricity suppliers to enter the market and compete in the dynamic price segment rather than in the fixed price segment. It can be concluded that in general competition among electricity retailers should be greater in segment of spot-linked prices.

The observation that in dynamic price contracts both average price levels and retail mark-ups are lower than in fixed-price offers reinforces this assumption: economic logic says that in a more competitive environment, prices are lower.

III. CONCLUSIONS

Matching supply and demand is becoming more challenging and the Baltic electricity system needs more flexibility. Lack of demand participation remains one of the most serious challenges.

In order to facilitate demand response consumers should be exposed to prices which are reflecting the actual energy balance in the system. Transition from fixed to spot-linked consumer prices would have positive impact on energy industry, including facilitation of the demand response, positive influence on the security of supply, higher competition both in generation and retail markets, reduction of financial risks for electricity suppliers, and reduction of costs of supply.

We conclude that the end-users might benefit from dynamic prices because of lower electricity bills. Our analysis shows that in 2018 retail margin in fixed price offers is close to 7.9 and 6.5 EUR/MWh in Estonia and Latvia respectively. In contrast, retail margin in spot-linked prices is 0.9 and 3.0 EUR/MWh for the same period.

Our analysis of ex-post forward risk premiums indicates that electricity traders pay considerable premium for hedging their price risks. Such risk management expenses are necessary only for traders, who offer fixed-price contracts for the end-users. Continuously declining turnover of Nordic electricity financial contracts traded in the Nasdaq OMX indicates that in the future, when liquidity of financial contracts decreases even more, hedging might become more expensive. We conclude that electricity retailers can escape from price risk and growing hedging costs by focusing on spot-linked offers.

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Elektroenerģijas pārvades tīklā būtiski palielināta starpvalstu tirdzniecības jauda

AST 80 GADUS ENERĢIJA KUSTĪBĀ

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Pēdējo piecu gadu laikā Baltijas elektroenerģijas tirgū ir divkāršojusies tirdzniecības jauda ar Eiropas tirgu un pieaudzis pārrobežu tirdzniecības apjoms. Tas ir panākts, gan efektīvi veicot investīcijas Baltijas pārvades tīkla infrastruktūrā, gan pilnveidojot elektroenerģijas tirgus modeli, kas nodrošina efektīvāku pārvades tīkla izmantošanu un arī sīvāku konkurenci starp elektroenerģijas ražotājiem plašākā reģionā. Tomēr Baltijas integrācija vienotajā Eiropas elektroenerģijas tirgū ir tikai pusceļā – tuvākajā piecgadē starpvalstu tirdzniecības jaudu plānots būtiski palielināt gan Baltijas reģionā, gan starp Baltijas un Eiropas enerģijas tirgiem.

Pēdējo piecu gadu laikā elektroenerģijas tirdzniecība starp Baltiju un Eiropu pieaugusi par 250%

Gan Latvija, gan visa Baltija ir salīdzinoši ļoti mazas energosistēmas. Baltijā gada elektroenerģijas patēriņš svārstās ap 25 TWh, Skandināvijā – ap 400 TWh, bet Eiropas Savienības kopējais elektroenerģijas patēriņš pārsniedz 3000 TWh gadā. Mazās energosistēmās noteikti faktori, tostarp elektroapgādes drošums, konkurence starp ražotājiem un elektroapgādes izmaksas, ir īpaši atkarīgi no ārējās starpvalstu tirdzniecības iespējām. Tāpēc AS "Augstsprieguma tīkls" pamata stratēģija, kā ilgtermiņā nodrošināt stabilu un ekonomiski pieejamu elektroapgādi Latvijā, ir Latvijas elektroenerģijas tirgus integrācija vienotā Eiropas elektroenerģijas tirgū. Līdzīgs mērķis ir arī Lietuvas un Igaunijas pārvades sistēmu operatoriem.

Lai nodrošinātu Baltijas integrāciju Eiropas tīklos, Baltijas pārvades sistēmu operatori pēdējos desmit gados ir konsekventi īstenojuši integrācijas projektus. Par integrācijas sekmīgo gaitu vislabāk liecina tirgus darbības rādītāji. 2014. gadā Baltijā tirdzniecībai pieejamā starpsavienojumu kapacitāte bija vidēji ap 800 MW, turpretī 2018. gadā vidējā kapacitāte sasniedza teju 1900 MW (1. att.). Tirgus dalībnieki aktīvi izmantojuši piekļuvi Eiropas elektroenerģijas tirgum: 2014. gadā Baltijas tirdzniecības apjoms ar Eiropu bija ap 3,5 TWh, 2018. gadā sasniedzot jau ap 8,7 TWh (2. att.). Tas liecina, ka gan elektroenerģijas iztrūkuma, gan pār-

palikuma periodos Baltijas tirgus dalībnieki piekļūst plašākam, diversificētākam, konkurējošākam tirgum, lai iegūtu ekonomiski pamatotākas cenas darījumus.

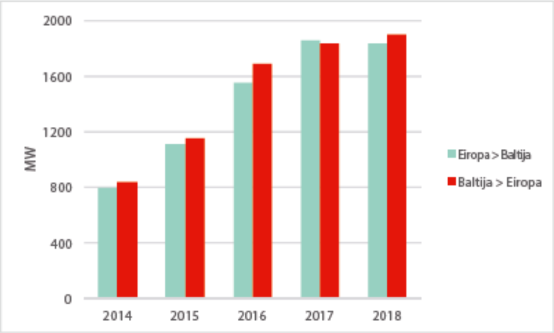
Viens no svarīgākajiem elektroenerģijas tirgus integrācijas pakāpes rādītājiem ir elektroenerģijas cenu tuvināšanās kaimiņu reģionos (3. att.). Īpaši kopš 2016. gada, kad tika nodoti ekspluatācijā *NordBalt* un *LitPol* starpsavienojumi, elektroenerģijas cenas satuvinājās gan Baltijas valstīs, gan Baltijas un Skandināvijas reģionā kopumā. Vēl 2014. gadā vidējā *spot* cenu starpība Latvijā un Igaunijā bija 12,5 EUR/MWh, bet 2018. gadā tā samazinājās vairāk nekā piecas reizes un sasniedza 2,3 EUR/MWh. Līdzīga tendence ir vērojama arī cenu dinamikā Baltijas un Skandināvijas tirgos. Vēl 2014. gadā vidējā *spot* cenu starpība Latvijā un Somijā bija 14,1 EUR/MWh, 2018. gadā tā samazinājās vairāk nekā piecas reizes un sasniedza 2,6 EUR/MWh. Cenu satuvināšanās liecina par augstāku konkurenci, jo cenu izlīdzināšanās gadījumā ražotāju konkurencei neierobežo pārvades tīkla ierobežojumi, tā veicinot vispārēju cenu samazināšanos.

Tuvākajos gados Baltijas starpsavienojumu jauda ar Eiropas energosistēmu varētu palielināties vēl par 50%

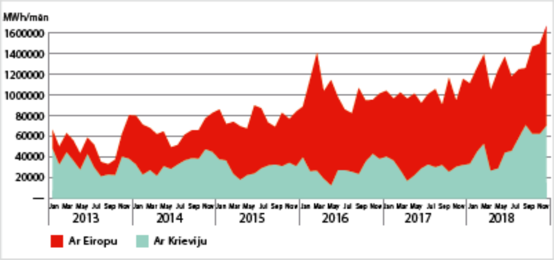
Patlaban Baltijai ir četri līdzstrāvas starpsavienojumi ar Eiropas energosistēmu ar summāro jaudu 2200 MW (4. att.). Tas ir ļoti daudz, ņemot vērā, ka Baltijas energosistēmas vidējais patēriņš ir ap 2900 MW, bet ziemas maksimums – ap 4500 MW. Tomēr Baltijas integrācijas process vēl aktīvi turpināsies līdz 2025. gadam, kad plānots pabeigt Baltijas energosistēmas pieslēgšanu sinhronam darbam ar kontinentālās Eiropas pārvades sistēmu un realizēt dažus citus nozīmīgus starpsavienojumu attīstības projektus.

Igaunijas-Latvijas 330 kV starpsavienojums

Uz Igaunijas-Latvijas robežas tiks rekonstruētas un pastiprinātas esošās divas 330 kV elektropārvades līnijas, kas atiet no Valmieras apakšstacijas uz Tartu un Tsirgulinu Igaunijā, kā arī tiks izbūvēts trešais savienojums – starp Rīgas TEC-2 un Kilingi-Nemmi Igaunijā (4. att.), kā rezultātā starpvalstu elektrolīniju jauda uz Igaunijas-Latvijas robežas pieaugs par vienu trešdaļu jeb aptuveni 600 MW. Šie projekti ir nepieciešami, lai palielinātu esošo pārvades jaudu starp Igauniju un Latviju, nodrošinātu Baltijas elektroenerģijas tirgus integrāciju kopējā Eiropas elektroenerģijas tirgū, izveidotu jaudīgāku un drošāku tranzīta koridoru caur Baltijas elektroenerģijas sistēmām ziemeļu-dienvidu virzienā, palielinātu elektroapgādes drošumu šķērsgriezumā starp Igauniju un Latviju, kā arī radītu nepieciešamo infrastruktūru Baltijas valstu veiksmīgai sinhronizācijai ar kontinentālo Eiropu.



1. attēls. Summārā tirdzniecībai pieejamā jauda Baltijas ārējos starpsavienojumos ar Eiropas elektroenerģijas tirgu (ietilpst Baltijas starpsavienojumi ar Skandināvijas valstīm un Poliju)



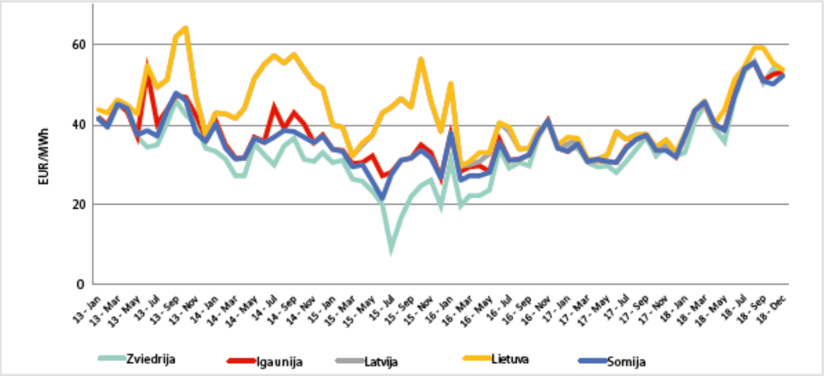
2. attēls. Baltijas elektroenerģijas tirdzniecības apjoms ar Eiropas valstīm un Krieviju

LitPol savienojums starp Lietuvu un Poliju

Patlaban starp Lietuvu un Poliju ir izbūvēta divķēžu maiņstrāvas elektropārvades līnija ar pārvades jaudu 1000 MW un konvertoru apakšstaciju Lietuvā ar uzstādīto jaudu 500 MW. Līdz ar to *LitPol* starpsavienojuma jaudu šobrīd iespējams izmantot 50% apmērā. Realizējot Baltijas sinhronizāciju ar kontinentālo Eiropu, *LitPol* starpsavienojumu plānots pieslēgt tieši Lietuvas pārvades sistēmai bez konvertoru apakšstacijas, tādējādi palielinot *LitPol* pārvades jaudu divas reizes – līdz 1000 MW.

Harmony Link

Sinhronizācijas projekta ietvaros 2018. gadā tika veikta dinamiskās stabilitātes izpēte un Baltijas valstu elektroenerģijas sistēmu pievienošanas ietekmes uz kontinentālās Eiropas sistēmu analīze. Veikto pētījumu rezultāti apliecināja, ka Baltijas pārvades sistēmas sinhronizāciju iespējams veikt caur esošo divķēžu *LitPol* līniju, papildus no Polijas uz Lietuvu izbūvējot līdzstrāvas kabeli. Šo starpsavienojumu nolemts nosaukt par *Harmony Link* (Saskaņa). Lietuvas un Polijas pārvades sistēmu operatori plāno pieņemt investīciju lēmumu 2020. gadā un kabeli nodot ekspluatācijā līdz 2025. gadam.



3. attēls. Mēnešu vidējās elektroenerģijas cenas *Nord Pool* biržā

Jaunā pārvades tīkla caurlaides jaudas aprēķināšanas metodika veicinās starpvalstu tirdzniecību

Pamatojoties uz Eiropas Komisijas Regulas 2015/1222, kas stājās spēkā 2015. gada 24. jūlijā (CACM – *Capacity Allocation And Congestion Management*), 20. panta 2. punktu visi t.s. Baltijas jaudas aprēķināšanas reģiona (turpmāk – Baltijas JAR) pārvades sistēmu operatori – AS "Augstsprieguma tīkls" (Latvija), *Elering* AS (Igaunija), *Litgrid* AB (Lietuva), PSE S.A. (Polija), *Svenska kraftnät* (Zviedrija) un *Fingrid Oyj* (Somija) – izstrādāja jaunu, kopīgu caurlaides spēju aprēķināšanas metodiku *(http://www.ast.lv/lv/content/eiropas-savienibas-tiesibu-akti* sadaļā "Tirgus kodeksi"). Šo metodiku 2018. gada 16. novembrī apstiprināja visas Baltijas JAR nacionālās regulatīvās iestādes (Regulatori), nosakot, ka tā stāsies spēkā 2019. gadā pēc trīs citu reģionāli saistošu metodiku apstiprināšanas, tostarp – jaunās metodikas (*http://www.ast.lv/lv/content/citi-saistosie-dokumenti*, "Pārvades jaudas aprēķināšanas un piešķiršanas metodika ar trešajām valstīm") par caurlaides spēju aprēķiniem ar trešajām valstīm, ko jau ir apstiprinājuši visi Baltijas valstu regulatori un kas stājas spēkā 2019. gada 1. februārī.

Jaunā Baltijas JAR metodika ievieš nozīmīgus uzlabojumus starpvalstu šķērsgriezumu caurlaides spēju lielumu aprēķināšanā, no kā ieguvēji būs tirgus dalībnieki. Jaunajā metodikā ir veiktas vairākas būtiskas izmaiņas salīdzinājumā ar iepriekšējo metodiku.

Jaunā metodika ietver caurlaides spēju aprēķināšanu ne tikai maiņstrāvas starpsavienojumiem starp Igauniju, Latviju un Lietuvu, bet arī līdzstrāvas starpsavienojumiem ar Somiju, Zviedriju un Poliju. Tādā veidā informācija par caurlaides spēju aprēķināšanas principiem kļūst pārredzamāka un saprotamāka Baltijas un Ziemeļvalstu reģiona tirgus dalībniekiem.

Tirdzniecībai paredzēto caurlaides spēju aprēķinā maiņstrāvas starpsavienojumos starp Igauniju un Latviju, kā arī starp Latviju un Lietuvu vairs nav paredzēta iespēja samazināt energosistēmās izvietoto garantēto avārijas rezervju apjomu sakarā ar to izmantošanu citu šķērsgriezumu (piemēram, Lietuvas-Baltkrievijas) minimālas, garantētās tirdzniecības jaudas garantēšanai. Rezultātā jaunā metodika nodrošinās tirdzniecībai izmantojamo caurlaides spēju palielinājumu uz starpsavienojumiem no Igaunijas uz Latviju, kā arī no Latvijas uz Lietuvu.

Jaunajā metodikā atbilstoši CACM Regulas prasībām paredzēta caurlaides spēju aprēķināšanas funkcijas centralizācija. Turpmāk caurlaides spēju aprēķinu visā Baltijas jūras reģionā veiks t.s. "koordinēto jaudas aprēķinātājs", kas padarīs caurlaides spēju aprēķina procesu efektīvāku.

Jaunajā metodikā paredzētās starpvalstu šķērsgriezumu caurlaides spēju lielumu aprēķināšanas būtība ir šāda (5. att.):

- maksimāla šķērsgriezuma caurlaides spēja (*Total Transfer Capacity* – TTC) starp dažādu valstu pārvades tīkliem tiek aprēķināta 330 kV pārvades tīklam, ievērojot kritērijus, kas nepieciešami elektroapgādes drošuma nodrošināšanai;
- pārvades drošuma rezerve (*Transmission Reliability Margin* – TRM) tiek aprēķināta, analizējot jaudas plūsmas novirzes statistiku par iepriekšējo laika periodu dotajam šķērsgriezumam. Jaudas plūsmas novirze ir starpība starp plānoto un faktisko jaudas plūsmu starpvalstu šķērsgriezumam;
- šķērsgriezuma neto pārvades jauda (*Net Transfer Capacity* – NTC) tiek aprēķināta, atņemot no maksimālās šķērsgriezuma caurlaides spējas pārvades drošuma rezerves lielumu;
- jau piešķirtā šķērsgriezuma caurlaides spēja (*Already Allocated Capacity* – AAC) ir kopējā jaudas vērtība, kura faktiski piešķirta tirdzniecībai pēc elektroenerģijas tirgus sesijas rezultātiem;

Avots: ENTSO-E.

4. attēls. Baltijas elektroenerģijas pārvades tīkls

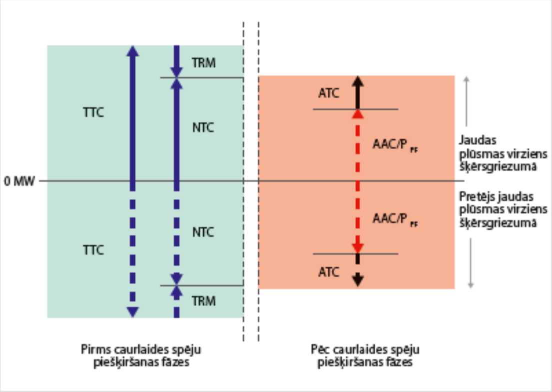
- pieejamā caurlaides spēja elektroenerģijas tirgum (*Available Transmission Capacity* – ATC) ir caurlaides spējas elektroenerģijas tirgum daļa, kas atlikusi un ir pieejama katrā tirdzniecības intervālā pēc katras elektroenerģijas tirdzniecības sesijas. Līdzstrāvas savienojumiem Baltijas JAR ATC vērtība ir vienāda ar NTC un AAC starpību, savukārt maiņstrāvas savienojumiem ATC tiek rēķināts ievērojot ne tikai NTC un AAC, bet arī TRM un aprēķinātās (prognozējamās) fiziskās plūsmas (PPF) attiecīgajā šķērsgriezumā, ņemot vērā elektroenerģijas tirgus sesijas rezultātus.

Maksimālās šķērsgriezuma caurlaides spējas (TTC) aprēķinos maiņstrāvas savienojumiem izmanto modelēšanu uz kopējiem tīkla modeļiem, ievērojot BRELL loka PSO metodiskos norādījumus un instrukcijas. Ņemot vērā energosistēmu tehniskās īpatnības, Igaunijas-Latvijas robežas caurlaides spēja cita starpā ir atkarīga arī šādiem diviem mainīgajiem – pieejamo garantēto avārijas rezervju apjoma un apkārtējās vides temperatūras. Zemāk dota izteiksme no Baltijas JAR caurlaides spēju metodikas caurlaides spēju (NTC) aprēķiniem Igaunijas-Latvijas robežai. Pirmais no parametriem (maksimālā šķērsgriezuma caurlaides spēja N-1 situācijā, ievērojot pieejamās garantētās avārijas rezerves) tiek ņemts vērā izteiksmes kreisajā pusē, savukārt otrais parametrs (ārgaisa temperatūra aprēķināmajam periodam) – tiek ievērots ar “TTC_2” vērtību. Tālāk tiek izmantota mazākā TTC vērtība, kas izriet no abiem parametriem, un, no tās atņemot TRM, tiek iegūta tirgum piešķiramā caurlaides spēja NTC.

$$NTC = \min\left(\left(\underbrace{\left(TTC_1 + \Sigma_{i=1}^{n} K_i \cdot P_i\right)}_{\text{TTC, kas ņem vērā TTC N-1 situācijai un vērtības palielinājumu dēļ pieejamajām rezervēm}} - TRM\right); \underbrace{TTC_2}_{\text{TTC, kas ņem vērā ārgaisa temperatūru}} - TRM\right)$$

Tirdzniecības jaudas NTC noteikšanā uz Latvijas-Lietuvas robežas, atšķirībā no Igaunijas-Latvijas robežas, nepastāv atkarība no temperatūras un caurlaides spējas tiek noteiktas, balstoties uz aprēķiniem un ņemot vērā tikai vienu papildu parametru – maksimālo šķērsgriezuma caurlaides spēju N-1 situācijā, ievērojot pieejamās garantētās avārijas rezerves. Šī iemesla dēļ Igaunijas-Latvijas robežas caurlaides spējas var mainīties pie vienas un tās pašas tīkla topoloģijas, ģenerācijas un slodzes sastāva, kā arī avārijas rezervju apjoma.

$$NTC = \underbrace{\left(TTC_1 + \Sigma_{i=1}^{n} K_i \cdot P_i\right)}_{\text{TTC, kas ņem vērā TTC N-1 situācijai un vērtības palielinājumu dēļ pieejamajām rezervēm}} - TRM$$



5. attēls. Tirdzniecībai paredzētās starpsavienojuma caurlaides spējas noteikšanas metode

No 2019. gada 1. februāra spēkā stājas jauna metodika, kas likvidēs garantēto 200 MW tirdzniecības jaudu ar Krieviju

Baltijas valstu tirdzniecība ar Krieviju tiek veikta caur Lietuvas-Baltkrievijas robežu. Pēdējos gados Lietuvas pārvades sistēmas operators *Litgrid* noteica, ka tirdzniecībai piešķirtā jauda nevienā brīdī nav mazāka par 200 MW. Šīs garantētās jaudas uzturēšanas dēļ regulāri bija nepieciešams ierobežot tirdzniecības jaudas starp Baltijas valstīm, īpaši starp Igauniju un Latviju. Tāpēc garantētās 200 MW jaudas nodrošināšana ar Krieviju bija pretrunīga un radīja neapmierinātību tirgus dalībniekos.

2018. gadā trīs Baltijas valstu Regulatori pieņēma lēmumu, ar kuru no 2019. gada 1. februāra stājas spēkā jaunā metodika caurlaides spēju aprēķiniem ar trešajām valstīm. Jaunā metodika paredz, ka uz Lietuvas-Baltkrievijas robežas vairs netiks pielietota minimālā caurlaides spēja 200 MW apjomā, ko izmantoja *Litgrid*, pamatojoties uz Lietuvas energosistēmā izvietotajām garantētajām rezervēm. Minimālās caurlaides spējas noņemšana ļaus pielietot lielāku garantēto rezervju apjomu no Lietuvas energosistēmas Igaunijas-Latvijas un Latvijas-Lietuvas robežu caurlaides spēju aprēķinos. Lielāks rezervju apjoms (palielinājums par 200 MW salīdzinājumā ar esošo situāciju) ļaus palielināt caurlaides spēju uz Latvijas-Lietuvas robežas (virzienā uz Lietuvu) par vismaz 68 MW, kā arī palielināt caurlaides spēju uz Igaunijas-Latvijas robežas (virzienā uz Latviju) par vismaz 68 MW gadījumos, kad nebūs temperatūras ierobežojumu.

Jāatzīmē, ka jaunā metodika caurlaides spēju aprēķiniem ar trešajām valstīm darbosies līdz Baltkrievijā jaunbūvējamās atomelektrostacijas palaišanai. Pēc atomelektrostacijas palaišanas Baltkrievijā caurlaides spēja elektroenerģijas tirdzniecībai uz Lietuvas-Baltkrievijas robežas tiks samazināta līdz nullei atbilstoši Lietuvas likumdošanai. Sagaidāms, ka Baltkrievijas atomelektrostacija varētu sākt darboties 2019. gadā. Līdz ar to Baltijas pārvades sistēmu operatoriem kopā ar Regulatoriem savlaicīgi jāsāk darbs pie jaunas caurlaides spēju aprēķina metodikas ar trešajām valstīm.

Benefits of regional balancing areas

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***Abstract*—The European power system is transforming rapidly to integrate more renewables, develop flexibility and enable consumers to play a more central role. For electricity markets, this transition means that trading needs to move closer to real time while respecting system security. As the system is changing, the more efficient balancing of the power system also needs to be developed. This paper provides an analysis of operation of common balancing area based on a case study of the Baltic common balancing energy market model which was launched as from 1st of January 2018. The objectives of development of the common Baltic balancing market were to increase balancing efficiency, to increase availability of balancing resources and to reduce the costs of power system balancing. Establishing the common Baltic balancing market required harmonization of balancing market frameworks of the three Baltic States including the settlement rules between market parties, introduction of a coordinated balance control on a regional level and introduction of common balancing IT platform. This paper analyses operational indicators assessing the performance of the new balancing system, including changes in area control error, changes in market liquidity and diversity, changes in balancing costs for market participants. Paper also analyses changes in balancing energy price dynamics in the Baltic States, including price volatility and price correlation to understand how imbalance prices could motivate balance steering of the balance responsible parties. Proposals for further balancing market model development are also provided in the paper.**[1]

***Index Terms*-- Power system, electricity balancing, electricity market.**

I. INTRODUCTION

Work on the Baltic integration into the European electricity balancing market started in 2009 with the approval of the Baltic Energy Market Interconnection Plan (hereinafter – Plan) [1]. The aim of the initiative was to provide a comprehensive guideline for establishing Baltic cross-border interconnections and facilitating market integration in the Baltic Sea Region. One of the main tasks listed in the Plan was to work jointly towards opening, liberalizing and harmonizing electricity market as well as creation of a common balancing market and harmonized imbalance settlement and imbalance pricing. The European power system, similarly to the Baltic region faces challenges regarding organizing processes for ensuring permanent balance between consumption and production of electric power in the grid system. Increasing share of intermittent generation resources is steadily growing and it requests development of the flexibility. This transition means that electricity markets move to the next level of development, where trading needs to move closer to real time, while continuously ensuring system security. As the system is changing, the efficient balancing of the power system also needs to be developed. The promoter and initiator for defining the balancing framework is the Commission Regulation (EU) 2017/2195 of 23 November 2017. It lays down detailed rules for the integration of balancing energy markets in Europe, with the objectives of fostering effective competition, non-discrimination, transparency and integration in electricity balancing markets, and by doing so, enhancing the efficiency of the European balancing system as well as security of supply.

This paper provides an analysis of common Baltic area balancing mechanism which was developed to establish coordinated balancing area (hereinafter - CoBA) starting from 2018. To achieve this, the TSOs established procedures for coordinated balance control, exchange of the balancing energy, imbalance netting and balance settlement. The objective of harmonized Baltic balancing market was to increase the safe operation of the power system by promoting the availability of balancing resources and reducing power system balancing costs. Establishing the Baltic balancing market involved harmonization of balancing market framework and introduction of a common balancing IT platform.

This paper analysis several indicators to assess performance of the new balancing system, which include changes in area control error (quality of balance management), changes in market liquidity and diversity, changes in balancing costs for market participants. This paper also analysis changes in imbalance energy price dynamics in the Baltic States, including price volatility and correlation.

We use data from 2017 and 2018, a full year with the new model in operation. This already allows comparing the

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performance between the old and the new approach allows capturing the trends created by the introduction of Common Baltic Balancing market and highlight possible improvement for the next operating periods and experience for other regions.

II. CREATING COBA

A. *Justificaton*

Goal for common Baltic balancing market is to increase transmission system operation reliability, to foster availability of balancing resources and to reduce costs of system balancing. Common balancing market creates competition between balancing service providers that respectively reduces costs of balance responsible parties.

Main objectives for Common Baltic balancing market are:

- Increased reliance on local balancing resources and improve balancing market liquidity;
- Leveling playing field and establishing incentivizing price signals that promote BRPs self-balancing;
- Harmonized settlement procedures to remove market entry barriers;
- Improved data transparency.

The following features were introduced with Baltic CoBA:

- Common balancing towards Russia;
- TSO-TSO imbalance netting;
- Common centralized mFRR activation model with shared merit order list;
- Nordic-Baltic mFRR exchange;
- Harmonized BRP balance management model and imbalance pricing methodology.

III. RESULTS OF ANALYSIS OF OPERATIONAL INDICATORS

From the first year there is visible significant impact on main balancing market performance characteristics:

A. *Area control error (ACE)*

Baltic's Area Control Error (hereinafter - ACE) means the Baltic's not netted imbalance towards Russia.

Successful cooperation models among TSOs for balance control and imbalance netting has been in place for some time, and one of successful examples is Grid Control Cooperation (GCC) between German TSOs [2], that has grown to pan-European imbalance netting project involving 24 countries. Introducing similar principles to common Baltic balancing area enables optimization of balancing effort. As each country is not balanced separately it is possible to avoid counter-activation by netting *"long"* and *"short"* positions and as a result there is higher availability of mFRR reserves for minimization of Baltic's Area Control Error (ACE).

Advantages and challenges for imbalance netting are widely discussed; [3] emphasizes importance of TSO-TSO settlement to maintain financial neutrality, thus all TSOs benefit from imbalance netting.

The analysis of the historical data of Baltic CoBA performance revealed that centralized balancing market approach led to significant decrease of Baltic ACE. Average ACE decreased by 43% from 42 MWh to 24 MWh per imbalance settlement period (ISP) in 2018 compared to year 2017. Similarly, improved results on maintaining ACE close to 0 MWh was observed. In 2018 ACE was within 50 MWh range 89% of operational hours compared to 65% in 2017.

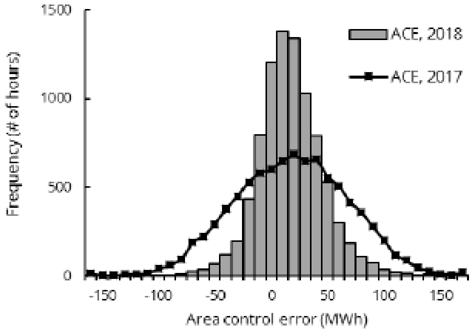

Figure 1. Baltic Area control error (ACE)

Trend of monthly acumulated ACE "Fig.2" indicates that ACE could continue decrease even further from gaining experience in choosing and ordering optimal amount of balancing energy. Improvements in ACE forecasting will also add to reduction of ACE.

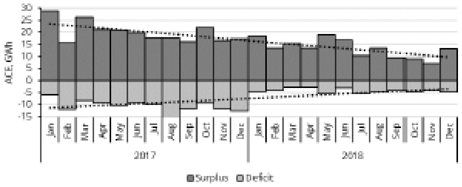

Figure 2. Monthly acumulated ACE

B. *Market liquidity*

More active balancing of CoBA with the goal to minimize Baltic ACE increased frequency of use of balancing energy bids. In 2018 Baltic TSOs ordered mFRR products in 79% of hours, which is twice as much as in 2017 (36% of hours), "Fig.3".

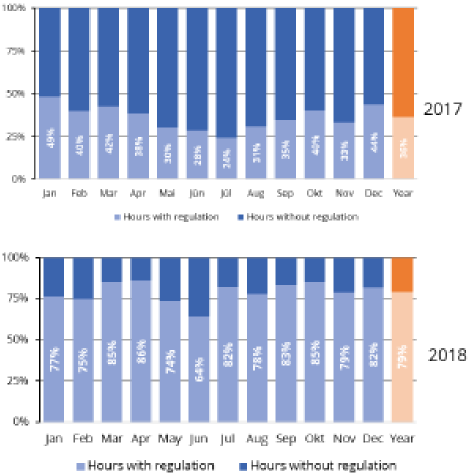

Figure 3. Share of hours with regulation

This higher demand for balancing resources, increased balancing market liquidity and made it more attractive to local generation. Therefore, amount of used balancing energy in 2018 tripled compared to 2017 "Fig. 4", while at the same time share of local balancing resources stayed at the level of 66%.

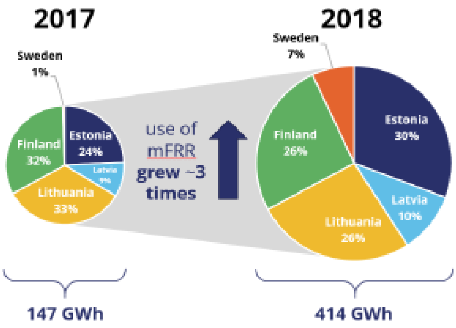

Figure 4. Use of balancing energy

C. *Imbalance pricing*

Major change is seen not only by balancing service providers, but also for balance responsible parties – introduction of single pricing for BRPs regardless of their imbalance position. Until 2018 settlement procedures were country based, imbalance prices included country specific components. Harmonization of settlement procedure and introduction of single imbalance price model (previously – dual price model) led to almost full convergence of imbalance prices in Baltic counties in 2018. Hourly imbalance prices were equal "Fig.5" in Latvia, Estonia and Lithuania in 97% of hours in 2018.

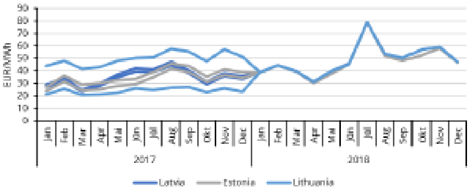

Figure 5. Imbalance price

Imbalance price in 2018 compared to day ahead market for Baltic countries show that 43% of hours has higher imbalance price than day-ahead price. In addition to that there are continuous periods of up to 88 hours long with imbalance price difference in one direction (smaller or larger) compared to day ahead price. Long periods of price difference in one direction may create motivation for BRPs to plan for intended imbalance with "long" or "short" position. This effect should be further monitored and analyzed to understand if it does not create counterproductive behavior at the system level.

Changes in imbalance pricing system created more level playing field for pan-Baltic BRPs and BSPs. Total Baltic BRP balancing costs decreased from 19,9 M.EUR in 2017 to 15,1 M.EUR in 2018. To evaluate the impact of changes in imbalance pricing model on pan-Baltic BRP's imbalance costs, we simulated BRP's portfolio.

Pan-Baltic BRP was created with average hourly planned consumption 100 MWh in each country. Hourly consumption was profiled according to Baltic weekly average consumption profile. To create multiple scenarios with randomized imbalances towards planned schedule actual position was randomly generated for each hour from planned value. Randomization was made with normal distribution and standard deviation of 5 MW to get on average 4% imbalance (no leaning towards surplus or deficit). In result calculated cost/profit from bought/sold imbalance volume. Average yearly cost/profit of imbalance MWh (300 scenarios) shown in "Fig.6". In result is visible that for simulated BRP cost reduced significantly comparing 2017 to 2018 and that BRP can benefit from netting its imbalances between Baltic countries therefore reducing cost of balancing.

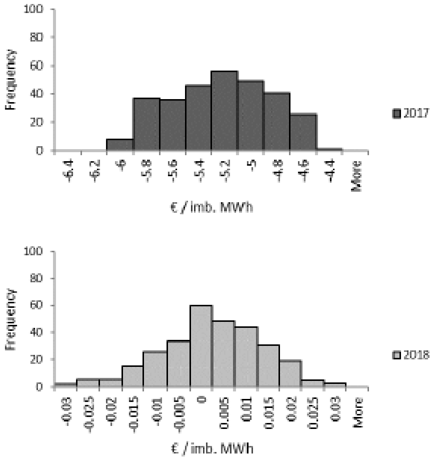

Figure 6. BRP imbalance costs

D. *Transparency*

Transparency issue is one of the top questions in energy market and the balancing market is not exception. The Baltic CoBA has solved the transparency issue and created balancing dashboard where all data is available in one place - common Baltic data platform. After the end of an imbalance settlement period (hereinafter – ISP)all Baltic TSOs ensure that all information regarding activation orders is completed and publicly available on Baltic balancing market dashboard and/or Baltic TSOs websites as well as on the central ENTSO-E information transparency platform based on EU regulation. Data items like the balancing prices, imbalance volumes and BSP offers are published 1 hour after operational hour. In addition to that, monthly balancing reports are created by transmission system operators (hereinafter -TSOs).

Until creation of CoBA dashboard individual country data were stored on each TSO's web-page, balancing prices were published only at the beginning of the next month and there was no information (volume and price) on BSP bids in market.

IV. CHALENGES IN FUTURE

Despite the good results of Baltic coordinated balancing area there are several challenges that lay ahead. There is still need for more mFRR resources and more active BSPs bid offering as there is not always sufficient volume of offered balancing bids available in six-month period from February 2018 were TSOs observed that in 12% of hours offered mFRR volumes was not sufficient. To improve this characteristic it is possible to add demand response (DR) to mFRR market [4]-[5]. Based on above mentioned at the end of the year 2017 Baltic transmission system operators held a common public consultation [6] on TSOs' position paper "Demand Response through Aggregation – a Harmonized Approach in the Baltic Region" [7].Key finding after public consultation were made - stakeholders recognize the need for DR integration in all Baltic countries. Furthermore, stakeholders see benefits for having a common demand response framework in the Baltic electricity markets and express strong overall support and willingness to participate in the DR market pilot studies.

Another challenges are the transition from 1h ISP to 15-minute ISP as well as further balancing market integration in Europe, joining MARI mFRR platform.

V. CONCLUSIONS

Analysis of performance indicators of the Baltic balancing system indicate clear benefits of common balancing areas and coordinated balance management. Market players including balancing service providers and balance responsible parties benefited from introduction of single price and single portfolio model. Considering that in 2018 97% of hours imbalance prices were similar in all three Baltic States, balance responsible parties are able to exercise imbalance netting and substantially reduce balancing costs that are passed onto end-users.

Analysis show that introduction of common balancing area and centralized balance management at a regional level has improved efficiency of system balancing, reduced ACE, improved availability of balancing resources and thus improved security of supply.

The model which is presented in this paper is not yet ready to ensure active real time balancing from BRP side, because imbalance and balancing prices are published after real time and that is issue which requires further study.

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Nākotnē pieaugs elektroapgādes jaudu nepietiekamības risks

80 GADUS
ENERĢIJA
KUSTĪBĀ

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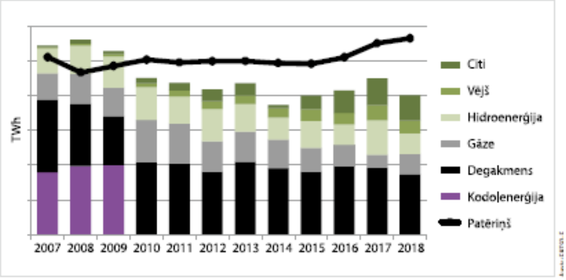
tirgus integrācijas un attīstības daļas projektu vadītājs

Baltijas valstu izstrādātie nacionālie enerģētikas un klimata plāni laikposmam līdz 2030. gadam paredz nozīmīgu atjaunojamo energoresursu īpatsvara palielinājumu galapatēriņā. Tāpēc nākamajā dekādē sagaidāma ievērojama vēja, saules un izkliedētās ģenerācijas attīstība Baltijas elektroenerģijas sistēmā un līdz ar to pieaugs nepieciešamība pēc balansēšanas jaudām. 2025. gadā plānotā Baltijas energosistēmas sinhronizācija ar kontinentālās Eiropas elektrosistēmu arī palielinās frekvences un balansēšanas rezervju nepieciešamību. Tajā pašā laikā, apturot nekonkurētspējīgo termoelektrostaciju darbību, Baltijā samazinās centralizētās, regulējamās jaudas. Šādai tendencei turpinoties, nākotnē pieaugs elektroapgādes jaudu nepietiekamības risks. Tāpēc ir svarīgi apzināt aktivitātes, kas palīdz šo risku mazināt, un savlaicīgi rīkoties.

Atjaunojamie energoresursi aizstāj fosilo enerģiju



1. attēls. Elektroenerģijas ražošana un patēriņš Baltijā

Pēdējos gados Baltijas elektroenerģijas ražošanas struktūrā nav notikušas straujas izmaiņas, tomēr ir skaidri redzama noturīga tendence pieaugt ražošanai no atjaunojamiem energoresursiem un samazināties ražošanai no fosilajiem energoresursiem.

Elektroenerģijas patēriņš pēdējo gadu laikā ir bijis stabils ar nelielu pieauguma tendenci. Pēdējo piecu gadu laikā patēriņš Igaunijā pieaudzis par 7%, bet Latvijā – par 2%. Lietuvas publicētie dati uzrāda 26% patēriņa pieaugumu pēdējo piecu gadu laikā, bet lielākā daļa no uzrādītā patēriņa pieauguma kopš 2017. gada ir radusies patēriņa uzskaites metodikas izmaiņu dēļ, patēriņā iekļaujot arī Kroņu HAES patēriņu sūkņa režīmā.

Pēdējos gados Baltijā saražoti ap 80% no patērētās elektroenerģijas; no tiem ap 60% iegūti no fosilā kurināmā (pamatā degakmens un dabasgāze), bet 40% – no atjaunojamiem energoresursiem (pamatā hidroenerģija un vēja enerģija). 2017. un 2018. gadā elektroenerģijas izstrāde no atjaunojamiem energoresursiem sasniegusi vēsturiski lielāko apjomu – attiecīgi pārsniedzot 10 TWh un 8 TWh.

Lielākie CO_2 emitētāji tiks izstumti no tirgus

Igaunijas degakmens elektrostacijām ir bijusi nozīmīga loma Baltijas energosistēmā. Pēdējos gados degakmens elektrostacijas saražojušas ap 9 – 10 TWh elektroenerģijas gadā jeb aptuveni pusi no kopējās ģenerācijas Baltijā. Svarīgi piemināt – tā kā degakmens tiek iegūts Igaunijā, šīs valsts elektrostacijas ir nodrošinājušas no ārējiem resursu piegādātājiem neatkarīgu elektroenerģijas ražošanu.

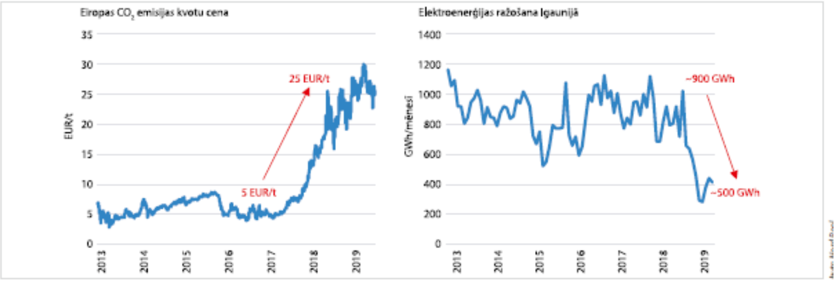
Taču degakmens dedzināšana rada ļoti daudz izmešu, īpaši CO_2 emisijas, līdz ar to šo elektrostaciju darbības rentabilitāti īpaši ietekmē CO_2 emisijas kvotu cenu izmaiņas Eiropas tirgū. Pēdējos gados degakmens elektrostaciju stabilos ražošanas apjomus pastāvīgi veicināja zemas un stabilas CO_2 emisijas kvotu cenas (2. att.). Tomēr jau 2019. gada sākumā CO_2 emisijas kvotu cena pārsniedza 20 EUR par tonnu un jūlijā vienubrīd sasniedza pat 29 EUR par tonnu. Rezultātā elektroenerģijas ražošana degakmens elektrostacijās būtiski samazinājās.

2019. gada jūlijā Igaunijas nacionālā energokompānija *Eesti Energia* paziņoja, ka pirmo reizi uzņēmuma vēsturē, 28. jūnijā, astoņu stundu periodā degakmens elektrostacijās nav notikusi elektroenerģijas ražošana. Vēl 2019. gada janvārī Narvas elektrostaciju ražošana sasniedza 1900 MW patēriņa pīķa stundās, turpretī jūnijā ģenerācija svārstījās 50 – 200 MW diapazonā.

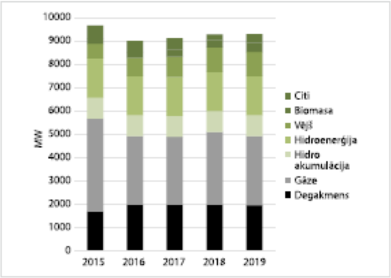
Igaunijā 2019. gada pirmajos desmit mēnešos saražotas 517 GWh jeb par 41% mazāk nekā līdzīgā periodā 2018. gadā. Baltijā kopumā līdzīgā periodā elektroenerģijas ražošanas apjoms samazinājās par 22%.

Reģionā sarūk centralizētās, regulējamās ražošanas jaudas

Pēdējo piecu gadu laikā Baltijā kopā uzstādīto elektrostaciju ražošanas jaudu apjoms ir bijis salīdzinoši stabils un šobrīd



2. attēls. CO_2 emisijas kvotu cena Eiropā (EUR/t) un elektroenerģijas ražošana Igaunijā



Avots: ENTSO-E

3. attēls. Baltijā uzstādītā elektrostaciju jauda

pārsniedz 9000 MW, kas ir aptuveni divas reizes vairāk par Baltijas patēriņa pīķa maksimumu. Pēdējo piecu gadu laikā par 25% (jeb aptuveni 1000 MW) samazinājās gāzes elektrostacijās uzstādītā jauda – to pamatā izraisīja vecāko gāzes elektrostaciju bloku slēgšana Lietuvā. Savukārt būtiskāko ražošanas jaudu pieaugumu nodrošināja jaunu vēja un biomasas elektrostaciju (ar kopējo jaudu ap 600 MW) nodošana ekspluatācijā, kā arī jaunas – 300 MW Auveres degakmens elektrostacijas (Igaunija) nodošana ekspluatācijā 2015. gadā (3. att.).

Sagaidāms, ka turpmākajos gados Baltijā turpinās samazināties lielo centralizēto bāzes elektrostaciju jaudas – pamatā ražošanu samazinās nekonkurētspējīgie veco termoelektrostaciju bloki Igaunijā un Lietuvā. Vienlaikus, lielākoties pateicoties vēja parku attīstībai, sagaidāms, ka kopējā uzstādītā ražošanas jauda Baltijā pieaugs. Ņemot vērā Baltijas valstu publicētos *Nacionālā enerģētikas un klimata plāna* projektus, kuros aprakstītas valstu ieceres saistībā ar atjaunojamās enerģijas ražošanas attīstību laikposmā līdz 2030. gadam, var secināt, ka Baltijā līdz 2030. gadam no atjaunojamiem energoresursiem saražotās elektroenerģijas apjoms varētu sasniegt vismaz 13 TWh gadā, kas ir par 5 TWh gadā vairāk nekā 2018. gadā un atbilst vismaz 40% no elektroenerģijas patēriņa Baltijā. Turklāt sagaidāms, ka jauno ražošanas jaudu lielāko daļu nodrošinās vēja parki.

Turpmākajos gados pieaugs elektroapgādes jaudu nepietiekamības risks

Baltijas pārvades sistēmu operatori regulāri izvērtē Baltijas valstu reģiona elektroenerģijas sistēmas darba drošumu un jaudas pietiekamību reģionā. PSO sagatavo ražošanas jaudu attīstības scenārijus, kas sniedz priekšstatu par to, kā turpmākajos gados mainīsies ģenerācijas jaudu un pieprasījuma līdzsvars un energoapgādes drošuma riski.

Pēc PSO novērtējuma, Baltijas reģionā maksimālās slodzes segšanu tehniski būs iespējams nodrošināt ar vietējām ražošanas jaudām (bez atbalsta, ko sniedz elektroenerģijas piegādes pa starpsavienojumiem no kaimiņu energosistēmām) līdz 2020. gadam. Pēc 2020. gada Baltijas valstu elektroapgādes jaudu pietiekamība būs atkarīga no importa pa starpsavienojumiem no kaimiņu elektroenerģijas sistēmām. Pīķa slodzes segšanai pieejamo jaudu rezerve nozīmīgi samazināsies pēc 2025. gada, kad Baltijas pārvades sistēma atvienosies no BRELL energosistēmas un uzsāks sinhronu darbu ar kontinentālās Eiropas elektroenerģijas sistēmu. Savukārt pēc 2030. gada Baltijas energosistēmas ģenerācijas un importa jaudas vairs nebūs pietiekamas, lai segtu pīķa slodzi un nodrošinātu atbilstošu drošuma līmeni Baltijas valstu elektroenerģijas sistēmā normālā režīmā, jaudu deficītam sasniedzot līdz pat 360 MW.

PSO izveidotie ģenerācijas jaudu attīstības scenāriji norāda uz jaunu elektroenerģijas un balansēšanas resursu attīstības nepieciešamību Baltijas reģionā, lai nodrošinātu elektroapgādes drošuma un kvalitātes nepasliktināšanos.

Ar izvērstāku Latvijas pārvades sistēmas operatora 2018. gada ziņojumu iespējams iepazīties AS "Augstsprieguma tīkls" mājaslapā: http://www.ast.lv/lv/content/parvades-sistemas-operatora-novertejuma-zinojumi

Nepieciešamas jaunas balansēšanas jaudas

Pieprasījums pēc balansēšanas jaudām energosistēmā pieaugs.

Pirms aptuveni 12 – 15 gadiem, kad tika ieviests elektroenerģijas tirgus, pārvades sistēmas operatori saskārās ar pirmo svārstīguma pieaugumu. Elektroenerģijas starpvalstu tirdzniecības plūsmas kļuva nepastāvīgākas. Plūsmu virzienu vairs neietekmēja pārvades sistēmas operatori, bet tās virzījās no zemāku cenu reģiona uz augstāku cenu reģionu, kā tas notiek ar jebkuru preci, kuras cena tiek noteikta saskaņā ar tirgus principiem.

Pirms 6 – 8 gadiem, kad aizsākās vēja un saules elektrostaciju strauja attīstība, pārvades sistēmas operatori saskārās ar otro svārstīguma pieaugumu. Nu jau vairākus gadus, līdzīgi kā citur Eiropā, arī Baltijā no jauna ekspluatācijā nodoto ražošanas jaudu vidū dominē svārstīgās vēja un saules elektrostacijas.

Patlaban energosistēmas vadība strauji mainās, energosistēmā pieaug plūsmu un enerģijas bilances svārstīgums, ir sarežģītāk prognozēt sistēmas stāvokli, tāpēc palielinās nepieciešamība pēc papildu balansēšanas jaudām, kuras tiktu izmantotas energosistēmas vadībā.

Turklāt jāņem vērā, ka pašlaik Baltijas elektroenerģijas pārvades sistēma ir integrēta apvienotajā energosistēmā BRELL, kur tīkla frekvence centralizēti tiek regulēta Krievijā. Sakarā ar plānoto Baltijas pārvades tīkla pārslēgšanu sinhronā darbā ar kontinentālās Eiropas energosistēmu, līdz 2025. gadam Baltijas pārvades sistēmas operatoriem būs jānodrošina spēja piedalīties frekvences regulēšanā gan normālos apstākļos, gan incidentu gadījumā pēc liela ģeneratora vai starpvalstu elektropārvades līnijas avārijas atslēgšanās. Tāpēc Baltijas PSO būs jāuztur frekvences regulēšanas un balansēšanas rezerves, kādas paredz kontinentālās Eiropas sinhronās darbības līgums. Tabulā ir uzrādīti indikatīvi nepieciešamo rezervju apjomi.

Tas ir liels izaicinājums pārvades sistēmu operatoriem, jo Baltijā vēl ir jāattīsta pilnvērtīgu balansēšanas rezervju tirgu un jārada nepieciešamos balansēšanas resursus.

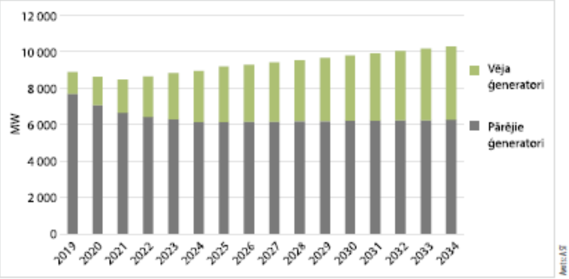
Darbības virzieni, lai veicinātu elektroapgādes jaudu pietiekamību un balansēšanas jaudu attīstību

Jāveicina ražošanas attīstība. Veicināšanas instrumenti ir dažādi, bet primāri būtu jāsāk ar esošo barjeru mazināšanu un jaunu barjeru neradīšanu (t.sk. birokrātiskie šķēršļi, atļauju saņemšana, ražotāju maksas u.c.).

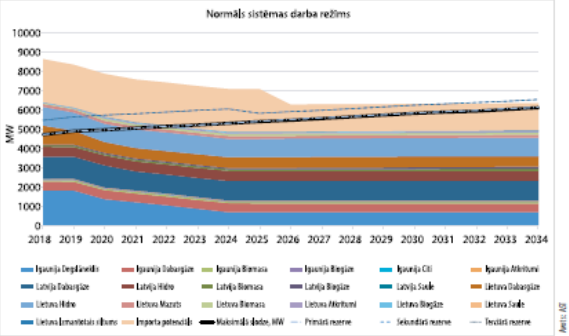
Jāinvestē elektrotīkla attīstībā. Tīkla attīstība ir nepieciešama gan lielas jaudas atjaunojamās enerģijas ģenerācijas pieslēgšanai, gan energosistēmas balansēšanai. Piemēram, šogad AS "Augstsprieguma tīkls" nodeva ekspluatācijā Kurzemes 330 kV elektropārvades loka pēdējo posmu. Tagad Latvijas rietumu daļā esošais pārvades tīkls spēj nodrošināt līdz pat 800 MW vēja parku pieslēgšanu.

Jāveicina patēriņa reakcija un agregācija. Latvijā un Baltijas reģionā patēriņa reakcijas potenciāls šobrīd netiek izmantots energosistēmas balansēšanai. Lai to darītu, pirmais nepieciešamais solis ir izveidot nepieciešamo regulējumu neatkarīgo agregatoru ienākšanai tirgū, kas ir priekšnosacījums tam, lai notiktu patēriņa reakcijas un agregācijas attīstība. Tas nodrošinātu iespēju patēriņa reakcijas agregatoriem līdzvērtīgi konkurēt ar ražotājiem, energosistēma kļūtu elastīgāka un drošāka ar mazākām investīcijām elektrostacijās un vienlaikus tas sekmētu jaunu tirgus produktu attīstību.

Jāattīsta balansēšanas tirgus. Īpaši pēc 2025. gadā plānotās Baltijas energosistēmas sinhronizācijas ar kontinentālās Eiropas elektrotīklu Latvijas pārvades sistēmas operatoram būs nepieciešamas papildu un jauna veida balansēšanas rezerves. Tāpēc Latvijā ir nepieciešams attīstīt balansēšanas rezervju tirgu, kas paredz integrāciju plašākā Eiropas balansēšanas tirgū, kas kalpo kā komerciālā vide balansēšanas resursu attīstībai un tirdzniecībai.



4. attēls. Baltijā uzstādītās elektroenerģijas ražošanas jaudas prognoze



5. attēls. Jaudas pietiekamības novērtējums Baltijas valstu energosistēmā

Tabula. Indikatīvi Baltijas PSO nepieciešamo rezervju apjomi pēc sinhronizācijas ar kontinentālās Eiropas elektrosistēmu 2025. gadā

Rezerves veids	Baltija	Igaunija	Latvija	Lietuva
FCR	30 MW	7 MW	11 MW	12 MW
aFRR uz augšu	100 MW	32 MW	23 MW	45 MW
aFRR uz leju	100 MW	32 MW	23 MW	45 MW
mFRR uz augšu	600 MW	218 MW	148 MW	234 MW
mFRR uz leju	600 MW	279 MW	21 MW	300 MW

FCR – *frequency containment reserve* (jāspēj palaisties dažu sekunžu laikā pēc incidenta un 30 sekunžu laikā jāspēj iedarbināt 100% no rezerves jaudas)

aFRR – *automated frequency restoration reserve* (tiek vadīta ar centralizētu, automātisku ģenerācijas kontroli; līdz pilnai jaudai tiek aktivizēta dažu minūšu laikā pēc incidenta sistēmā)

mFRR – *manual frequency restoration reserve* (aktivizē manuāli, līdz pilnai jaudai tiek aktivizēta dažu minūšu laikā)

Elektroenerģijas un gāzes sektora sadarbība. Tālākā perspektīvā jāizvērtē elektroenerģijas un gāzes sektoru ciešāka integrācija. Eiropas elektroenerģijas un gāzes pārvades sistēmu operatoru asociācijas ENTSO-E un ENTSO-G uzskata, ka sektora integrācijai ir liels potenciāls, tāpēc abas asociācijas sadarbojas un veic pētījumus šajā jomā (*the Focus study*).[1] E&P

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[1] https://docstore.entsoe.eu/Documents/Publications/Position%20papers%20and%20reports/ENTSOs%20-%20Interlinkages%20Focus%20Study%20-%20Final%20report.pdf

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ROLE OF BALANCING MARKETS IN DEALING WITH FUTURE CHALLENGES OF SYSTEM ADEQUACY CAUSED BY ENERGY TRANSMISSION

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The national energy and climate plans developed by the Baltic States for the period up to 2030 foresee a significant increase in the share of renewable energy in final consumption. Therefore, the development of wind, solar and distributed generation in the Baltic electricity system is expected to increase significantly in the next decade and, thus, the need for balancing capacity will increase. The planned synchronisation of the Baltic power system with the power system of Continental Europe in 2025 will also increase the need for frequency restoration and balancing reserves. At the same time, the shutdown of uncompetitive thermal power plants in the Baltics reduces centralized generation capacity. If this trend continues, the risk of electricity supply shortages will increase in the future. Therefore, it is important to identify activities that help mitigate this risk and take timely actions.

Keywords: Baltic ACE, Baltic balancing market, Baltic power system

1. RENEWABLE ENERGY SOURCES REPLACE THE FOSSIL ENERGY

During the years, there is a clear trend towards increasing production from renewable energy sources and decreasing production from fossil energy sources in the Baltic States. During the past years, on average around 40 % of the produced electricity has come from renewable sources (mainly hydropower and wind energy), while about 60 % – from fossil fuels (mainly oil shale and natural gas). In 2017 and 2018, the generation of electricity from renewable energy sources exceeded 40 % of total generation threshold for the first time, exceeding 10 TWh and 8 TWh, respectively. However, in 2019 the share of renewable generation exceeded 50 % for the first time.

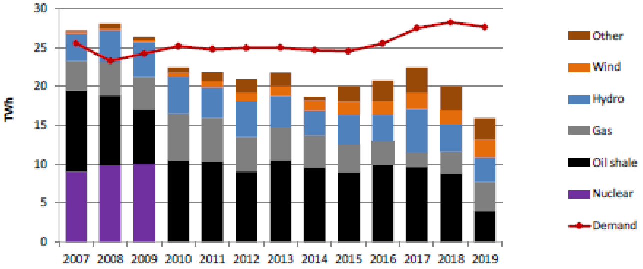

Fig. 1. Electricity production and consumption in the Baltic States.

Source: ENTSO-E

2. LARGEST CO_2 EMITTERS WILL BE PUSHED OUT OF THE MARKET

Estonian oil shale power plants have played an important role in the Baltic power system. In recent years, oil shale power plants have generated around 9–10 TWh of electricity annually, or about half of the total electricity output in the Baltics.

Oil shale combustion generates substantial CO_2 emissions; therefore, the profitability of the operation of these power plants is particularly affected by the price changes in CO_2 emission allowances on the European market. Low and stable CO_2 emission allowance prices have been contributing to stable electricity production at oil shale power plants in recent years (Fig. 2). However, since 2018 CO_2 emission allowance price has experienced a significant rise [1] exceeding EUR 25 [2] per tonne. As a result, electricity generation at oil shale power plants declined significantly reaching record low 4 TWh in 2019. Overall electricity production in the Baltics also reached record low 58 % of demand in 2019, while electricity generation from renewable sources reached record high 50 % in the Baltic electricity generation mix in 2019.

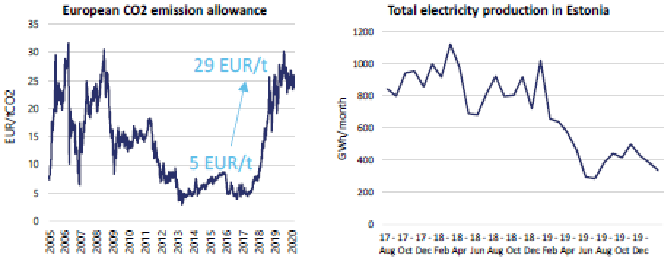

Fig. 2. Price of CO_2 emission allowances in Europe (EUR/t) and electricity production in Estonia.

Source: EEX and Nord Pool market data

3. CENTRALIZED, CONTROLLABLE PRODUCTION CAPACITY IS SHRINKING IN THE REGION

During the past five years, the total installed capacity of power plants in the Baltics has been relatively stable and now exceeds 9000 MW, which is about twice the peak of the Baltic consumption peak.

During the past five years, the installed capacity of gas power plants has decreased by 25 % (or about 1000 MW), mainly due to the closure of the oldest gas power plant units in Lithuania [3]. The most significant increase in production capacity was due to commissioning of new wind [4], [5] and biomass power plants (with a total capacity of 600 MW), as well as commissioning of a new 300 MW Auvere shale power plant (Estonia) in 2015 [6].

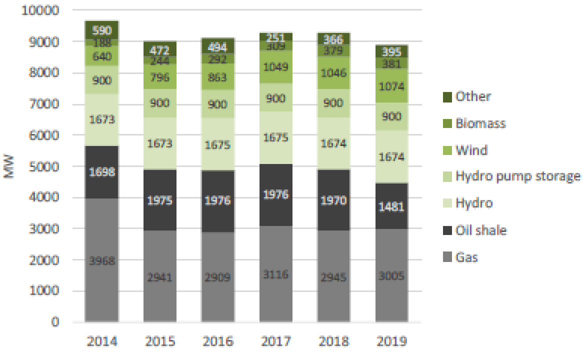

Fig. 3. Installed power capacity in the Baltic States.

Source: ENTSO-E

In 2019, the Baltic mix of installed capacity consists of approximately 50 % of fossil and 50% of renewable capacity. The capacity of centralized power plants in the Baltic countries is expected to decline in the coming years – mainly due to uncompetitive old thermal power plant units in Estonia and Lithuania.

4. GROWING SHARE OF INTERMITTENT GENERATION INCREASE DEMAND FOR BALANCING RESOURCES

Although the overall installed generation capacity is expected to grow in the Baltic region, the proportion of centralized, controllable generation capacity is expected to decrease, while the proportion of intermittent and distributed generation is expected to increase [7]. The biggest increase is expected for wind generation capacity – from approximately 1000 MW in 2020 to 4000 MW by 2034 [8] (Fig. 4).

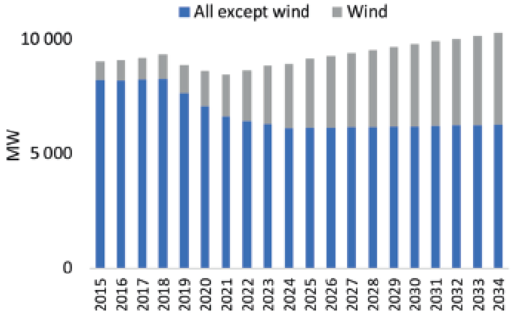

Fig. 4. Forecast of installed generation capacity in the Baltics.

Source: Baltic transmission system operators

While the rising amount of wind power entering the electricity grids greatly contributes to the climate goals [9], [10], it also makes the operation of the power system systematically more complex. Wind is an intermittent energy source [11] and output fluctuations must be offset to maintain continuous power balance in the system. Therefore, demand for balancing resources in the power system is expected to increase [12].

Analysis of data from the Baltic power system indicates the relation between growing wind generation and growing area control error ACE (Figs. 5, 6, 7). Analysis of statistical data for period from 2015 till 2019 suggests that increasing wind generation by 400 % during the next decade could increase the average Baltic ACE by 50 %.

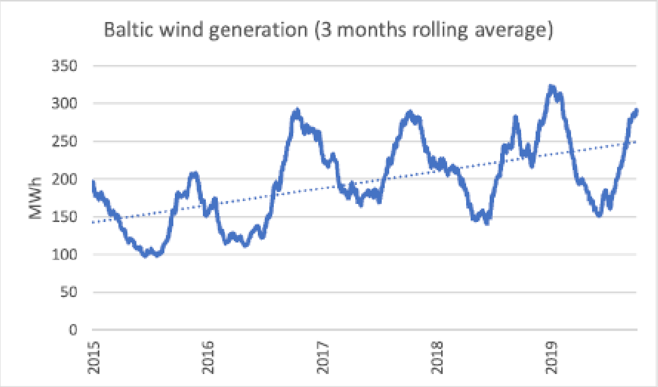

Fig. 5. Baltic wind generation (3 months rolling average).

Source: Baltic transmission system operators

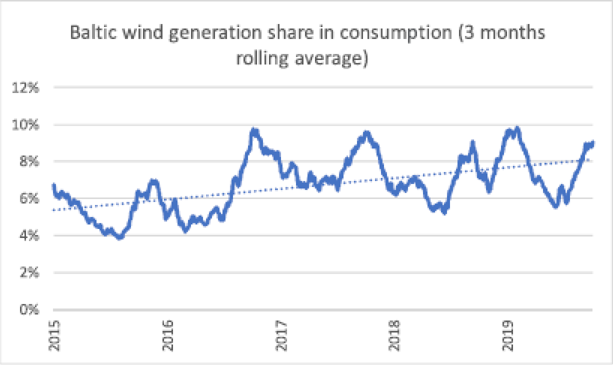

Fig. 6. Baltic wind generation share in consumption (3 months rolling average).

Source: Baltic transmission system operators

Fig. 7. Baltic area control error (3 months rolling average).

Source: Baltic transmission system operators

5. SUPPLY OF BALANCING RESERVES DECREASES AS CONVENTIONAL, CENTRALIZED POWER PLANTS EXIT THE MARKET

The creation of new Baltic balancing market and more active power system control have been implemented since the beginning of 2018. It has resulted in a more active usage of balancing resources [13], more active balance control and lower ACE after balance control (Table 1). Average Baltic ACE after balance control in 2019 was two times smaller than in 2017 and the number of hours with Baltic ACE after balance control within 50 MWh limit increased from 65 % in 2017 to 94 % in 2019 [14].

Table 1. Indicators of the Baltic Power System Balancing Accuracy and ACE after balance control

Period	2019	2018	2017
Average ACE, MWh	18.81	23.99	41.99
Hours with Baltic ACE inside 50MWh	94 %	89 %	65 %

The oldest conventional, centralized power plants in the Baltics have been gradually decommissioned during the past years. However, 2019 was particularly significant as generation decreased by 29 % in 2019 compared to 2018. Particularly, power generation from oil-shale – the largest source of power generation in the Baltics – decreased by more than a half in 2019. Since the conventional thermal power plants are also a significant source of balancing power, this fact affects the availability of balancing reserves in the Baltic market. Amount of balancing energy from the Baltic balancing reserves decreased by 1/3 in 2019 compared to the previous year (Fig. 8).

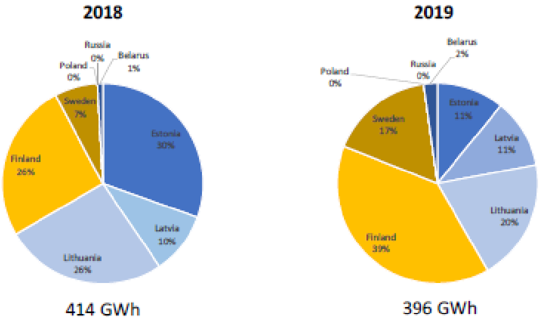

Fig. 8. Origin of used balancing energy in the Baltic market.

Source: Baltic transmission system operators

6. THE RISK OF SHORTAGE OF GENERATION CAPACITIES WILL INCREASE IN THE COMING YEARS

According to the TSO evaluation [8] after 2020, the adequacy of electricity supply in the Baltic States will highly depend on imports through interconnections from neighbouring power systems. The peak load capacity will be significantly reduced after 2025 [5], when the Baltic transmission system will disconnect from the unified Russian power system and start synchronous operation with the continental Europe power system. After 2030, however, generation and import capacities of the Baltic power system are expected to be insufficient to cover peak loads and provide an adequate level of safety in the Baltic electricity system in normal operation, with a capacity deficit of up to 360 MW.

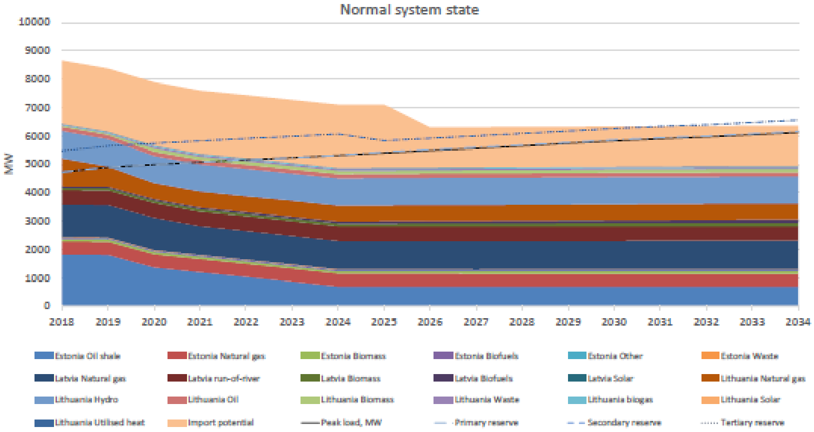

Fig. 9. Capacity adequacy (peak load) evaluation on normal system state.

Source: Baltic transmission system operators

7. BALTIC SYNCHRONISATION WITH POWER SYSTEM OF CONTINENTAL EUROPE WILL INCREASE DEMAND FOR BALANCING RESERVES

Currently, the Baltic electricity transmission system is integrated into the unified Russian power system BRELL. Due to the planned Baltic desynchronisation from the BRELL system and synchronous operation with the Continental Europe system as from 2025, the Baltic transmission system operators will have to be able to participate in frequency regulation both in normal conditions and in the event of a major generator or cross-border interconnection outage. Synchronisation with Continental Europe grid will require changes in network balancing routines by reacting to changes in quicker and more automatised way by using frequency containment reserves and automated frequency restoration reserves. Desynchronisation from BRELL will require additional balancing reserves to the Baltic transmission system operators. Table 2 shows the indicative reserve requirements, which will be required by the Baltic TSOs in accordance with the operational guidelines of the power system of Continental Europe.

Table 2. Indicative Reserve Requirements for Baltic TSOs after Synchronisation with the Continental European Power System in 2025 (MW)

Reserve type	Baltic	Estonia	Latvia	Lithuania
FCR	30	7	11	12
aFRR upward	100	32	23	45
aFRR downward	100	32	23	45
mFRR upward	600	218	148	234
mFRR downward	600	279	21	300

FCR – *frequency containment reserve*
aFRR – *automated frequency restoration reserve*
mFRR – *manual frequency restoration reserve*

CONCLUSIONS

Supply of balancing reserves is expected to decrease in the Baltic power system in the coming years because the oldest, centralized power plants (mainly oil-shale and natural gas) are expected to exit the market. Rising price of CO_2 emission allowances and low electricity price are important factors.

Demand of balancing reserves is expected to increase in the coming years due to the growing share of intermittent and distributed generation in the Baltic power system. Quadrupling the installed wind generation capacity during the next decade could increase the area control error of the Baltic power system by 50 %.

Synchronisation of the Baltic power system with the grid of Continental Europe will further increase demand for balancing reserves as Baltic TSOs will have to participate in frequency control process and ensure availability of additional frequency containment reserves and automated/manual frequency restoration reserves.

The Baltic power system could face the increased risk of a shortage of generation capacities for covering peak load and shortage of balancing capacities in the next decade if the current trend of capacity decommissioning continues without new adequate, controllable capacities replacing them. One of the activity that help mitigate the risk is implementation of the Balancing capacity market and Capacity remuneration mechanisms.

ACKNOWLEDGEMENTS

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The assessment of the impact of electric vehicles on the power balance of the Baltic energy system

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***Abstract*—Energy systems are undergoing permanent and profound changes. A powerful driving force behind these changes is the need to halt climate change that occurs as a result of greenhouse gas emissions. The problem can be solved by replacing traditional power plants using fossil fuel with renewable energy sources (RES). However, to stop climate change, it is necessary not only to eliminate the emissions of electricity generation, but also to solve a more complex problem - to eliminate emissions in other infrastructures, particularly in transport. This article is devoted to the consideration of scenarios for the development of the energy systems of the Baltic countries. Significant capacities of RES (10 GW) and 2 millions of electric cars are expected to be commissioned until 2050 year. The issue of the region's ability to self-sufficiency, export/import of energy and to reduce emissions into the atmosphere is being investigated. The analysis is completed on the basis of modeling the behavior of the power system of Baltic States taking into account the connections with Sweden, Finland and Poland.**

Keywords—renewables, power imbalance, Baltic power system, energy consumption, electric vehicles

I. INTRODUCTION

The evolution of mankind and the growth in the number of the world's inhabitants, an increase in demand for goods and services, for energy and energy carriers, variations in the production, distribution and consumption of energy, the influence of many random and uncertain events and processes predetermine changes in the living environment of society. The operating conditions of many critical infrastructure facilities that provide acceptable living conditions for residents are changing. In particular, energy systems are undergoing permanent and profound changes. A powerful driving force behind these changes is the need to halt climate change that occurs as a result of greenhouse gas emissions. The problem can be solved by replacing traditional power plants (PP) using fossil fuel with RES that make up most of the newly commissioned capacities in the world [1]. In 2019, renewable energy represented 19.7 % of energy consumed in the EU-27, only 0.3 % short of the 2020 target of 20 % [2]. Another record for global solar PV additions is anticipated for 2021, with nearly 117 GW installed – a nearly 10% rise from 2020 [3].

Solar and wind farms are emission-free and have become competitive in terms of return on investment. However, to stop climate change, it is necessary not only to eliminate emissions of electricity generation, but also to solve a more complex problem - to eliminate emissions in other infrastructures. First of all, in transport and heating of dwellings, which is possible in case of their electrification. The above problem can only be solved by the efforts of most countries. The process of electrification of sectors of the national economy and the construction of renewable energy sources is in full swing. For example, the share of renewable energy used in transport activities in 27 EU countries reached 8.9% in 2019 [4].

The Baltic States are also planning significant transformations, leading to a severe decrease in air emissions. The goal is to create an emission-free economy in the region by 2050. Solving this problem will require great investments and the transformation of not only power plants, but also the transmission and distribution networks. The introduction of new principles of management in normal and emergency modes will be required. In the Baltic countries, the planned transformations are complicated by the additional goal of synchronizing the Baltic energy system with the energy system of continental Europe. At the same time, there will be desynchronization with the Russian and Belarusian power systems. This conversion will cause deep changes in generation reservation, power and frequency regulation, and emergency automation. The upcoming transformations of the Baltic energy sector are associated with the need to solve many complex problems, one of which, namely, assessing the joint impact of the massive use of renewable energy sources and a sharp increase in the number of electric vehicles (EV) on the ability of the energy system to self-sufficiency in electricity, the need and possibility of its import or export. This article is devoted to a partial solution of the named problem. This goal is achieved on the basis of modeling the behavior of the power system of the future. To do this, it is necessary to choose a planning period and predict the capacity and generation of energy sources, energy consumption, and its prices.

An extensive scientific literature is devoted to the problems of assessing the properties of power systems of the future [5-8], predicting processes affecting the functioning of the power system [9,10], modeling the power system and various generators [11, 12] and consumers. Considerable attention is also paid to the modeling of electricity consumption by EVs [13, 14].

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The solution of the listed tasks based on the example of the Baltic countries and scenarios of their state in 2050 constitutes the main contribution of this article. The developed methodology for modeling power systems, the tools and models used were described in detail in our previous article [15]. The models used, however, did not take into account the presence of a powerful consumer - electric transport. In this article, we have focused on demonstrating the simulation results of scenarios for the transition to an all-electric vehicle.

The remaining part of this article is organized as follows: Section 2 describes the methodology, models, constraints and forecasting process. Section 4 deals with the case study and results. The last sections are devoted to conclusions and discussion.

II. METHODOLOGY AND MODELS

A. *Baltic power system model*

The structure of the Baltic power system (BPS) model used in this article is given in Fig.1.

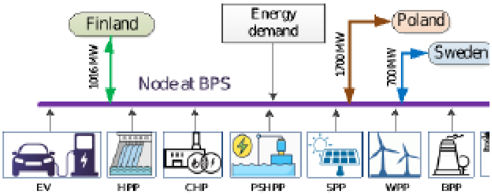

Fig. 1. A structure of the modelled BPS

The structure depicted in Fig. 1. includes the following main objects, the list of which corresponds to existing and foreseeable energy sources: pumped storage hydropower plant (PSHPP), hydropower plant (HPP), small HPP (sHPP), solar PP (SPP), wind PP (WPP), storage PP (StPP); EV; combined heat PP (CHP); electricity demand and interconnections between Baltic states and Finland, Poland, Sweden. We assume that all the above mentioned objects are connected to one Baltic electricity node. We accept that the plants shareholders strive to increase their profitability and are forced to follow the technical and legal constraints established by the laws of the NORDPOOL [16] day-ahead electricity market, the government and the networks. The model under consideration covers Finland, Sweden, Poland and the Baltic States. However, only the Baltic countries are modeled in detail, taking into account the specifics of major PP and consumers/producers, heat demand and similar factors. The other countries in the region are modeled taking into account the interconnection constraints and the projected dynamics of electricity prices in the respective trade areas. The method and algorithms for forecasting market prices, energy demand and PP regimes are described in our previous publications [17, 18].

Transmission lines capacities between Baltic and neighbouring countries (Lithuania-Poland, Lithuania-Sweden, Estonia-Finland) are severely restricted [19] (see Fig.1.). Table I contains generalized information on the adopted parameters of PPs and consumers.

TABLE I. MODELED ANNUAL ELECTRICITY CONSUMPTION OF BPS AND PLANNED INSTALLED CAPACITIES OF PP OF 2050 YEAR

BC* TWh	Number of EVs, mil.	BC of EVs, GWh	SPP, GW	WPP, GW	HPP, GW	sHPP, GW	BPP, GW	PSHP, GW	Reserve of CHP, GW
33.47	2	3 276	3	7	1.69	0.067	0.578	1.625	1.349

* Baltic consumption (BC) here is estimated without EVs

The model used provides for a significant increase in the capacity of PSHPP. It is envisaged as a reserve to keep the thermal stations using natural gas in working order. However, the generation of these stations is assumed only in cases of a shortage of RES capacities and a lack of import opportunities.

The last column of Table I shows the reserved capacity of conventional stations. We assume that gas-fired CHPs will operate in cogeneration mode.

B. *Modeling the energy demand of EVs*

When modelling the consumption of EVs, we assume the following:

- The total number of EVs (2 million in Baltic States) is known. We accept that by 2050 all cars in region will be electric.
- We assume that the average daily mileage is known (we take 15 km/day). The average energy consumption is also known (0.3 kWh/km).
- Energy storage capacity of EV batteries is 90 kWh. We suppose that all cars will be loaded evenly overnight, from 11 p.m. to 7 a.m. (during 8 hours).
- We assume that at night and in 2050 the price of energy will be lower than during business hours.

Fig. 2 reflects the Baltic energy consumption in 2050.

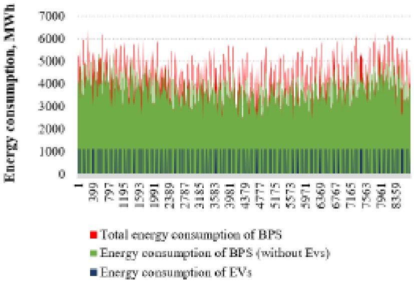

Fig. 2. BPS 2050 modelled energy consumption

It can be seen from the Fig. 2 that the consumption of EVs is about 10% of the energy consumption in the Baltics. This is a significant quantity that affects the operation of the power system.

III. CASE STUDY AND RESULTS

To demonstrate the impact of electrification of transport on the self-sufficiency of the Baltic energy system and the need to exchange energy with neighbouring countries, we will consider two main cases:

1. The power system operates without EVs.

2. To the conditions of the model according to the first point, we add the energy of the car battery charge.

A. 1st case

Fig. 3. demonstrates the imbalance of energy production/ consumption of the BPS in the event when reserve stations using natural gas are not used.

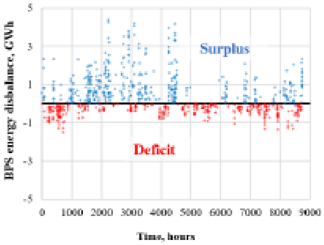

Fig. 3. BPS 2050 energy imbalance after energy import/export procedures (reserve stations are not used)

The graph shows the presence of time intervals when the energy balance is not ensured. The increase in imports is impossible due to the limited capacity of the lines. At the same time, there are periods of time when excess energy is generated. Surplus energy can be eliminated by turning off generators. However, the energy deficit is 0.13 TWh. The hourly frequency of energy deficit is 4.36%. Consequently, we see the need to use reserve power station capacities.

Fig. 4. demonstrates the imbalance of energy production/ consumption of the BPS in the event when reserve stations are used.

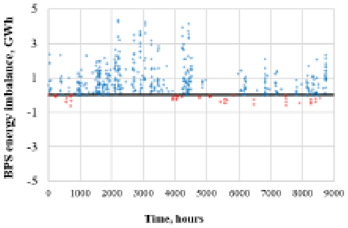

Fig. 4. BPS 2050 energy imbalance after energy import/export procedures (reserve stations are used)

Analyzing the results of Fig. 4, it can be concluded that the use of reserve stations reduces the energy deficit to the level of 0.009 TWh, which is 0.03% of the energy consumption. The frequency of occurrence of the energy deficit also decreased to the level of 0.52%. The shortage of the named insignificant volume of energy could be eliminated, for example, by organizational measures (increase in tariffs or bonuses for reducing consumption. However, as will be shown below, electrification of cars will dramatically worsen the situation.

B. 2nd case

Fig. 5. presents the imbalance of energy production/ consumption of the BPS corresponding to the use of EVs.

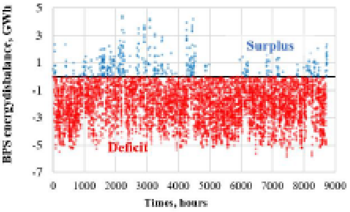

Fig. 5. BPS 2050 energy imbalance after energy export procedure (reserve stations are not used, 2 mil. EVs are used)

We show the graph corresponding to the power supply of two million EVs. Analyzing this graph, it can be stated that the the frequency of power deficit occurrence equals to the 65.57 % during 2050 (when in the 1st case it is equal to 61.66%).

The graph shown in the Fig. 5 allows us to draw a conclusion about the inability of the power system of the structure under consideration to meet the demand for energy (without reserve plants). Either additional generators of electricity are required, or additional stations capable of storing energy, or stronger ties with neighboring countries.

Energy import in BPS 2050 practically reduces the energy deficit up to 12.19% (Fig. 6). However, this value of the deficit is not acceptable either.

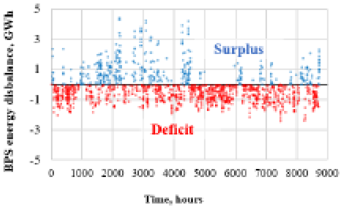

Fig. 6. BPS 2050 energy imbalance after energy import/export procedures (reserve stations are not used, 2 mil. EVs are used)

Fig. 7. presents BPS 2050 electricity imbalance, using reserved energy.

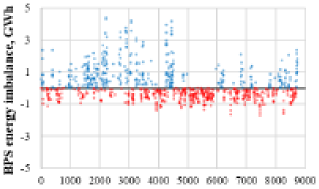

Fig. 7. BPS 2050 energy imbalance after energy import/export procedures (reserve stations are used, 2 mil. EVs are used)

The energy reserve activation leaded to the electricity deficit appearing frequency diminishing to 6.08% level, which is much more than in the 1st case.

Comparing the BPS energy imbalance in the 1st case with the 2nd case, a rather serious problem of energy deficit arises.

IV. DISCUSSIONS

Let us return to the accepted initial data and estimate the volume of CO_2 emissions into the atmosphere for 2 mil. EVs that run 15 km per day for all 364 days. The total annual mileage (TAM) in this case is:

$$TAM = 2\,000\,000 \cdot 15 \cdot 364 \\ = 10\,920\,000\,000\ km/year \tag{1}$$

To determine the total CO_2 emissions (TE), it is necessary to know the emissions that occur at a distance of 1 km. According to the test results, the average CO_2 emissions of a diesel car (EDC) are 152 g/km compared to an average emission of 186 g/km emitted when running on a petrol engine (EPE) [20], the average CO_2 emissions of a diesel car are 152 g/km compared to an average of 186 g/km. Then, the sum of the annual emissions of CO_2 are as follows:

$$TE = (EDC + EPE) \cdot \frac{TAM}{2} \\ = 1\,845\,480\,000\,000\ g \\ = 1\,845\,480\ t \tag{2}$$

If we assume that the cost of emissions (CE) per ton is 30 €/t, then the cost of total emissions (CTE):

$$CTE = TE \cdot CE = 1\,845\,480 \cdot 30 \\ = 55\,364\,400\ €/year \tag{3}$$

The above sum reflects only the effect of CO_2 emissions; however, the combustion products of automobile fuel contain many other harmful substances, and their accounting is beyond the scope of this work.

V. CONCLUSIONS

1. Solar and wind power plants are emission-free and have become competitive in terms of return on investment. However, to stop climate change, it is necessary not only to eliminate the emissions of electricity generation, but also to solve a more complex problem - to eliminate emissions in other infrastructures. First of all, in transport, which is possible in case of their electrification.

2. The upcoming transformations of the Baltic energy sector are associated with the need to solve many complex problems, one of which, namely, assessing the joint impact of the massive use of renewable energy sources and a sharp increase in the number of electric vehicles on the ability of the energy system to self-sufficiency in electricity, the need and possibility of its import or export.

3. Electrification of cars will worsen the Baltic power systems capacity balancing situation. To meet the demand for electricity, it will be necessary: to build additional stations that can generate energy in the absence of sun and wind or create new transborder transmission lines and long-term energy storage capacities.

4. Electrification of road transport in the Baltic countries can reduce CO2 emissions into the atmosphere by about 2 000 000 tones.

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Neapliecinātās elektroenerģijas izcelsmes sastāvs

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Mūsdienu elektroenerģijas tirgus modelī nopirktajai elektroenerģijai nav nekādas tiešas piesaistes elektroenerģijas izcelsmei; ražotājiem biržā iesniedzot savus ģenerācijas piedāvājumus un patērētājiem – patēriņa pieprasījumus, nav iespējams noteikt, kādu daļu no kopējā piedāvājuma patērētājs ir saņēmis, turklāt biržām nav detalizētas informācijas par piedāvātās elektroenerģijas ražošanas enerģijas avotiem[1]. Attiecīgi ir nepieciešams mehānisms, kā noteikt patērētājiem piegādātās elektroenerģijas izcelsmi. Atbilstoši Direktīvai (ES) 2018/2001 par no atjaunojamajiem energoresursiem iegūtas enerģijas izmantošanas veicināšanu izplatītākais mehānisms ir elektroenerģijas izcelsmes apliecinājumi, kurus izsniedz izdevējiestāde. Saskaņā ar Elektroenerģijas tirgus likumu Latvijas izcelsmes apliecinājumu izdevējiestāde ir Latvijas elektroenerģijas pārvades sistēmas operators AS "Augstsprieguma tīkls" (AST). AST izsniedz Eiropas enerģijas sertifikācijas sistēmas izcelsmes apliecinājumus (*European Energy Certificate System* – EECS) saskaņā ar līgumu, kas noslēgts starp pārvades sistēmas operatoru un Eiropas Enerģijas izcelsmes apliecinājumu sistēmas pārvaldītāju, par elektroenerģiju, kas ražota no atjaunīgajiem energoresursiem (AER) vai augstas efektivitātes koģenerācijā.

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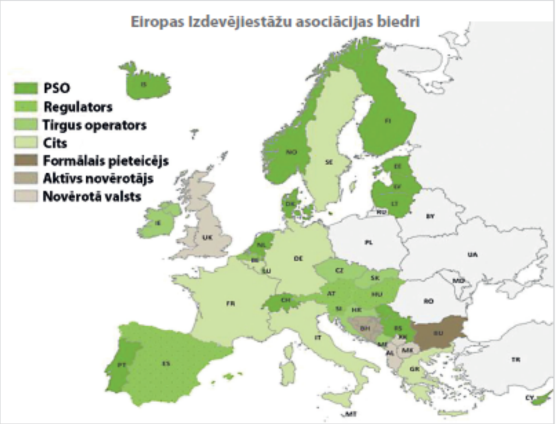
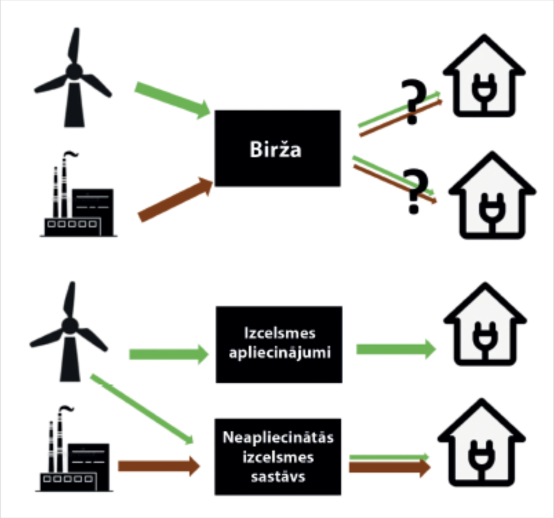


Latvijā izcelsmes apliecinājumi tiek izsniegti ražotājiem par saražoto un neto tīklā nodoto elektroenerģiju, un tos neatkarīgi no biržā pārdotās elektroenerģijas var tirgot tālāk elektroenerģijas tirgotājiem, lai apliecinātu patērētājiem piegādātās elektroenerģijas izcelsmi. Šāda papildu informācija dod patērētājiem iespēju izvērtēt un pieņemt lēmumu attiecībā uz elektroenerģijas tirgotājiem ne tikai pēc to piedāvātā tarifa, bet arī atbilstoši piegādātās elektroenerģijas izcelsmei un tādā veidā sniegt savu artavu kopīgo klimata neitralitātes mērķu sasniegšanā un atbalstīt tos ražotājus, kuri izmanto atbilstošus enerģijas avotus.

Lai patērētājs varētu apliecināt izlietotās elektroenerģijas izcelsmi, viņam ir nepieciešams izmantot viņa rīcībā esošos izcelsmes apliecinājumus. Ja patērētāja rīcībā nav izcelsmes apliecinājumu, pastāv vairāki veidi, kā tos iegūt: saņemt tos no sava elektroenerģijas tirgotāja par iepriekš saskaņotu cenu, iegādāties no cita elektroenerģijas tirgotāja, starpnieka vai arī pašam iesaistīties izcelsmes apliecinājumu tirgū. 2020. gada decembrī AST, kļūstot par Latvijas izcelsmes apliecinājumu izdevējiestādi, pievienojās Eiropas Enerģijas izcelsmes apliecinājumu sistēmai, kas Eiropas dalībvalstu vidū nodrošina drošu un uzticamu izcelsmes apliecinājumu apmaiņu starp dalībvalstīm, garantējot gan korektu enerģijas izcelsmes avotu atspoguļojumu, gan izvairīšanos no “dubultās grāmatvedības” riska, proti, ka ar vai bez nolūka izcelsmes apliecinājumi tiek pārdoti un izlietoti divas reizes dažādiem klientiem.

Ir būtiski saprast, ka elektroenerģijas izcelsmes apliecinājumi ir papildu ienākumu avots elektroenerģijas ražotājiem, kas ražo zaļo elektroenerģiju, savukārt, elektroenerģijas tirgotājiem tie ir neatņemama sastāvdaļa, ja vēlas saviem klientiem piedāvāt zaļās enerģijas produktus, bet elektroenerģijas lietotājiem tie ir rīks, lai apliecinātu, ka viņu patērētā elektroenerģija ir saražota no AER.

Šobrīd tikai dažās no Eiropas valstīm ir noteikta prasība tirgotājiem apliecināt 100% piegādātās elektroenerģijas apjomu ar izcelsmes apliecinājumiem (*full disclosure*), Latvijas likumdošana to neprasa, kā rezultātā veidojas neapliecinātā elektroenerģijas apjoms, kura sastāvu ir nepieciešams aprēķināt. Neapliecinātās elektroenerģijas izcelsmes sastāvs raksturojams kā valstī gadā patērētās elektroenerģijas kopējā izcelsmes struktūra, kas neietver patērēto elektroenerģiju, par kuru izlietoti izcelsmes apliecinājumi.



Atbilstoši Eiropas Direktīvai (ES) 2019/944 visiem elektroenerģijas tirgotājiem saviem klientiem jāsniedz informācija produktu līmenī par patērētās elektroenerģijas izcelsmi, kā arī ziņas par CO_2 gāzes emisijām un radioaktīvajiem atkritumiem, ko radījusi elektroenerģijas ražošana, informāciju padarot pieejamu elektroenerģijas rēķinos. 2020. gada nogalē tika sperts nozīmīgs solis

Latvijas elektroenerģijas izcelsmes apliecināšanai galapatērētājiem – Sabiedrisko pakalpojumu regulēšanas komisija atjaunoja noteikumus[2], kuros atbilstoši Direktīvai (ES) 2019/944 paredzēts, ka tirgotāji elektroenerģijas izcelsmes sastāvu piegādātajiem produktiem var apliecināt, tikai izlietojot izcelsmes apliecinājumus un pielietojot neapliecinātās elektroenerģijas izcelsmes sastāvu par piegādātās elektroenerģijas daudzumu, kas nav nosegta ar izcelsmes apliecinājumiem. Iepriekšējā noteikumu redakcija neparedzēja izcelsmes apliecināšanu 100% piegādātās elektroenerģijas apmērā, ja nav zināma tās izcelsme, attiecīgi neuzliekot par obligātu neapliecinātās elektroenerģijas izcelsmes sastāva norādīšanu, jo Latvijā nebija noteikta institūcija, kas veiktu oficiālu neapliecinātās elektroenerģijas izcelsmes sastāva aprēķinu. Pēc grozījumiem Elektroenerģijas tirgus likumā AST tika nominēts kā atbildīgā institūcija par Latvijas neapliecinātās elektroenerģijas izcelsmes sastāva aprēķinu, kam ir jānotiek saskaņā ar izstrādāto metodiku, kura ir publiski pieejama AST mājaslapā.

Neapliecinātās elektroenerģijas izcelsmes sastāvs		
Atjaunīgā enerģija (%)	Fosilā enerģija (%)	Kodolenerģija (%)
15,184	66,763	18,053

Neapliecinātās elektroenerģijas vides indikatori	
CO_2 izmeši, gCO_2/kWh	Radioaktīvie atkritumi, mg/kWh
391,47	0,65

Latvijas neapliecinātās elektroenerģijas sastāvs

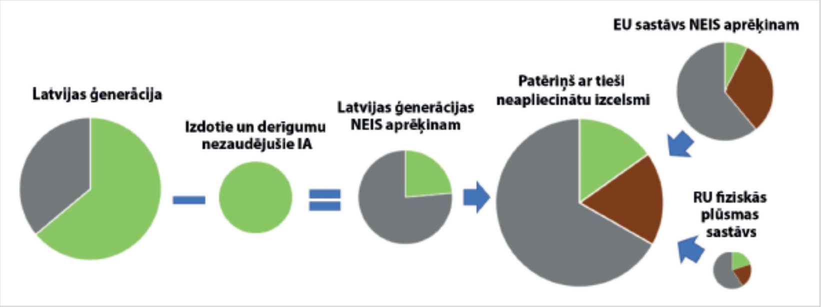
2020. gadā Latvijā tikai par 5,8% no kopumā pārdotās elektroenerģijas ir izlietoti izcelsmes apliecinājumi jeb tieši apliecināts, ka enerģija ir ražota no atjaunīgajiem energoresursiem vai augstas efektivitātes koģenerācijas procesā. Ņemot vērā pagaidām zemo tirgotāju aktivitāti, būtisku lomu galalietotāju informētībā par izlietotās elektroenerģijas izcelsmi spēlē neapliecinātās elektroenerģijas sastāvs.

AST veic neapliecinātās elektroenerģijas izcelsmes sastāva aprēķinu līdz 30. jūnijam, un 2021. gadā tika iegūti pirmie rezultāti. 2020. gada neapliecinātās elektroenerģijas izcelsmes sastāvu būtiski ietekmēja arī izņemtie, bet vēl derīgumu nezaudējušie nacionālie izcelsmes apliecinājumi, kurus līdz 2020. gada 1. decembrim izdeva Ekonomikas ministrija, tādējādi samazinot atjaunīgo resursu proporciju, kas attiecīgi 2021. gada sastāvā darbosies pretēji, nacionālajiem elektroenerģijas izcelsmes apliecinājumiem zaudējot derīgumu. AST neapliecinātās elektroenerģijas izcelsmes sastāva un tam atbilstošo vides indikatoru aprēķina rezultāti 2020. gadam redzami tabulās.

AST neapliecinātās elektroenerģijas izcelsmes sastāva aprēķinu veic sadarbībā ar Eiropas Izdevējiestāžu asociāciju (*Association of Issuing Bodies* – AIB)), izmantojot uz izdoto apjomu bāzēto neapliecinātās elektroenerģijas izcelsmes sastāva aprēķina metodi, kas izstrādāta AIB un pārņemta AST izstrādātajā un publicētajā aprēķina metodikā.

Neapliecinātās elektroenerģijas izcelsmes sastāva aprēķina gaita

Aprēķina gaitā Latvijas neapliecinātās elektroenerģijas izcelsmes sastāvā ietverta gan Latvijas ģenerācija, par kuru nav izsniegti izcelsmes apliecinājumi, kā arī elektroenerģijas izcelsmes sastāvs no trešo valstu importa (fiziskās plūsmas) un Eiropas neapliecinātās elektroenerģijas izcelsmes sastāvs, kas izriet no dalībvalstu ģenerācijas, par kuru nav izsniegti izcelsmes apliecinā-



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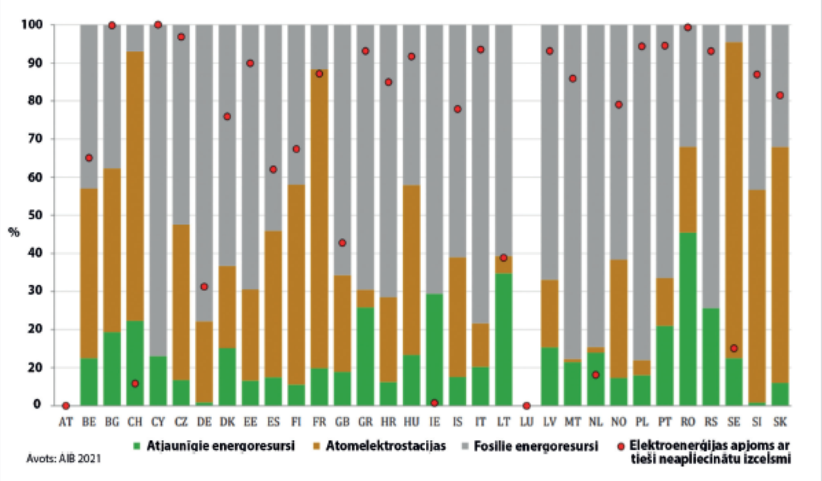
[2] Noteikumi par informāciju elektroenerģijas un dabasgāzes galalietotājiem: https://www.vestnesis.lv/op/2020/236.23



Avots: AIB 2021

jumi, un patēriņa ar neapliecinātu izcelsmi. Gala neapliecinātās elektroenerģijas sastāvs būtiski atšķiras no tīrā valsts ģenerācijas sastāva (Latvijā ģenerētā elektroenerģija pēc ģenerācijas veidiem), un attiecīgi, tā kā izcelsmes apliecinājumu tirgus, tāpat kā elektroenerģijas tirgus, ir starptautisks, nepieciešama koordinēta kopējā Eiropas deficīta / pārpalikuma groza izveide, ko nodrošina AIB. Dalībvalstīm, kuru patēriņš ar tiešu neapliecinātu izcelsmi ir mazāks par ģenerētās elektroenerģijas apjomu, par ko nav izdoti izcelsmes apliecinājumi, pārpalikumu norāda pārpalikumu grozā, bet dalībvalstīm, kurām ir deficīts, to sedz no šī groza.

Latvijā 2020. gadā gandrīz pusi no neapliecinātās elektroenerģijas izcelsmes sastāva sastāda Eiropas Savienības kopējā groza sastāvs. Papildus neapliecinātās elektroenerģijas izcelsmes sastāvam noteikti to raksturojošie vides parametri: CO_2 izmešu apjoms un radioaktīvie atkritumi.

Neoficiālu neapliecinātās elektroenerģijas izcelsmes sastāva aprēķinu un publicēšanu visām Eiropas valstīm veic AIB, balstoties uz *Eurostat* datiem. Vairākas valstis pašas nenosaka neapliecinātās elektroenerģijas izcelsmes sastāvu un par oficiālo vērtību pieņem AIB aprēķina rezultātu, bet dalībvalstīm, kas pašas veic aprēķinus, var būt novērojamas minimālas atšķirības, kas skaidrojams ar dažādu datu avotu izmantošanu.

Latvija uz pārējo dalībvalstu fona

Latvijai Eiropas Savienības dalībvalstu vidū, kā redzams pēc AIB apkopojuma, ir samērā liels patērētās elektroenerģijas apjoms, kura izcelsmes apliecināšanai nav izmantoti izcelsmes apliecinājumi. Tādās valstīs kā Austrija, Šveice un Nīderlande ir izplatīta izcelsmes apliecinājumu izmantošana, tāpēc ka tajās noteiktas "*full disclosure*" prasības, bet arī Īrijā un Luksemburgā, neskatoties uz šādu prasību neesamību, aktīvi tiek izmantoti izcelsmes apliecinājumi.

Tāpat redzams, ka starp dalībvalstīm ir arī samērā liels skaits valstu, kurās, tāpat kā Latvijā, ar izcelsmes apliecinājumiem nosegtā patēriņa apjoms nepārsniedz 10 procentu. Apskatot kaimiņvalstis Igauniju un Lietuvu, redzams, ka Lietuvā aktīvi tiek izmantoti izcelsmes apliecinājumi (tikai ~ 40% no patēriņa nav nosegti), bet Igaunijā nav novērojama tik aktīva tendence (nedaudz virs 10% patēriņa ir nosegti ar izcelsmes apliecinājumiem). Jāpiebilst, ka šobrīd Latviju ar pārējām dalībvalstīm nevar objektīvi salīdzināt, jo EECS izcelsmes apliecinājumu sistēma dalībniekiem ir pieejama tikai no 2020. gada 1. decembra, kā arī tirgotājiem piemērojamie noteikumi, kas skāra izcelsmes apliecinājumu lietojumu, tika aktualizēti tikai 2020. gada beigās.

Tendence ir pozitīva

2021. gada pirmie trīs ceturkšņi ļauj secināt, ka tirgotāju aktivitāte izcelsmes apliecinājumu izlietošanā ir augsta, kas liecina, ka pieņemtais lēmums kļūt par Eiropas Izdevējiestāžu asociācijas biedru bijis tālredzīgs un pareizs, jo starptautiski vienoti, caurspīdīgi un visām pusēm skaidri spēles noteikumi kopā ar AST izveidoto izcelsmes apliecinājumu pārvaldības modeli veido labu sinerģiju.

Balstoties uz AIB biedru pieredzi, kas iekļauj vairāk nekā 30 Eiropas valstis, var secināt, ka, palielinoties elektroenerģijas patērētāju informētības līmenim par iespējām un tiesībām iegūt pārskatāmu un viegli uztveramu informāciju par elektroenerģijas tirgotāja produktu izcelsmes sastāvu, kā arī kopējo tirgotāja piegādātās elektroenerģijas izcelsmes sastāvu, patērētājs spēj izdarīt pareizu izvēli, tādējādi sekmējot videi draudzīgāku elektroenerģijas produktu parādīšanos elektroenerģijas tirgū. E&P

Vienota elastības platforma – INTERRFACE

Projekts ir saņēmis finansējumu no Eiropas Savienības pētniecības un inovāciju programmas "Apvārsnis 2020" saskaņā ar granta līgumu Nr. 824330

Aigars Sīlis, AS "Augstsprieguma tīkls" Datu analīzes grupas vadītājs
Ivars Zikmanis, AS "Augstsprieguma tīkls" Datu analīzes grupas biznesa analītiķis

Nākotnes energosistēma ir pārmaiņu priekšā. Virzoties uz Eiropas Savienības mērķiem ar Eiropas zaļā kursa un Tīrās enerģijas paketes palīdzību, tiek ievērojami ietekmēta arī enerģētikas joma. Eiropas zaļā kursa mērķis ir līdz 2050. gadam sasniegt Eiropas klimatneitralitāti, kas nozīmētu, ka vairākums saražotās elektroenerģijas īpatsvara veidosies no atjaunīgajiem energoresursiem. Savukārt, Tīrās enerģijas pakete izceļ nepieciešamību nodrošināt elektroenerģijas galalietotāju dalību elektroenerģijas tirgos, tostarp enerģijas balansēšanas tirgos.

Pārmaiņu posma vidū ir gan energosistēma, gan tās elektroenerģijas pārvades un sadales sistēmas operatori, kuri ir atbildīgi par nepārtrauktu un kvalitatīvu elektroenerģijas plūsmu sistēmā. Gaidāmās pārmaiņas ir jauns izaicinājums sistēmas operatoriem ikdienas darbā, kā rezultātā ir radusies vajadzība pēc atbalsta risinājuma.

Ievads

INTERRFACE[1] (*TSO-DSO-Consumer INTERFACE aRchitecture to provide innovative Grid Services for an efficient power system*) ir atbalsta programmas "Apvārsnis 2020" projekts, kura ietvaros tiek veidots risinājums, balstoties uz izaicinājumiem, kas sagaida Eiropas sistēmas operatorus, lai atbalstītu tos ikdienas darbā energosistēmās ar augstu izkliedēto atjaunīgo energoresursu īpatsvaru un vienlaikus veicinātu jauno galalietotāju potenciāla efektīvu izmantošanu sistēmas stabilas darbības nodrošināšanā.

Latviju INTERRFACE pārstāv AS "Augstsprieguma tīkls" un Rīgas Tehniskā universitāte, kas ar partneriem no Igaunijas un Somijas projekta ietvaros veido kopīgu Baltijas un Somijas reģiona darba grupu. Baltijas un Somijas reģions izstrādā risinājumu "Vienota elastības platforma" (VEP) ar reģionāli harmonizētu procesu kopu, lai atvieglotu galalietotāja elektroenerģijas iekārtu potenciāla izmantošanu sistēmas vajadzībām gan sistēmas operatoriem, gan galalietotāja iekārtu pārvaldītājam.

1. Elastības platforma

Elastības platforma ir specifiska sistēmas programmatūra, kas paredzēta darbībai ar elastības resursiem. Tajā elastības

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[1] H2020 INTERRFACE projekts: http://www.interrface.eu/

resurss ir elektroenerģijas patēriņa, ražošanas un uzkrāšanas iekārta vai to kopa, kuras darbības grafiku tieši vai ar citas sistēmas starpniecību var mainīt pēc nepieciešamības.

Elastības platformas funkcionalitāte galvenokārt iekļauj elastības resursu pārbaudi un koordinētu izmantošanu starp sistēmas pārvades un sadales operatoriem, nodrošina nepieciešamo datu apmaiņu starp elastības resursiem un elastības platformu, kā arī veic saistītās informācijas apstrādi. VEP ir elastības platforma, un tās galvenie darbības procesi ir apkopoti šajā nodaļā, un to kopskats aplūkojams pirmajā attēlā.

A. Silis

I. Zikmanis

1.1. Pamata informācijas ievade

Pirms jebkādu VEP apstrādes procesu sākšanas ir nepieciešama pirmreizējā informācija no elastības platformas galvenajiem lietotājiem: elektroenerģijas sistēmas operatora, tirgus operatora un elastības pakalpojuma sniedzēja.

Katram VEP lietotājam tiek izveidots VEP konts atbilstoši tā darbības lomai: sistēmas operators, tirgus operators vai elastības pakalpojuma sniedzējs. Balstoties uz lietotājam definēto lomu, elastības platformas vietnē (skat. 2. attēlu) tiek atspoguļota tikai lomai paredzētā specifiskā informācija, tai skaitā ierobežojot platformas mašīnas-mašīnas sakaru komunikācijas kanālus atbilstoši lomas nosacījumiem.

Elektroenerģijas sistēmas operatoru lietotāju skaits VEP nav ierobežots, un lietotāji tiek sadalīti starp pārvades un sadales sistēmas operatoriem atkarībā no tā, pie kura sistēmas operatora lietotājs ir pieslēgts. Sistēmas operatori VEP sniedz informāciju par savu elektrotīklu, kas ietver tīkla elementus un to starpsavienojumus, kā arī par katra tīkla elementa elektroenerģijas plūsmas ierobežojumiem. Izmantojot šo informāciju, VEP veic tīkla kvalifikācijas procesu saskaņā ar 1.2. apakšnodaļu, kas nodrošina koordinētu elastības resursu izmantošanu starp vairākiem sistēmas operatoriem.

VEP lietotāju pieslēgšanās ekrāns[2]

Tirgus operatoru lietotāju skaits VEP nav ierobežots, un tiem atšķirībā no sistēmas operatoriem nav nekāda papildu iedalījuma. Tirgus operatori VEP var definēt savus tirgus produktus, norādot vērtības visiem produkta būtiskajiem tehniskajiem parametriem. VEP šo informāciju izmanto, lai veiktu produkta kvalifikācijas procesu (1.2. apakšnodaļa) un informētu VEP elastības pakalpojuma sniedzējus par tiem pieejamo produktu klāstu.

Arī elastības pakalpojuma sniedzēju skaits VEP nav ierobežots, un tiem nav nekādu specifisku lomu iedalījuma. Elastības pakalpojuma sniedzējs caur VEP veido savu elastības resursu portfeli, kas sastāv no individuāliem resursiem un resursu grupām. VEP izmanto sniegto resursu un resursu grupu informāciju elastības resursu kvalifikācijas (1.2. apakšnodaļa), tirgus solījumu kvalifikācijas (1.3. apakšnodaļa) un norēķinu procesā (1.4. apakšnodaļa).

Elastības pakalpojuma sniedzējam, radot savu elastības resursu portfeli VEP, vispirms izveido virtuālu individuālo elastības resursu, fiksējot visas pieprasītās detaļas par konkrēto elastības resursu. Obligāti norādāmā informācija ir saistīta ar elastības resursa elektroenerģijas tehniskajiem parametriem un pieslēguma punktu elektrotīklā, un tā ir jāsniedz, lai VEP spētu veikt nepieciešamos datu apstrādes procesus. Pēc individuālu elastības resursu izveides VEP portfelī elastības pakalpojuma sniedzējs VEP saskarnē var atlasīt izveidotos individuālos elastības resursus un apvienot tos resursu grupā. Resursu grupu izveide ir nepieciešama, jo VEP atbalsta mazjaudīgus elastības resursus, kas individuāli var neatbilst tirgus produktu prasībām, bet grupēti to potenciāls krietni pieaug.

Saņemot minēto informāciju, VEP ir visi nepieciešamie dati, lai veiktu kvalifikācijas procesus, kas aprakstīti nākamajā apakšnodaļā.

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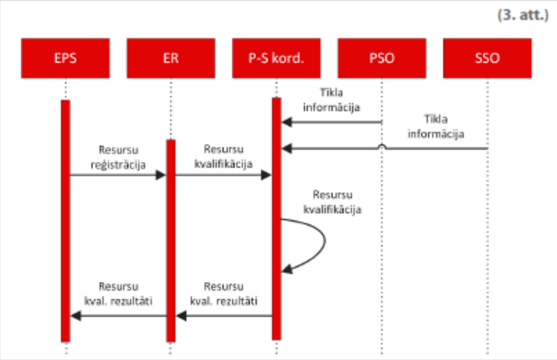
[2] H2020 INTERRFACE projekta IEGSA platforma: http://www.interrface.eu/

(3. att.)



Tīkla kvalifikācija[3]

1.2. Elastības resursu kvalifikācija

Elastības resursu kvalifikācija ir VEP pārbaudes procesu kopa, kas satur tīkla un produkta kvalifikācijas procesus. Tīkla un produkta kvalifikācijas procesi nav saistīti, bet tie bieži notiek secīgi.

Tīkla kvalifikācijas ietvaros VEP pārbauda tā saskarnē izveidoto elastības resursu un resursu grupu teorētiski radīto noslodzi uz elektroenerģijas sistēmas operatora elektrotīklu. VEP izmanto elastības resursa tehniskajā specifikācijā sniegto informāciju un, balstoties uz norādīto pieslēguma punktu, to ievieto attiecīgā sistēmas operatora elektrotīkla struktūrā. Tālāk ar izstrādāta algoritma palīdzību VEP simulē elastības resursa radīto noslodzi uz pārējo tīkla daļu, kas var ietekmēt pat vairākus sistēmas operatoru elektrotīklus. Pārbaudes mērķis ir neradīt pārslodzes tīklā, kas tiek panākts, ņemot vērā visus ietekmētos sistēmas operatoru elektrotīklus, tādējādi nodrošinot koordinētu elastības resursu izmantošanu.

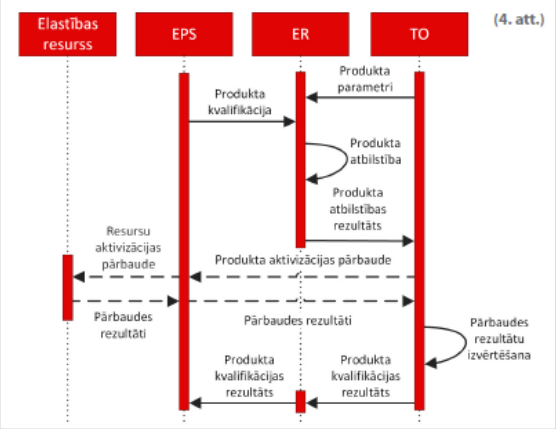
Tīkla kvalifikācijas process ir atspoguļots trešajā attēlā. Kvalifikācijas procesa veikšanai ir nepieciešami divi informācijas bloki: elektrotīkla un elastības resursu informācija. Elektrotīkla informāciju sniedz pārvades sistēmas operators (attēlā: PSO) un sadales sistēmas operators (attēlā: SSO), un šo informāciju abi sistēmas operatori nodod pārvades un sadales koordinācijas modulim (attēlā: P-S kord.). Otru informācijas daļu par elastības resursiem iegūst no elastības pakalpojuma sniedzēja (attēlā: EPS), un šo informāciju tas sniedz elastības reģistram (attēlā: ER), kas tālāk to nodod pārvades un sadales koordinācijas modulim tīkla kvalifikācijas procesam.

Pēc pārbaudes procesa elastības pakalpojuma sniedzējs tiek informēts par konkrētā resursa un resursu grupas kvalifikācijas rezultātu. Ja resurss vai resursu grupa rada pārslodzi tīklā, šo resursu izmantošana tirgū tiek ierobežota un iegūtā informācija tiek ņemta vērā tirgus solījumu kvalifikācijas laikā (1.3. apakšnodaļa).

Produkta kvalifikācijas ietvaros VEP pārbauda saskarnē izveidoto resursu grupu teorētisko atbilstību tirgus operatora definētajiem produktiem. VEP šo procesu veic, izmantojot resursu grupas tehniskajā specifikācijā norādīto informāciju, un salīdzina to ar tirgus operatora definēto produktu tehniskajām prasībām. Procesa beigu posmā VEP konkrētai resursu grupai sniedz produkta kvalifikācijas izvērtējumu un izceļ resursu grupas tehniskos parametrus, kas neatbilst produkta definētajām vērtībām. Pēc VEP produkta kvalifikācijas procesa tirgus operators caur VEP saskarni var pārskatīt pārbaudes rezultātus un nepieciešamības gadījumā veikt papildu pārbaudes ārpus VEP vides pirms resursu grupas atbilstības VEP vidē apstiprināšanas.

Produkta kvalifikācijas process ir atspoguļots ceturtajā attēlā. Lai veiktu produkta kvalifikācijas procesu, tirgus operatoram (attēlā: TO) VEP ir jādefinē savs tirgus produkts un pēc tam elastības pakalpojuma sniedzējs, izmantojot elastības reģistru, var pieteikt sava resursu grupas produkta kvalifikāciju. Attēlā ar raustītu līniju ir attēlots praktiskas elastības resursu pārbaudes process, ko tirgus operators veic pēc nepieciešamības ārpus VEP vides. Process noslēdzas ar produkta kvalifikācijas rezultātu, kad galalēmumu pie

(4. att.)



Produkta kvalifikācija[3]

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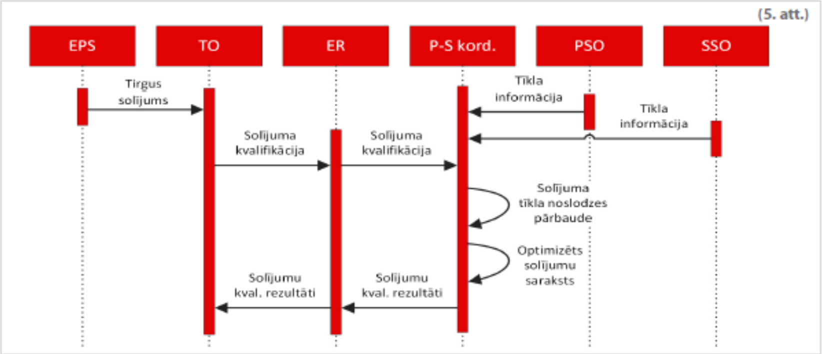
[3] H2020 INTERRFACE projekts, D3.2. Definition of new / changing requirements for Market Designs: http://www.interrface.eu/sites/default/files/publications/INTERRFACE_D3.2_v1.0.pdf



Tirgus solījumu kvalifikācija[4]

ņem tirgus operators un elastības pakalpojuma sniedzējs par to tiek informēts caur VEP elastības reģistra saskarni.

Elastības resursu kvalifikācijas process noslēdzas, kad ir veikts elastības resursu tīkla un produkta kvalifikācijas process. Process var tikt atkārtots, mainoties sistēmas operatoru elektrotīkla informācijai, tirgus operatora produkta prasībām un elastības resursa tehniskajai informācijai. Tādējādi tiek nodrošināts, ka energosistēmā pieejamie elastības resursi var tikt izmantoti atbilstoši, neradot pārslodzes sistēmā.

1.3. Tirgus solījumu kvalifikācija

Tirgus solījumu kvalifikācija ir otrreizējs elastības resursu kvalifikācijas process, un tas tiek veikts īsi pirms elastības resursu dalības konkrētā tirgū. Tādējādi procesam ir pieejama jaunākā elektrotīkla informācijas prognoze no sistēmas operatoriem, un veiktā tīkla noslodzes pārbaude ir atbilstošāka reālajai situācijai tīklā. Procesa mērķis ir ne tikai veikt kvalitatīvu tirgū piedāvāto elastības resursu tīkla noslodzes pārbaudi, bet arī izvērtēt dažādu elastības resursu mijiedarbību attiecībā uz tīkla noslodzi. Tātad atšķirībā no iepriekš veiktā kvalifikācijas procesa šajā procesā tiek iegūts precīzāks tīkla noslodzes izvērtējums ar atjauninātu elektrotīkla informāciju un pieejamo resursu mijiedarbību.

VEP tirgus solījumu kvalifikācijas procesu veic tirgū saņemtiem elastības pakalpojuma sniedzēja resursu solījumiem, kurus tirgus operators ir apkopojis savam tirgum noteiktā laika intervālā un nosūtījis uz VEP vidi. Pēc informācijas saņemšanas VEP veic tirgus solījumu kvalifikācijas procesu tikai tiem elastības resursiem, kuri iepriekš ir izgājuši elastības resursu kvalifikācijas procesus (apakšnodaļa 1.2.) un saņēmuši apstiprinājumu par dalību konkrētā tirgū. Pārbaudes procesa gaitā katrs atsevišķais tirgus solījums tiek skatīts individuāli pēc radītās tīkla noslodzes caur tīkla kvalifikācijas procesu, un pēc tam visi saņemtie solījumi tiek izvērtēti kopīgi, tādā veidā nosakot atsevišķo solījumu elastības resursu mijiedarbību uz tīkla noslodzi.

Kopējais process aplūkojams piektajā attēlā, kur galvenie pārbaudes procesi notiek pārvades un sadales koordinācijas modulī "solījumu tīkla noslodzes pārbaudes" un "optimizēta solījumu saraksta" procesu ietvaros. VEP veiktajā procesā tiek sastādīts optimizēts solījumu saraksts, iekļaujot visus tirgū iesniegtos solījumus, kas nerada tīkla pārslodzes un var tikt izmantoti attiecīgajā tirgū.

1.4. Pakalpojumu norēķini

Pakalpojuma norēķina process ir VEP noslēdzošais posms, kas norit pēc elastības pakalpojuma sniedzēja tirgus solījuma izpildes. Solījuma izpilde nozīmē, ka konkrētais tirgus piedāvājums tika nopirkts tirgū, bet elastības pakalpojuma sniedzējam ir jānodrošina nopirktā solījuma izpilde. VEP pakalpojuma norēķina procesa mērķis ir noteikt solījuma izpildes apjomu un izvērtēt izpildes precizitāti, salīdzinot ar tirgū iegādāto apjomu.

Lai izpildītu šo procesu, VEP nepieciešama informācija par tirgus solījuma izpildē lietoto elastības resursu plānoto patēriņu un elektroenerģijas skaitītāju uzskaitīto patēriņa apjomu. Starpība starp plānoto un uzskaitīto elektroenerģijas patēriņu ir tirgus solījuma izpildes apjoms, kas tiek salīdzināts ar tirgū iegādāto apjomu, nosakot piegādes precizitāti.

VEP pakalpojuma norēķina process ir vēl agrīnā izstrādes stadijā, un to paredzēts papildināt ar vairākiem apakšprocesiem INTERRFACE projekta darbības laikā.

2. Nākamie soļi

Baltijas un Somijas reģions šī gada laikā ir veicis VEP pirmās versijas darbības pārbaudi, identificējot nepieciešamos esošo funkciju pilnveidojumus, kā arī jaunu papildu funkciju vajadzību. Šobrīd reģiona uzdevums ir attīstīt VEP risinājumā identificētos uzlabojumus, virzoties uz VEP otrās versijas izlaidumu. Otrajā VEP versijā ir paredzēts ievērojami paplašināts pieejamo funkciju klāsts, kuru Baltijas un Somijas reģiona pārstāvji pārbaudīs un atkārtoti uzlabos, lai līdz INTERRFACE projekta noslēgumam attīstītu pilnvērtīgu VEP risinājuma prototipu. E&P

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[4] H2020 INTERRFACE projekts, D3.2. Definition of new / changing requirements for Market Designs: http://www.interrface.eu/sites/default/files/publications/INTERRFACE_D3.2_v1.0.pdf

Annexes 13.

Reserve power estimation according to the Baltic power system 2050 development plan

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Abstract— **Development plans in energy sector of European countries assume modifications almost in all fields of energy systems. Global use of renewable energy sources is expected to complete primary purpose of energy sector development plan - reduction of greenhouse gas emission into the atmosphere. Towards that goal, national energy development plans intend implement huge number of renewable energy sources and to reduce capacity or shut down fossil fuel power plants. However, results of last action are not well researched. For timely reaction to avoid any accident in the future, there is need comprehensive assessment of mentioned power plants impact on power system in long-term perspective. Reasonableness of conventional power plants in energy systems of the Baltic countries in 2050 is focused in this article.**

Keywords—power balance, Baltic power system, power reserve

I. INTRODUCTION

Key challenge for contemporary world is to stop the climate change.

Dissemination of renewable energy sources (RES) seems to be the best solution to the problem. RES distribution is in full swing . For instance, the share of RES in European Union (EU) in energy consumption increased continuously from 9.6% to 19% from 2004 to 2019 [1].

The Baltic states was not an exception - power generation and consumption have fundamental changes. In last decade, there has been a rapid development of RES, in their installed capacity and encapsulation into power systems [2].

Several new RES projects have already been implemented in each Baltic country [3], [4]: 50 MW Fortum Tartu Raadi solar power plant (Estonia, 2019); 138 MW Tootsi wind farm (Estonia, 2019); 910.7 MW wind power plants (Estonia, 2019–2029); 3.96 MW Pärnu Power Plant (Estonia, 2020); 11 MW Lizums Power Cogeneration Station (Latvia, 2017); 73.5 MW Pagėgiai 13 largest wind park in the Baltic States (Lithuania, 2016) etc. Furthermore, several renewable energy and transmission network development projects are planned: Estonia and Latvia's 1 GW Gulf of Riga offshore wind farm; an experimental floating photovoltaic (PV) power plant (PP) project at Kruonis pumped storage hydropower plant reservoir; reconstruction of two of the existing Latvian-Estonian interconnections; the capacity change of the LitPol Lithuania–Poland direct current interconnection (from 700 MW to 1000 MW); a new interconnection between Lithuania and Poland (the Harmony Link project); a new 500 MW pumped storage hydropower plant (PSHP) in Estonia; 7 MW solar PP (SPP) project in Estonia, etc. Moreover, it is planned to shutdown several PPs operating with fossil fuel. All these projects are envisaged to achieve national targets for the period up to 2030 [5].

Ensuring the sustainability of the system and reducing greenhouse gas emissions require significant changes in the structure of energy systems, warranting an acceptable balance between energy production and consumption, and in parallel providing power system stability [6].

Balancing is troubled by the variability of wind and solar generation capacity. There are periods of time when the RES generation come close to zero. Backup (reserve) power plants can be maintained to deal with possible power outages.

This article is devoted to the problem of forecasting and analysing the future role and needs of the Baltic Power System Reserve Generation. The forecast methodology and results constitute the main contribution of the article.

The rest of the article is organized as follows: Section 2 is devoted to the methodology and models. Description of case study and estimation of minimal power reserve maintenance are observed in Section 3. The last section is devoted to conclusions.

II. METHODOLOGY AND MODELS

A. Modelling platform

For comprehensive assessment of Baltic power system (BPS) energy balance there is need in a list of mathematical models. Dropped flowchart in Figure 1 reflects the structure of required models for analysing BPS energy balance.

As can be seen from the Figure 1 two different methods for the BPS operating mode forecast are applied:

- Assessment of recorded time-series impact on the BPS operating mode (historical data);
- scenario approach, the primary objective is to forecast BPS power consumption, power generation, etc.

Scenario generator block, depicted in Figure 1, operates with relatively large mount of data for BPS modelling: power generation (P GEN) and consumption (P CON) in BPS, electricity market prices (Price EL) in neighbouring countries that have interconnections through transmission lines with BPS etc.

The final step of BPS modelling provides an opportunity with hourly discretization step to analyze power disbalance of the BPS, its energy import/export, as well as allows to determine electricity price for BPS zone.

The following heads deals with comprehensive information about each calculation block of the modelling platform structure.

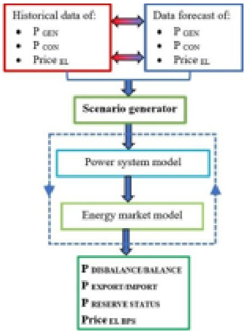

Fig. 1. The structure of the modelling platform.

1) Historical data

At the initial state the deep study of historical data of input processes for power system structure analyse and forecasting must be realized. For instance, there is a list of historical data used in the article: hourly energy market price in Finland, Sweden and Poland (interconnected countries with Baltic States, Fig. 2) [7], [8]; hourly data of water inflow of Daugava river in Plavinas hydropower plant (HP) reservoir[9]; hourly solar irradiation data [10]; wind generation data [7].

Fig. 2. Interconnections and NordPool market areas.

2) Prediction of time-series processes

Next modelling step requires forecasting of previously selected time-series processes. Methodology of long-term prediction of time processes used in the article is described in our previous articles in details [11]–[13]. For instance, Figure 3 depicts minimal, average and maximal values of predicted hourly electricity market prices in 2050 for different price zones namely for Finland, for Sweden (SE4) and for Poland.

Analysing graph in Figure 3, can be stated that the hourly electricity market price as time-series process vary in relatively wide range: plus ~1.5 times and minus ~4 times from mean hourly electricity market price value (€/MWh).

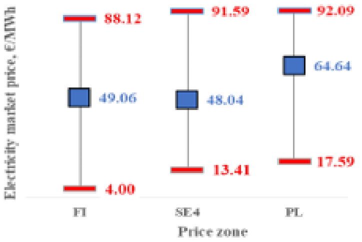

Fig. 3. Forecasting of low-average-high electricity market prices for 2050 accordingly to price zone.

One more example of long-term prediction (Figure 4), is BPS 2050 hourly energy demand. That forecasted BPS energy consumption in 2050 equals to 41.796 TWh with minimal energy consumption 2 749 MWh/h, maximal value equal to 7 233 MWh/h and average electricity demand level 4 784 MWh/h (red curve).

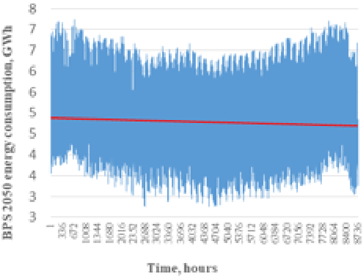

Fig. 4. BPS 2050 modelled energy consumption.

3) Baltic power system model

Baltic power system model used in the article has a nested structure depicted in Figure 5. Reflected BPS structure includes separate comprehensive mathematical models (submodels) correspondingly to the existing and foreseeable energy sources: pumped storage hydropower plant [14], [15]; hydropower plant (HP) [13], [16]; small hydropower plant (sHP); solar power plant; wind power plant (WPP); electric vehicles (EV); power reserve (PR (cogeneration power plants and thermal power plants))[17]–[19]; bioenergy power plant (BPP); BPS electricity demand and interconnections between Baltic power system and Finland, Sweden and Poland [11].

Furthermore, each submodel consider wide range of specific features: technic-economic limitations as well as environmental constraints. BPS internal distribution network (330 kV) represents a simplified mathematical model excluding power loses and limitations of transmission lines capacities.

Considered BPS mathematical model covers Finland (Estonia-Finland), Sweden (Lithuania-Sweden), Poland (Lithuania-Poland) interconnections potentials. Environmental conditions have impact on the transmission lines features [20]. However, in the article are assumed corresponding transmission lines capacities: 1 016 MW (Estonia-Finland), 700 MW (Lithuania-Sweden) and 1 700 MW (Lithuania-Poland).

In that way BPS mathematical model gives the opportunity for analysing energy balance into the Baltic power system.

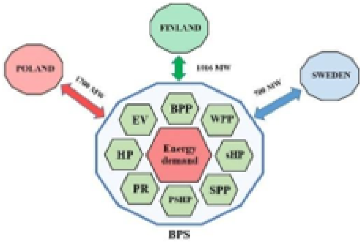

Fig. 5. A structure of modelled BPS.

4) *Energy market model*

Other one speculation of the article is that the plants shareholders strive to increase their profitability and are forced to follow the technical and legal constraints established by the laws of the NordPool [21] day-ahead electricity market, the government and the networks.

Two last steps of the modelling structure, namely subchapter 3 and subchapter 4, operate in tandem to strive optimal power flows, with objective to get maximal benefits from energy export and in opposite – minimize expenses related with need in energy import and local power reserve.

Figure 6 depicts simplified structure of energy market model. Resolution of each structure of modelling platform equals to one hour. Each hour energy market model receives information about BPS energy balance before import\export procedure. As result there are few possibilities:

- energy deficit;
- energy surplus;
- energy neutral.

In the last case BPS has energy balance and no action is required. In the second operating mode of BPS there exist energy surplus which capacity can be sold to the neighbour power systems via transmission lines taking into account their power transit constraints. Due to the power market rules at energy surplus state the goal is to maximize profit from the energy export realisation (flowchart in Figure 6).

Otherwise, in the first operating mode energy deficit takes place. In this case the objective tries to minimize expenses. To carry out the last goal energy market model operates with energy import, electricity export, and in specific cases with the power reserve capacities.

Should be highlighted that in the first (energy deficit) and the second (energy surplus) BPS operation mode the energy market model works under transmission lines capacity limitations.

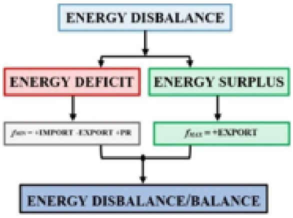

Fig. 6. Applied energy market model simplified structure.

III. CASE STUDY AND RESULTS

A. *Input data and assumptions*

Table I provides data of forecasted total power consumption and power generation by source for scenario 1 (BPS 2030), for scenario 2 (BPS 2050) and for scenario 3 (BPS 2050).

Information in Table II deals with maximal values of the predicted power consumption and power generation by source for BPS modelling scenarios under consideration [3].

Baltic power system consumption (BPSC) in 2030 is 37.86 TWh. However, BPS consumption in 2050 is 41.80 TWh [22]–[27].

1) *Electrification of transport sector*

Long-term forecast of electric vehicles has respectively strong impact on the BPS energy consumption. Hence, in BPS 2030 predicted EV amount is 1 million units. Mentioned value of EV provides 4.33% of BPS 2030 energy consumption. However, in BPS 2050 is planned that EVs amount will be 3 million and it corresponds to 11.36% of total consumption [3], [23]–[26], [28].

Taking into account Baltic countries development plans accordingly EVs integration the following assumptions are considered in the article:

- The total number of EVs for 2030 and 2050 is known – 1 million and 3 million respectively.
- The average daily mileage is 15 km/day. The average energy consumption equals to the 0.3 kWh/km.
- Energy storage capacity of EV batteries is 90 kWh. As well as all cars will be loaded evenly overnight, from 11 p.m. to 7 a.m. (for 8 hours) when predicted market price will be lower than during business hours.

Increasing trend in renewable energy sources (RES) installed capacities can be observed in second part of Table I in columns SPP and WPP respectively. It is need to be noted that scenario 2 and scenario 3 differs in RES installed capacity in two times. Assessment of renewable energy sources impact on the BPS energy balance is major reason for the mentioned above parameters distinction.

The capacity of the local power reserve is supported by conventional power plants that pollute greenhouse gas into the atmosphere. Power reserve (PR) value summarize capacities of thermal power plants (TPP) located in Estonia and fuelled by the oil shale. As well as PR includes existing and planned CHP of Latvia and Lithuania.

In the long-term perspective, capacity of fossil energy production is planned to be limited. For example, in the long term, the Estonian National Energy Sector Development Plan implies a reduction in CO2 emissions by reducing oil shale TPPs [3]. In Table I last column, named PR, reflects trend of conventional power plants capacity reduction. Thus, PR hourly available capacity in 2030 is equal to 4 300 MWh (scenario 1). Due to politic of the CO2 emission to atmosphere reduction it is planned that reserve power hourly capacity has declined to 1 500 MWh (scenario 2 and scenario 3).

Capacity reduction of conventional power plants is questionable development plan of the energy sector and more in-depth consideration and argumentation are required.

TABLE I. POWER CONSUMPTION AND POWER GENERATION DATA FOR MODELLING SCENARIOS 1, 2 AND 3

	BPSC TWh	SPP TWh	WPP TWh	HP TWh	sHP TWh	BPP TWh	PSHP TWh
1	37.86	1.74	11.66	1.90	0.34	3.52	2.85
2	41.80	2.19	17.64	1.90	0.34	3.52	2.85
3	41.80	4.52	34.57	1.90	0.34	3.52	2.85

TABLE II. MAXIMAL POWER CONSUMPTION AND MAXIMAL POWER GENERATION DATA FOR MODELLING SCENARIOS 1, 2 AND 3

	BPSC MW	SPP MW	WPP MW	HP MW	sHP MW	BPP MW	PSHP MW	PR MW
1	6 026	1 489	3 907	1 562	165	522	1 625	4 300
2	7 233	1 876	5 913	1 562	165	522	1 625	1 500
3	7 233	3 872	11 586	1 562	165	522	1 625	1 500

Bar diagram in Figure 7 illustrates power reserve activation impact on the BPS energy imbalance for all considered scenarios. Thus, PR activation in scenario 1 (BPS2030) completely balances energy system.

In the scenario 2 (BPS2050) the installed capacity of RES is higher; however, value of PR is reduced more than 2 times. Results in Figure 6 show, that activation of local power reserves can not fully compensate for the BPS energy deficit. As a result, the energy deficit in BPS is equal to 0.177 TWh or 0.42% of total BPS 2050 energy consumption.

In the scenario 3 PR capacity stays unchanged and is equal to 1 500 MWh. Meanwhile installed capacity is higher than in scenario 2 by two times. In Figure 6 red bar (BPS2050(3)) reflects energy deficit reduction: from 1 847 TWh (4.42%) to 0.784 TWh (1.88%). It can be concluded that increasing of RES capacities leads to energy imbalance mitigation in BPS. However, last blue bar in diagram 6 shows energy deficit termination impossibility due to the insufficient capacity of power reserve.

Next subchapter describes comprehensive survey of optimal power reserve value for each scenario under consideration.

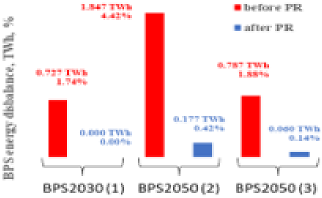

Fig. 7. Power reserve impact on the BPS energy balance

B. Estimation of minimal power reserve maintenance.

Value of power reserve, needed to terminate BPS energy deficit, can vary in respectively wide range. Thereby, maximal capacity of power reserve needed to compensate energy deficit in BPS 2030 is equal to the 1 740 MWh (Figure 8). At the sane time frequency analysis of required PR activation for BPS 2030 energy deficit compensation shows that mentioned maximal value was applied only once during a whole year. However, to ensure the BPS 2030 energy balance, it is vital to maintain the required amount of power reserve. Accordingly to the Table I results, power reserve capacity in 2030 is 4 300 MWh. It can be noted that maintained PR value covers energy deficit in BPS 2030.

Histogram in Figure 9 shows an opposite result. Here maximal capacity of energy deficit in 2050 is 2 890 MWh. As listed in Table I planned power reserve capacity in 2050 is 1 500 MW. As a consequence of short-sighted energy sector development policy planned PR capacity can not compensate energy deficit. As a result hourly maximal energy deficit in BPS2050 remains to be equal to 1 390 MWh.

It is expected that significant number of RES will help in energy balancing. Figure 10 reflects bar diagram of required capacities to balance BPS 2050 energy deficit in the scenario 3. In contrast with previous case of scenario 2, where hourly maximal energy deficit capacity was 2 890 MWh, result of RES increased installed capacity in two times leaded to the 2 756 MWh maximal hour energy deficit. As in the previous case planned amount of power reserve is impossible to cover energy deficit and BPS 2050 continues to be unbalanced.

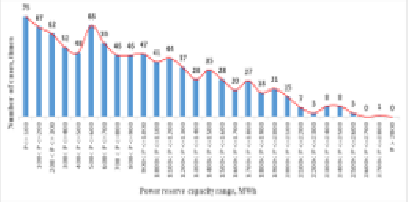

Fig. 8. Histogram of energy deficit in BTS2030 (scenario 1) after electricity import / export procedures.

Fig. 9. Histogram of energy deficit in BTS2030 (scenario 2) after electricity import / export procedures.

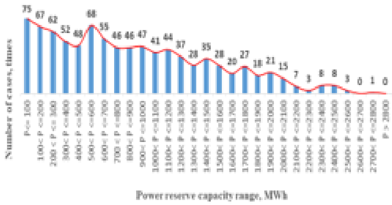

Fig. 10. Histogram of energy deficit in BTS2030 (scenario 3) after electricity import / export procedures.

IV. CONCLUSIONS

Popularization of stopping climate change by reducing greenhouse gas emissions has become one of the priority tasks in the development plans of world energy. According to the European Commission, one of the main reasons for the large-scale volume of CO2 emissions is operation of conventional power plants that utilize fossil fuels.

To achieve mentioned goal and to stop climate change, the global and European energy development plans propose to apply several strategies, whereas at least two of them significantly affect the structure of energy systems:

strategy 1: a precipitous increase in the capacity of power plants operating on a renewable energy sources;

strategy 2: reducing the capacity, suspending or shutdown of power plants that use fossil fuels.

Well known fact that the production of electricity by RES is unpredictable and impermanent process. As a result, there is a problem to constant energy production and ensuring the power balance of any energy system. Sometimes, to entirely compensate power deficit by energy import from neighbouring countries is an impossible issue due to the limited capacity of transmission lines. Thus, the last opportunity to mitigate energy deficit is to activate local power reserve.

The BPS 2030 energy development plan provides for a reserve capacity of 4 300 MW. As a result, the energy deficit of BPS 2030 is completely covered and the energy balance is maintained (Figure 7, scenario 1).

Above mentioned strategies (strategy 1 and strategy 2) of energy development plan are realized in BPS2050 (scenario 2). That, simulation results of BPS2050 (scenario 2) argue that attempts to ensure the energy balance by power import procedure and to cover the energy deficit by increasing the installed capacity of RES do not lead to success. At the same time, the reduced capacity of reserved power plants does not allow to get rid of the power deficit.

Nearly twofold increase in the installed capacity of wind and solar power sources is considered in BPS2050 (scenario 3). However, the above-described power generation potential is not panacea and the BPS2050 system remains as energy deficit.

The results of the paper prove that BPS needs a more detailed assessment and analysis. The developed mathematical model allows to determine the minimal value of power reserve needed to be maintained for the energy balance of the BPS ensuring.

Only a rational, reasonable and timely selection operation mode of BPS` power plants, as well as a carefully thought-out development strategy is the only way to form a sustainable and balanced energy system of the future.

ACKNOWLEDGMENT

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Efficient market-based storage management strategy for FCR provider with limited energy reservoir

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***Abstract*—We present a market-based storage state of charge management strategy for primary frequency control providers with limited energy reservoirs such as battery energy storage systems. The strategy is the result of research work motivated by relatively recent regulatory condition updates in Continental Europe which stipulate that frequency containment reserve providers cannot rely on dead-band utilization and delivery overfulfillment to manage their reservoirs. In addition, we show how the devised strategy allows an appropriately sized battery system to withstand the realization of a worst-case scenario, even if the unit is providing multiple reserve products at once and is allowed to recover its state of charge only via the intraday market.**

***Index Terms*-- ancillary services, balancing, BESS, FCR, storage**

I. INTRODUCTION

The role of energy storage technologies in the power systems has been rapidly growing as the rising share of intermittent renewable energy sources increases the need for system flexibility. To that end, storage is seen as an invaluable resource able to provide fast-acting ancillary services to system operators in decarbonized electricity systems. Consequently, there has been a significant growth of battery-based grid-scale storage during the recent years worldwide. However, their intrinsic differences when compared to conventional balancing resources must be accounted for and reflected in regulation.

In order to both facilitate and regulate integration of storage systems in ancillary service markets, especially for provision of frequency containment reserve (FCR), the EU System Operation Guideline [1] stipulates specific rules applicable to limited energy reservoirs (LERs), i.e. storage units that can be depleted within two hours of operation. Namely, the minimum activation period (T_{minLER} criterion) to be ensured by FCR providers qualified as LERs is 15–30 min during the system alert state with a specific value to be proposed by all TSOs of each synchronous area. While the Continental Europe (CE) TSOs lean towards a 30-min T_{minLER} at least for newly installed storage power plants, the final proposal is still under development as of mid-2023.

Furthermore, CE TSOs have already developed a number of additional properties of FCR [2]. Here, the definition of a LER has been clarified as an FCR provider that cannot maintain full reserve activation for at least two hours without performing corrective actions for reservoir management. Furthermore, the TSOs have disallowed overfulfillment or dead-band utilization, which means LERs should rather use existing market-based or similar measures for their reservoir recovery, intraday market being one of the most feasible possibilities.

Another important addition is the introduction of Reserve Mode, whereby LERs that are technically capable to should change their mode of FCR provision to react to only short-term frequency deviations when the reservoir is near exhaustion [2]. Reserve Mode allows for more beneficial usage of LERs during power system alert state, however, the technical intricacies of it have not been sufficiently harmonized yet.

LERs as FCR and frequency restoration reserve (FRR) providers are of particular interest for the Baltic power system, which is scheduled to desynchronize from IPS/UPS and connect to the CE synchronous area by 2025 [3]. By this time, the Baltic TSOs ought to be able to cover their FCR and FRR needs themselves while historically the primary frequency control has been ensured by the neighboring Russian power system [4], [5]. Hence, large-scale battery energy storage system (BESS) projects are under development in the Baltics to ensure FCR and FRR adequacy [6]–[8]. The outlined EU-level developments and regional challenges around the Baltic synchronization project have motivated the research question of this study: develop efficient market-based BESS operational management strategy subject to a set of technical and regulatory constraints related to ancillary service markets and specific reserve products as well as to electricity wholesale markets for storage recovery.

Even though a number of different strategies for FCR-providing BESS management can be found in the literature, the recent EU regulatory advances and the regional intricacies of the Baltic power system introduce the need for a more sophisticated methodology to conform to a number of binding requirements towards LERs. Notable previous studies include, for instance, FCR-providing BESS management algorithms developed for the German case described in [9]–[11] which use three degrees of freedom for storage management: overfulfillment,

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dead-band utilization and scheduled intraday (ID) transactions (with a 30-min gate closure time (GCT)). Reference [9] also uses provision rate adjustment, but finds it inconsequential.

On the other hand, [12] explores three methods of state of charge (SOC) recovery in a Finnish context: dead-band utilization (which they admit as incompliant with the new regulations), day-ahead (DA) bidding in time intervals when FCR capacity has not been sold and overfulfilling day-ahead trades when it is favorable to the balance of the power system.

In the Baltic context, a recent study [13] also considers overfulfillment and dead-band utilization as viable SOC recovery strategies along with ID transactions. An important additional drawback is that the ID GCT time is not considered, which is 60 min in the Baltics [14].

In contrast, we fill the gap of the previous studies by proposing and validating an active energy reservoir management strategy for an FCR providing BESS respecting the prohibition of delivery overfulfillment, dead-band utilization and subject to a specific T_{minLER} in line with the recent EU regulation. Moreover, the strategy successfully implements market-based storage recovery exclusively in the ID market (i.e. a stand-alone BESS) which means that intentional imbalance is disallowed, and it is also applicable to a LER providing both FCR and FRR. Consequently, our proposed management strategy respects all the regulatory requirements that a stand-alone frequency reserve providing BESS will be subjected to in the Baltic power system in the near future as well as in the EU in general. The strategy has been implemented in a mathematical simulation tool to validate its performance. Hence, the tool also allows testing the BESS operational strategy under various market settings (e.g. varied T_{minLER}, ID GCT etc.) and parameters (e.g. BESS size) to validate the BESS ability to deliver the contracted services.

II. SOC MANAGEMENT STRATEGY

The SOC management strategy is only a part of the overall management model necessary for a LER participating in balancing markets. The other two major components deal with the transition to and from Reserve Mode when nearing storage exhaustion during the alert state and the preparation of FCR and FRR bids, particularly the voluntary FRR energy bids which, due to short lead time, are the most dependent on the current energy level of the storage. However, to limit the scope of this paper, only the SOC management strategy is described in detail.

The main goal of the strategy is to prepare ID bids, while delivering the reserves, in order to assure a sufficient SOC level in line with the undertaken reserve (FCR and/or FRR) obligations. The overall philosophy of the strategy envisions a robust approach, i.e. the BESS must strive to be prepared for the realization of a worst-case scenario at any future point in time.

A. Assumptions and Simplifications

We assume that the FCR provider is a single BESS with a LER which can only use market-based mechanisms for restoring the energy content of its reservoir (i.e. no alternative generation or load neither in the reserve provider's portfolio nor contracted bilaterally which could be used to charge/discharge the BESS; intentional imbalance to manage storage disallowed). Ultimately, this means that the BESS can manage its SOC only by participating in the ID market as it has a much shorter lead time than the DA market and thus allows for more flexibility.

To achieve the most effective storage management under the laid out conditions, the optimum decision-making time on whether an ID trade offer needs to be submitted would be at the last possible moment before the GCT. However, for the sake of robustness, a certain bid preparation time should be added before each ID GCT by which the decision is made.

The relationship between various time-related variables employed in the management strategy is explained in Fig. 1, where $t_{\mathrm{ID,decision}}$ – moment in time for ID offer decision; $t_{\mathrm{ID,GCT,next}}$ – the closest ID GCT; $t_{\mathrm{ID,start}}$ and $t_{\mathrm{ID,end}}$ – the start and end time of the ID trading period with the closest GCT; $\Delta t_{\mathrm{prepare}}$ – user-selectable time period for bid preparation (expressed in minutes before GCT, e.g. 5 min); $\Delta t_{\mathrm{ID,GCT}}$ – ID GCT (in minutes before delivery start, e.g. 60 min in Baltics [14]); Δt_{MTU} – market time unit duration (assumed 15 min [4]).

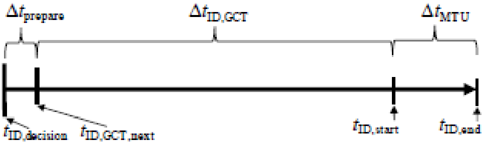

Figure 1. Relationship between the time-related variables

To minimize over-correction risks, ID trades are prepared only for the shortest possible delivery periods, i.e. at each decision time only one potential MTU is considered for delivery. On the other hand, this means that the need for corrective trade has to be evaluated before each ID GCT; with a 15-min MTU this equals to 96 decisions a day.

Based on analysis of the EU regulatory framework, we derive the following main requirements for the SOC management strategy of a BESS to provide FCR with a LER qualification:

- Capability to provide a prolonged full FCR activation at least until the T_{minLER} criterion is satisfied during the system alert state.
- Capability to provide uninterrupted prolonged FCR up to 25% of the total committed reserve power in one direction during the system normal state.
- Recovery of sufficient storage level to be able to again fulfill the T_{minLER} criterion no later than 2 hours after the end of a prior system alert state.
- The previous three requirements need to be met also when the BESS provides FRR alongside FCR. However, the committed FRR must be able to be fully activated at any given time for any duration regardless of the T_{minLER} criterion and post-alert state recovery status. This is because there are no special properties defined or exemptions allowed for an FRR provider with a LER.

B. Algorithm

The main steps of the devised algorithm are generalized in Fig. 2 and henceforth explained.

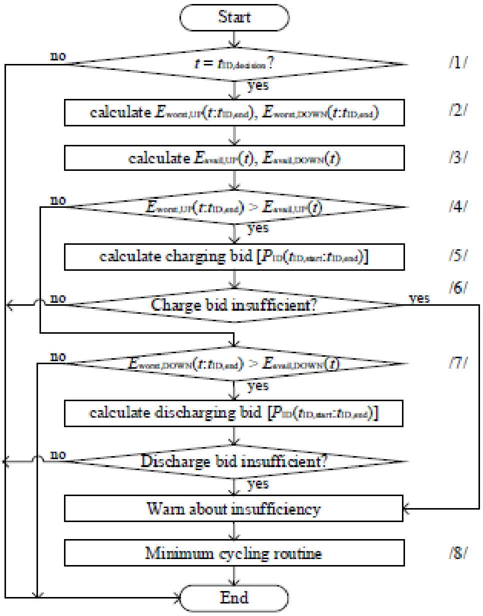

Figure 2. Main steps of the energy recovery algorithm

1) Check if the current timestep equals ID decision time. It depends on the closest ID GCT and bid preparation time:

$$t_{\mathrm{ID,decision}} = t_{\mathrm{ID,GCT,next}} - \Delta t_{\mathrm{prepare}}. \tag{1}$$

If it does, the remaining part of the algorithm is executed, otherwise the process can end for this time instance (it is then launched anew at the next time step).

2) Calculate the worst-case up-regulation (discharging) energy for the time interval from the current ID decision time to the end of the ID delivery period for which trading with the closest GCT is open, i.e. from t to $t_{\mathrm{ID,end}}$, where, as per Fig. 1:

$$t_{\mathrm{ID,end}} = t + \Delta t_{\mathrm{prepare}} + \Delta t_{\mathrm{ID,GCT}} + \Delta t_{MTU}. \tag{2}$$

Evidently, the necessary look-ahead horizon has a duration equal to the sum of $\Delta t_{\mathrm{prepare}}$, $\Delta t_{\mathrm{ID,GCT}}$ and Δt_{MTU}.

In general, the worst-case energy consists of the sum of fully activated FCR and FRR up-regulation reserves (according to the sold capacity) as well as the full delivery of prior ID trades:

$$E_{\mathrm{worst,UP}}\left(t : t_{\mathrm{ID,end}}\right) = \\ = \sum_{t_x = t}^{t_{\mathrm{ID,end}}} \left(\begin{pmatrix} P_{\mathrm{FCR,cap}}\left(t_x\right) + P_{\mathrm{FRR,UP,man}}\left(t_x\right) + \\ + P_{\mathrm{FRR,UP,vol}}\left(t_x\right) + P_{\mathrm{ID}}\left(t_x\right) \end{pmatrix} \cdot \frac{\Delta t}{(1\ \mathrm{h})} + \Delta E_{\mathrm{s.d.}}\left(t_x\right) \right), \tag{3}$$

where $P_{\mathrm{FCR,cap}}$ – FCR capacity at the particular time; $P_{\mathrm{FRR,UP,man}}$ and $P_{\mathrm{FRR,UP,vol}}$ – FRR up-regulation capacity due to mandatory and voluntary FRR bids respectively; P_{ID} – capacity to fulfill priorly scheduled ID trade (a negative value for charging trade); $\Delta E_{\mathrm{s.d.}}$ – expected self-discharge losses of the BESS. t_x denotes a timestep between the current time t and the look-ahead horizon end time $t_{\mathrm{ID,end}}$, the number of these steps depends on the selected granularity of the calculations denoted by Δt.

The loss expectation component assumes maximum self-discharge losses (i.e. as occurs when the SOC is at its maximum):

$$\Delta E_{\mathrm{s.d.}}\left(t_x\right) = k_{\mathrm{s.d.\%}} \cdot SOC_{\max} \cdot \frac{\Delta t}{(24\ \mathrm{h})}, \tag{4}$$

where $k_{\mathrm{s.d.\%}}$ is the self-discharge losses as a percentage of the SOC during one day, $SOC_{\max}$ is the permissible depth of charge.

It must be noted that the worst-case energy estimation (3) is valid for a conventional (non-LER) FCR resource. For LERs, there are special considerations since, as previously discussed, a LER does not have to endure full activation for the whole look-ahead horizon. Instead, in a worst-case scenario it has to deliver *nearly 50% activation* for 10 min and *nearly 100% activation* for 5 min (which would trigger the alert state [1]), followed by a *full activation* for 30 min (or 15 min) during the alert state to fulfill the T_{minLER} criterion (similarly as in [11]). Furthermore, if the alert state ends when the criterion is met, the LER still needs to be able to provide FCR continuously during the normal state, i.e. up to a 25% activation. For a safe and predictable LER operation transition from Normal to Reserve Mode after fulfilling the criterion, we add a requirement of another 5 min of full activation in the worst-case energy need estimation.

The outlined combination of worst-case FCR energy is trivial to calculate if the LER has an invariable capacity obligation (due to FCR market results) throughout the entire look-ahead duration. However, in principle, it is possible for the FCR capacity obligation to be different in each MTU within the horizon. This creates a combinatorial problem as there are numerous ways how the alert state and its preconditions could be temporally placed in the look-ahead horizon implying a multitude of potential FCR activation trajectories. Fig. 3 provides two examples, but the total number of alternatives depends on the calculation time granularity.

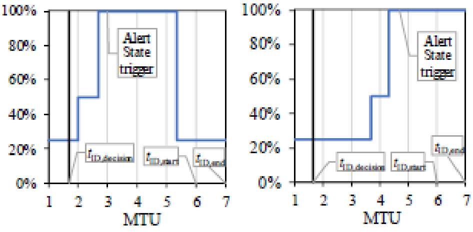

Figure 3. LER worst-case FCR activation temporal alternative examples

The worst-case up-regulation energy for a LER FCR provider can thus be expressed as:

$$E_{\text{worst,UP}}\left(t:t_{\text{ID,end}}\right)= = \sum_{t_x=t}^{t_{\text{ID,end}}}\left(\begin{pmatrix}P_{\text{FRR,UP,man}}\left(t_x\right)+\\ +P_{\text{FRR,UP,vol}}\left(t_x\right)+P_{\text{ID}}\left(t_x\right)\end{pmatrix}\cdot\frac{\Delta t}{(1\text{h})}+\Delta E_{\text{s.d.}}\left(t_x\right)\right)+ +E_{\text{LER,FCR,UP}}\left(t:t_{\text{ID,end}}\right) \tag{5}$$

where

$$E_{\text{LER,FCR,UP}}\left(t:t_{\text{ID,end}}\right)= =\max\left(\begin{matrix}\sum_{t_x=t}^{t_{\text{ID,end}}}\left(P_{\text{FCR,cap}}\left(t_x\right)\cdot\frac{\Delta f_{\text{s1}}\left(t_x\right)}{\Delta f_{\text{f.a.}}}\cdot\frac{\Delta t}{(1\text{h})}\right),\ldots,\\ \sum_{t_x=t}^{t_{\text{ID,end}}}\left(P_{\text{FCR,cap}}\left(t_x\right)\cdot\frac{\Delta f_{\text{s}N}\left(t_x\right)}{\Delta f_{\text{f.a.}}}\cdot\frac{\Delta t}{(1\text{h})}\right)\end{matrix}\right), \tag{6}$$

where $\Delta f_{\text{f.a.}}$ is the frequency deviation at which the FCR provider has to be fully activated and $\Delta f_{\text{s1}}(t_x)\ldots\Delta f_{\text{s}N}(t_x)$ are the frequency deviation alternatives.

The worst-case FCR activation alternative for a LER is thus identified by taking the one corresponding to the largest required energy as per (6). The found value is then input in (5).

However, a full enumeration as in (6) is only necessary if indeed the sold FCR capacity differs between the MTUs under consideration. Otherwise, if the FCR capacity is uniform, the worst-case LER FCR energy can be estimated using any of the alternatives (e.g. the right-side alternative in Fig. 3).

Once the worst-case up-regulation energy is estimated, the worst-case down-regulation energy requirement also needs to be assessed. The principle is the same as for the up-regulation in (3)–(6). The only differences are that now we look at the mandatory and voluntary FRR down-regulation bids (unlike FCR, FRR product is not symmetric), and that the self-discharge losses ($\Delta E_{\text{s.d}}$) are not considered as they do not worsen the situation in worst-case down-regulation scenario.

For both up- and down-regulation worst-case energy need considerations, a LER could, in principle, calculate the necessary energy as a non-LER (e.g. as in (3)). This would result in more active SOC management via ID trading, thus allowing a LER to accumulate more energy and exceed the T_{minLER} criterion (if desired). The priorly described approach, on the other hand, corresponds to conservative SOC management, the primary goal of which is to ensure meeting the minimum requirements a LER is subjected to (with a small safety margin) whilst taking advantage of the reduced FCR requirements for LERs.

3) The third step of the algorithm envisions calculating the energy available in the BESS for both up- and down-regulation. This primarily depends on the energy content in the reservoir at the current time t, its storage capacity and charge/discharge efficiency. The respective values can be calculated by:

$$E_{\text{avail.UP}}\left(t\right)=\left(SOC\left(t\right)-SOC_{\min}\right)\cdot\eta_{\text{disch}}, \tag{7}$$

$$E_{\text{avail.DOWN}}\left(t\right)=\left(SOC_{\max}-SOC\left(t\right)\right)/\eta_{\text{ch}}, \tag{8}$$

where $SOC(t)$ is the current energy content, $SOC_{\min}$ – the permissible depth of discharge, η_{disch} and η_{ch} – discharging and charging efficiency, respectively.

4) When both the worst-case energy and available energy are calculated for the respective activation directions, we check if the worst-case up-regulation energy exceeds the available one. If so, a charge (buy) ID bid is prepared. Otherwise, we check energy sufficiency in the other (down-regulation) direction.

5) The first step in preparing a charge bid is identifying the maximum capacity available for its execution in the respective delivery period:

$$P_{\text{ID,max}}\left(t_{\text{ID,start}}:t_{\text{ID,end}}\right)=-\begin{pmatrix}P_{\text{ch.max}}-P_{\text{FCR,cap}}\left(t_{\text{ID,start}}:t_{\text{ID,end}}\right)-\\ -P_{\text{FRR,DOWN,man}}\left(t_{\text{ID,start}}:t_{\text{ID,end}}\right)\end{pmatrix}, \tag{8}$$

where $P_{\text{ch.max}}$ is the total charging capacity of the BESS. At this point we do not consider voluntary FRR energy market bids since FRR energy market has a shorter GCT compared to ID (25 vs 60 min), thereby at the ID decision time no FRR obligations from the energy market should have been undertaken yet.

Finally, we calculate the power corresponding to the delivery of the required energy within Δt_{MTU}. The maximum of the two values corresponds to the charging bid that can be made:

$$P_{\text{ID}}\left(t_{\text{ID,start}}:t_{\text{ID,end}}\right)= =\max\begin{pmatrix}P_{\text{ID,max}}\left(t_{\text{ID,start}}:t_{\text{ID,end}}\right),\\ -\left(E_{\text{worst,UP}}\left(t:t_{\text{ID,end}}\right)-E_{\text{avail.UP}}\left(t\right)\right)\cdot\frac{1\text{h}}{\Delta t_{\text{MTU}}}\end{pmatrix}. \tag{9}$$

6) Next, we check if the prepared buy bid is sufficient to meet the worst-case up-regulation requirements. If it is found to be insufficient, namely

$$\left|P_{\text{ID}}\left(t_{\text{ID,start}}:t_{\text{ID,end}}\right)\right|\cdot\frac{\Delta t_{\text{MTU}}}{1\text{h}}<E_{\text{worst,UP}}\left(t:t_{\text{ID,end}}\right)-E_{\text{avail.UP}}\left(t\right), \tag{10}$$

then a warning is issued to the BESS operator. In principle, however, such a situation could only occur if the reserves to be provided by the BESS are oversized or if a worst-case scenario has already begun, in which case it is not necessarily a concern for the BESS operators since LER conditions give them ample time to recover post-alert state.

7) If a charge (buy) bid was not found to be necessary, we check if a discharge (sell) trade is needed to have the BESS ready for a worst-case down-regulation scenario realization.

The following steps are sufficiently similar as in the up-regulation case and thus will not be elaborated here.

8) The overall BESS management model should also include a specific subroutine for cases when BESS has been idle for a prolonged period and sequential ID trades to ensure minimum cycling conditions might have to be scheduled. However, due to space limitations, this has been left out of scope of this paper.

III. VALIDATION

In the following example, we show the performance of the devised BESS SOC management strategy in a counterfactual scenario which includes prolonged activation of the committed FCR and FRR in the same direction. This allows validating the ability of the proposed approach to indeed withstand the occurrence of a worst-case scenario. While the real-life realization of such a scenario is a low-probability event, it would however be a high-impact non-compliance if the BESS failed to deliver reserves in accordance to its obligations.

We assume a BESS with 80 MW charge/discharge capacity, 160 MWh rated storage, 0.95 charge and discharge efficiencies, reservoir limits 10% and 90%. The BESS has to provide 8 MW of FCR and 32 MW of FRR in each direction. The selected parameters have been derived from the estimated reserve needs in the Latvian power system after desynchronization from the IPS/UPS in 2025 and from the specification of BESS that is being discussed for installation in Latvia [15].

In terms of reserve activations, for FCR we assume a six-hour frequency deviation profile as depicted by the brown line / right axis in Fig. 4 (NB: FCR providers observe a ±10 mHz dead-band followed by a proportional response reaching a full activation at ±200 mHz deviation). This profile is entirely artificial as its only purpose is to demonstrate that the devised BESS management strategy can ensure the reserves as expected. The FRR activations are likewise simulated to enforce a worst-case scenario realization (i.e. full activation for the entire six hours).

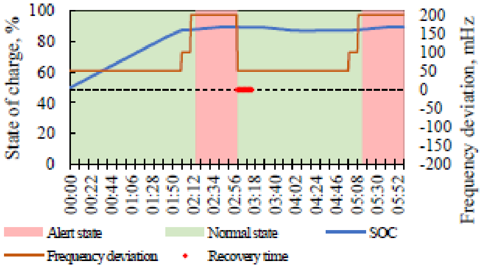

Figure 4. Simulated frequency deviation and LER SOC evolution

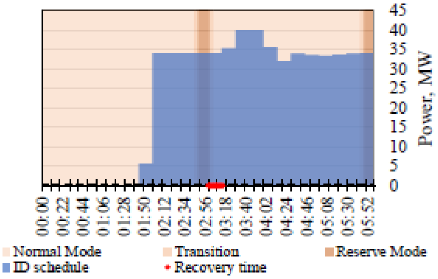

Figure 5. The schedule of corrective ID trades and FCR provision mode

In the simulated scenario, the BESS is able to continuously provide a 25% FCR activation during the normal state of the power system together with a full FRR activation without any issues. At 2:15 an alert state is declared due to frequency deviation exceeding 50 mHz for 15 minutes and 100 mHz for 5 minutes. The LER starts transition to Reserve Mode only at 2:44 when the 30 minute T_{minLER} criterion has been fulfilled. At 3:00 the alert state ends due to the frequency deviation dropping slightly below 50 mHz, at which point the 2-hour countdown for LER recovery starts. However, the LER already completes the recovery at 3:16, which means that it only required 16 min to be completed.

This is due to the robust nature of the storage management algorithm. It is also partly because of the fact that scheduled future ID deliveries are taken into account when evaluating the recovery conditions, provided that there is no risk of violating the SOC constraints at any point in the considered future time horizon. At 5:15 another alert state is declared and again the LER only starts transition to the Reserve Mode once 30 min of full activation have been endured.

From Fig. 4 it can be seen how the SOC trajectory approaches the upper constraint of 90% but does not violate it, instead remaining near it. Moreover, thanks to the scheduled ID deliveries (Fig. 5), the LER can even guarantee continued capability to provide the required FCR and FRR despite the SOC presently being close to the constraint.

IV. CONCLUSIONS

The validated market-based BESS SOC management strategy enables robust and reliable LER participation in FCR provision, meeting all the additional properties and regulatory provisions that FCR providers with LERs are subjected to in Continental Europe. It is also suitable for LERs providing both FCR and FRR. The devised strategy can be applied to prospective BESS installations in the Baltic power system after synchronization with CE and also elsewhere in the EU as it follows the most recent regulations to be adopted by the Member States. Moreover, the tool allows testing the impact of important technical parameters and market settings to aid in decision-making.

The crux of the offered approach is anticipating and preparing for the emergence of a worst-case scenario. Due to paper size limits, only a part of the overall BESS operational management strategy has been presented which, among other aspects, also manages the LER's transition between Normal/Reserve Mode and estimates the voluntary FRR energy bids. Hence, elaboration of the additional model components and features remains a venue for future work.

Furthermore, the mathematical model developed to simulate and validate the outlined strategy could be used in future work to study the impact of BESS technical parameters on their reserve provision capabilities as well as the impact of market regulations on BESS performance. The potential topics of future studies include BESS and reserve sizing, pros and cons of qualification as a LER, duration of the T_{minLER} criterion, recovery duration, market lead time etc. Moreover, the model can be extended to also consider diverse economic criteria to ultimately provide a comprehensive cost-benefit assessment of a LER-qualified BESS with varied control strategies.

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