Implementation of Green and Digital Technologies in International Educational Environment, October 03-10, 2022

Latvian EPS in the long term: the challenge and possible solutions for grid inertia maintaining.

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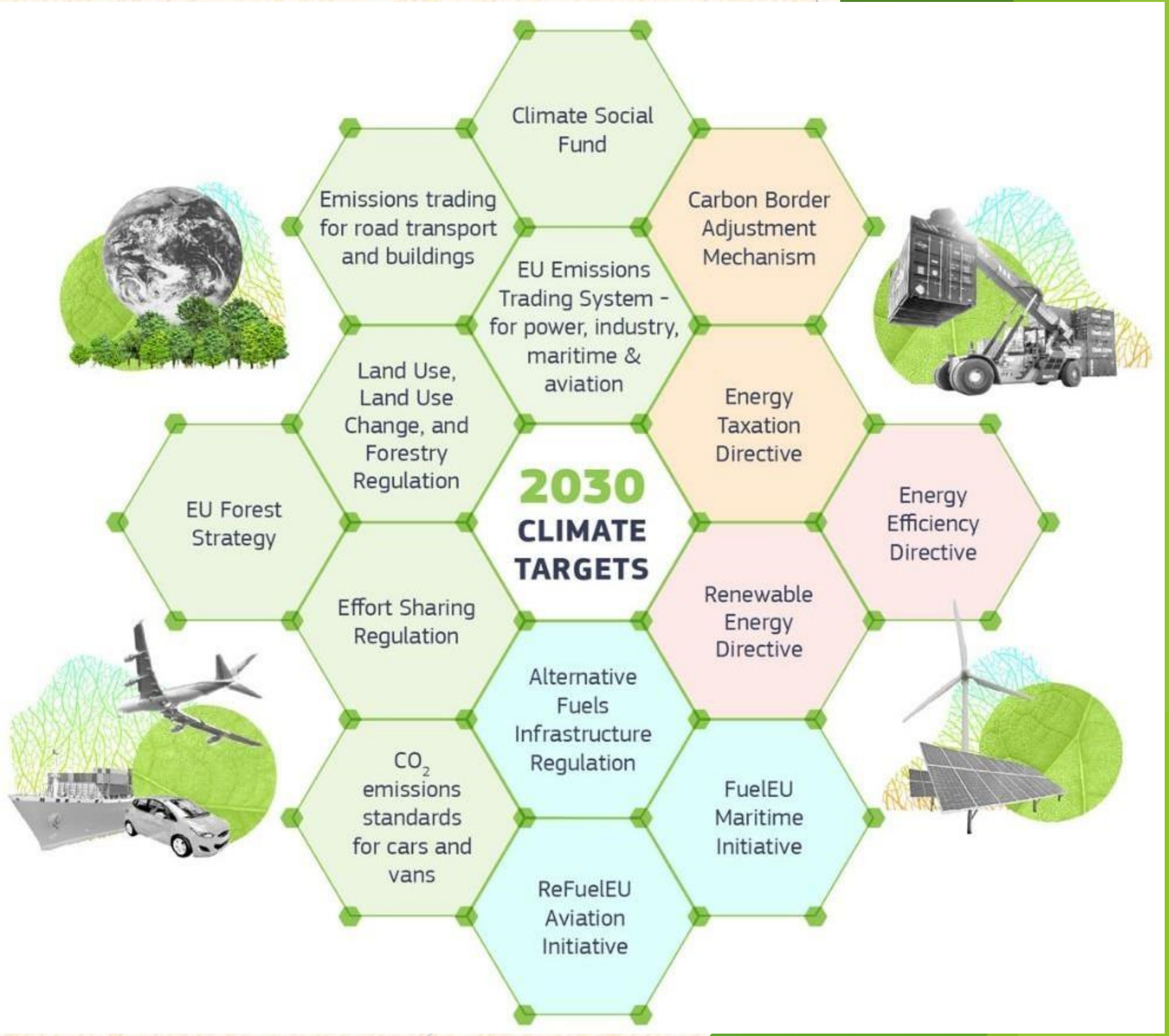
INTRODUCTION

National targets is an emerging set of actions to provide navigation towards a low-carbon future targeting the energy sector.



2030 CLIMATE TARGETS

Climate Social Fund

Emissions trading for road transport and buildings

Carbon Border Adjustment Mechanism

EU Emissions Trading System - for power, industry, maritime & aviation

Land Use, Land Use Change, and Forestry Regulation

Energy Taxation Directive

EU Forest Strategy

Energy Efficiency Directive

Effort Sharing Regulation

Renewable Energy Directive

Alternative Fuels Infrastructure Regulation

CO_2 emissions standards for cars and vans

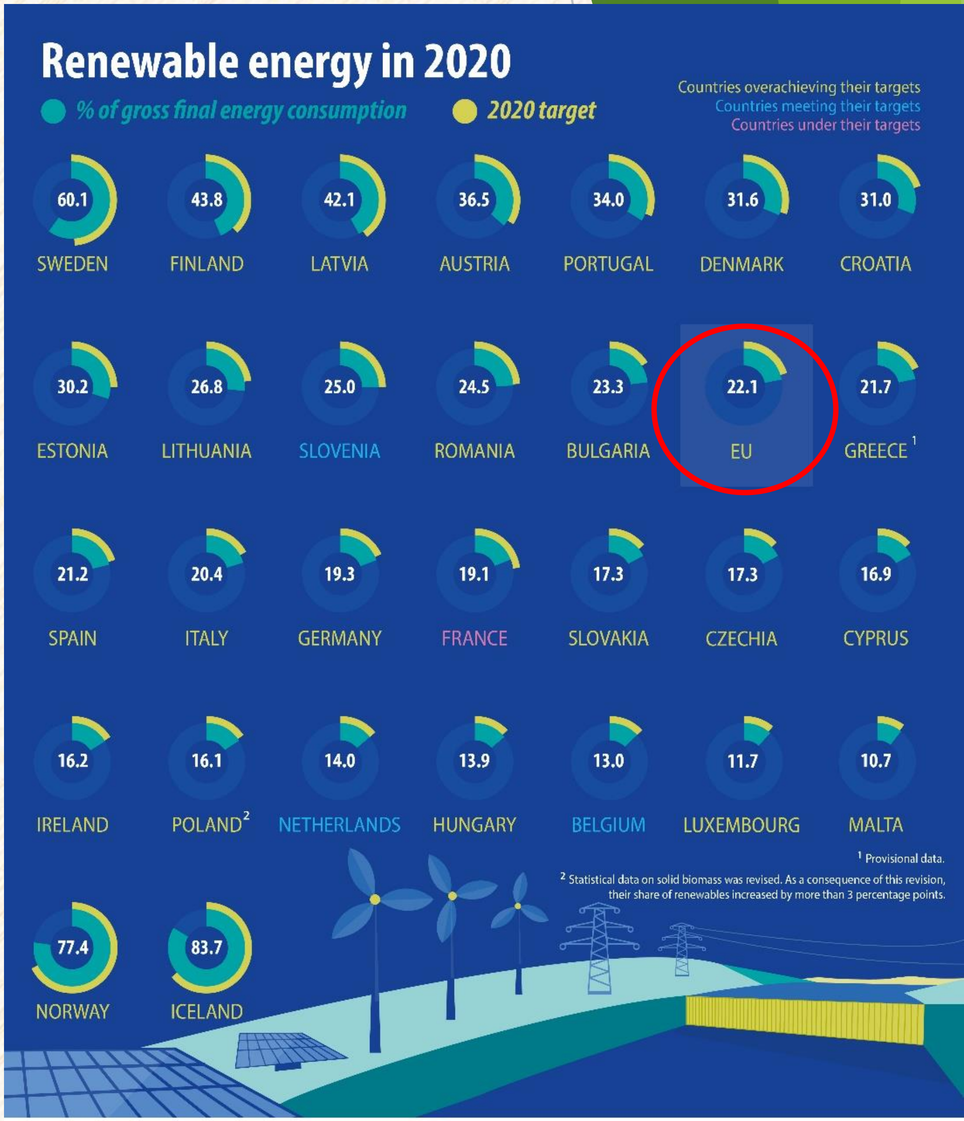
FuelEU Maritime Initiative

ReFuelEU Aviation Initiative

Despite the increase in the share of renewable energy sources worldwide is relatively small, cross-border carbon regulation has become part of the Paris Agreement aimed at achieving zero carbon emissions in sectors that account for more than 70% of global emissions by 2030. This is planned to be done through the energy transition — ***the process of replacing the coal economy with renewable energy sources (RES).***

In 2020, renewable energy represented ***22.1 %*** of energy consumed in the European Union (EU), around 2 percentage points above the 2020 target of 20 %.

In the first half of 2020, about 40% of the total electricity of the EU was produced from renewable sources.



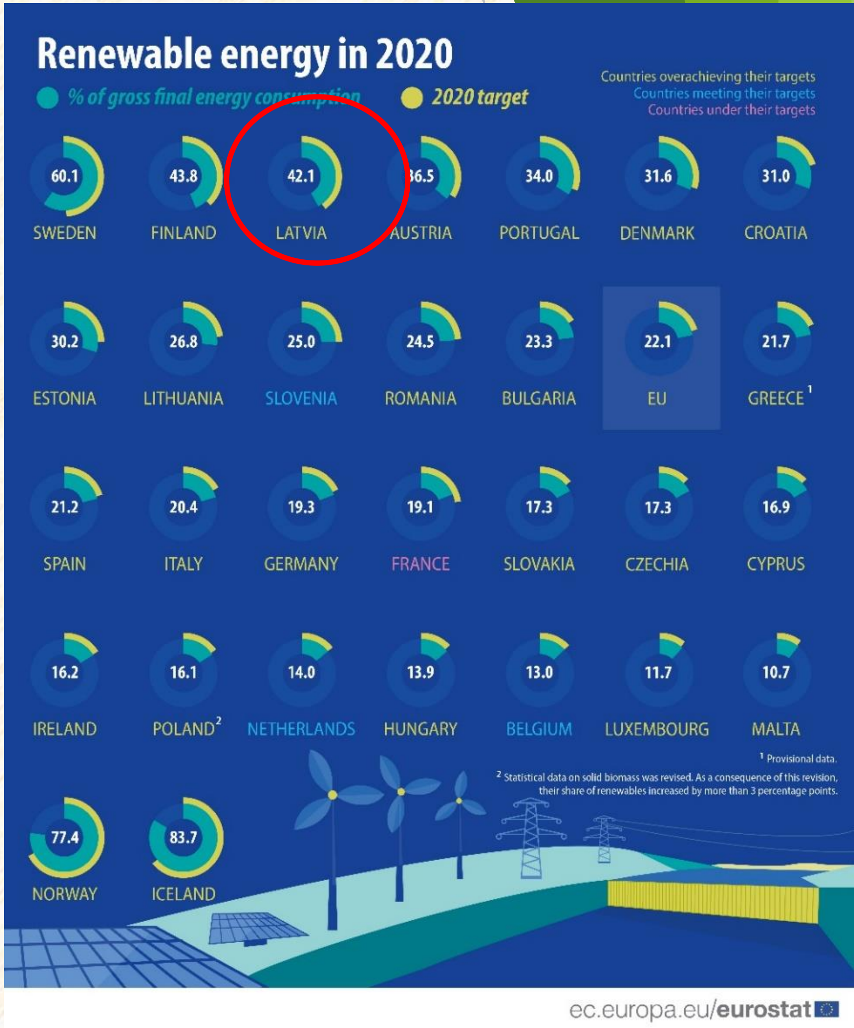
Share of energy from renewable sources, %

ec.europa.eu/**eurostat**

Latvia's National Long-Term Strategy and National Energy and Climate Plan were adopted in January 2020. ***Energy security, broader sources of renewable energy, and energy efficiency are the three important dimensions of Latvia's energy policy.***

Latvia plans to fully integrate into EU energy markets and modernise its energy infrastructure. This will increase the use of RES technologies in industry as well as in electricity and heat supply. ***By 2027, 47.5% of total energy consumption is expected to come from RES.***

Share of energy from renewable sources, %



Renewable energy in 2020

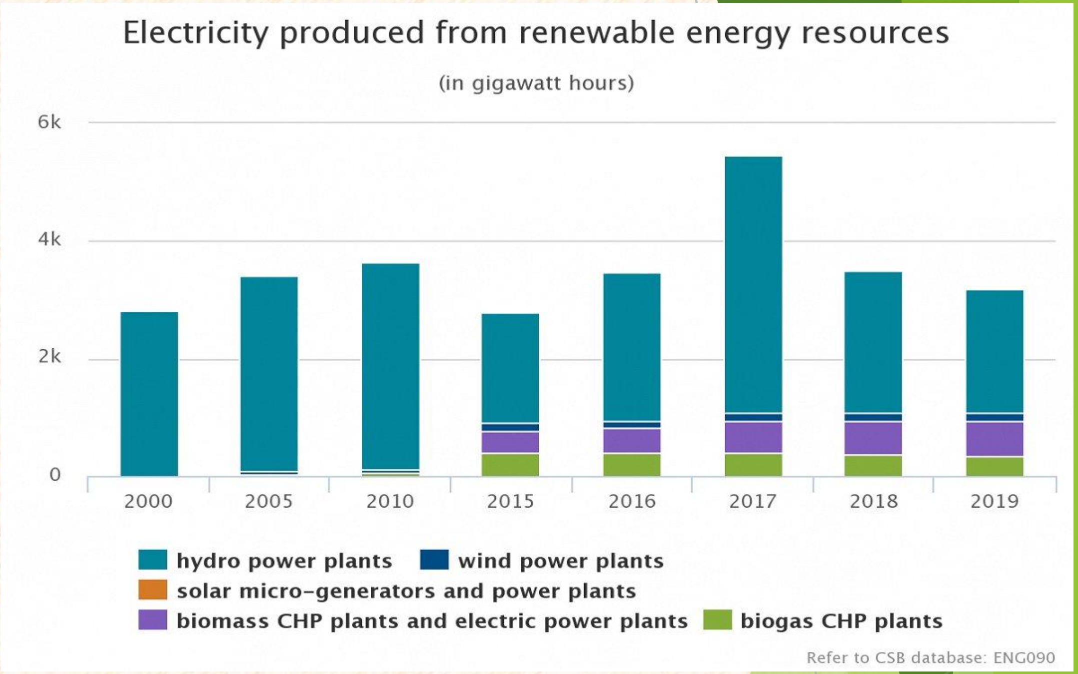
[1] Provisional data.

[2] Statistical data on solid biomass was revised. As a consequence of this revision, their share of renewables increased by more than 3 percentage points.

ec.europa.eu/eurostat

The use of RES in the energy sector will increase and they will fully replace fossil energy sources by 2050.

According to the Strategy of Latvia for the Achievement of Climate Neutrality by 2050, the use of RES in the energy sector will have been promoted by supporting the obtaining of wind and solar energy.



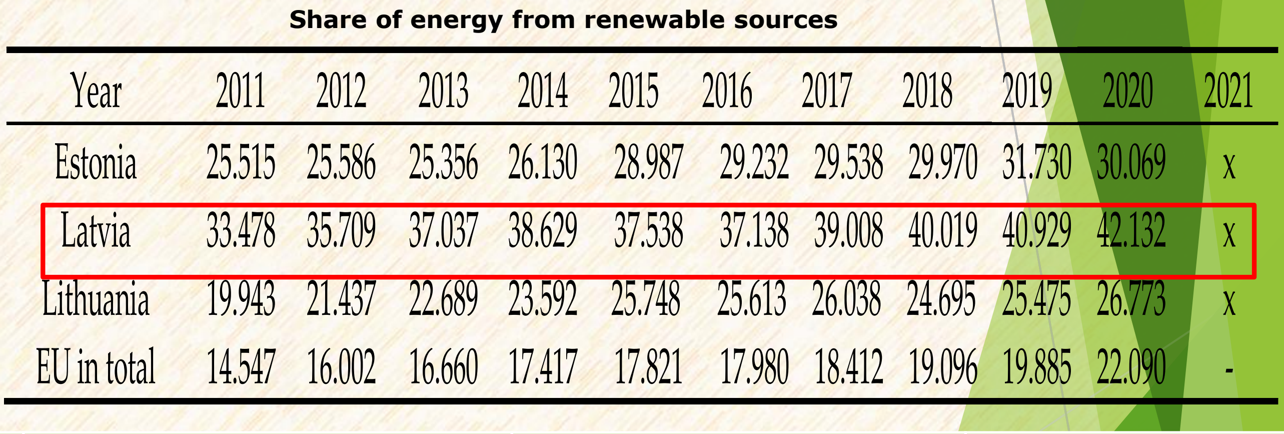
Refer to CSB database: ENG090

Now, the most significant types of RES in Latvia are hydroenergy, wind energy, biogas, and biomass, however, a visible amount of energy is also expected to receive from solar, geothermal/hydrothermal energy.

All the three Baltic countries have serious plans for the development of ***offshore wind energy*** for the nearest future. Lithuania, for example, intends to commission at least 700 megawatts (MW) of offshore wind farms by 2030.

Latvia and Estonia are also considering the possibility of jointly building a 1,000 MW joint wind farm in the Gulf of Riga.

In addition, Estonia wants to build a 1,000 MW offshore wind farm near the island of Saaremaa by 2028, in addition to many other projects that are under consideration.



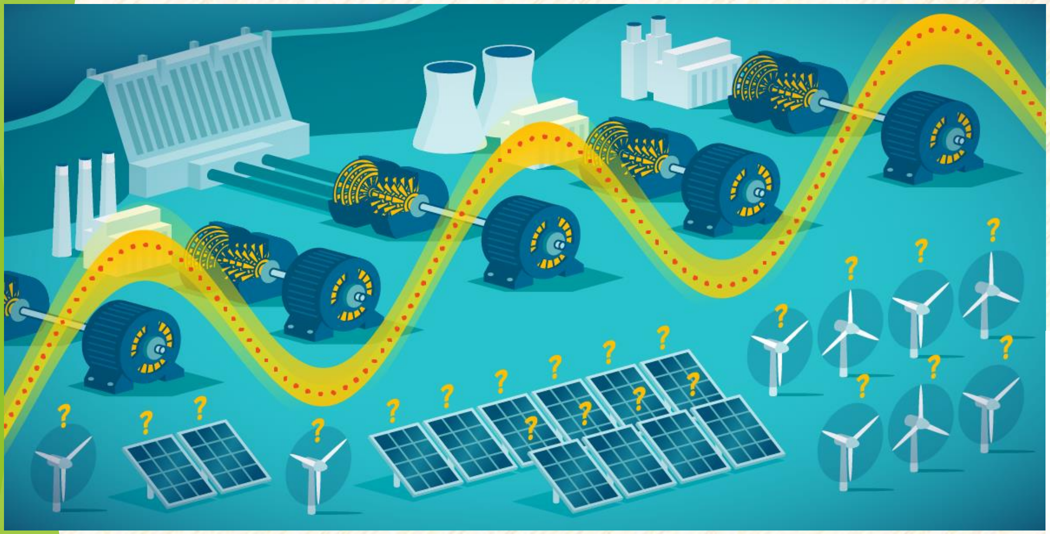
Share of energy from renewable sources

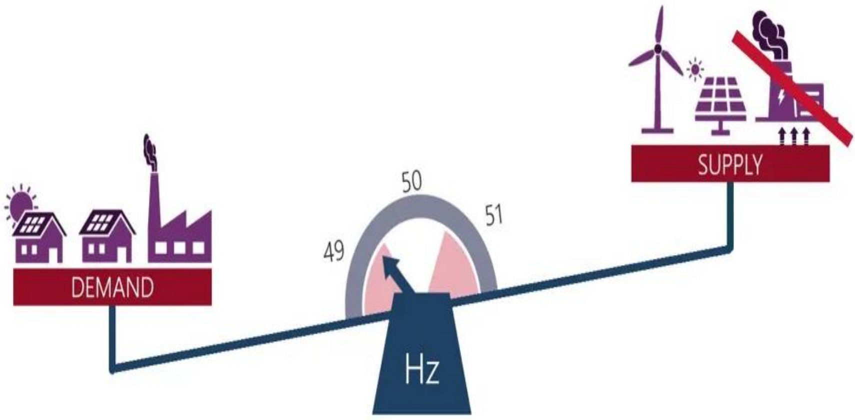
Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Estonia	25.515	25.586	25.356	26.130	28.987	29.232	29.538	29.970	31.730	30.069	x
Latvia	33.478	35.709	37.037	38.629	37.538	37.138	39.008	40.019	40.929	42.132	x
Lithuania	19.943	21.437	22.689	23.592	25.748	25.613	26.038	24.695	25.475	26.773	x
EU in total	14.547	16.002	16.660	17.417	17.821	17.980	18.412	19.096	19.885	22.090	-

Installed offshore wind power capacity, MW (2019)		2050 Low	2050 Central	2050 High
Estonia		900	1530	2880
Latvia		620	1290	3470
Lithuania		960	1960	4950
In total		**2480**	**4780**	**11300**

More than, according to a ***recent study*** by Wind Europe, the Baltic Sea could be the next important factor for Europe's energy transition. It is estimated that by 2050 Lithuania may have up to 3,600 MW, Latvia - up to 2,900 MW, and Estonia - up to 1,500 MW of offshore wind farms.

All this sounds tempting, but it is not only great news, but also a new challenge for the network.





Three main development trends are changing the transmission and distribution systems of power energy

DECARBONIZATION

- **Increasing the share of generation from RES;**
- **Shutting down of classic incinerated fuel power plants and nuclear power plants;**
- **Transition from classical rotating generators to generation based on power electronics;**
- **Generation with a significant degree of volatility and unpredictability**

DECENTRALIZATION

- Location of generating stations in places where there is a primary energy source (wind, solar radiation);
- The emergence of producing consumers;
- Redistribution of power flows with an increase in consumption volumes;
- The need to expand the network and build new power lines faces significant public resistance

DEREGULATION

- Market division of electricity generation, transmission and distribution;
- The emergence of free electricity markets, such as "for the day ahead", "intraday";
- Interregional and interstate interconnection of networks and free trade in electricity

The power balance and network topology are dynamically changing

Additional measures are needed to ensure static and dynamic stability within the existing power system

What does it mean to ensure the stability of the energy system in the conditions of new directions of development?

Active Power Balance and Frequency

GENERATION:

- High proportion of generation based on power electronics;
- **Reduction of inertia of the system;**
- Reduction of short circuit power;
- High volatility;
- Distance from consumption centers;

CONSUMPTION:

- Increased consumption;
- Concentration in large centers /cities

Reactive Power Balance and Voltage

GENERATION (COMPENSATION):

- Shutdown of large generators;
- With an increase in consumption, priority is given to active power with a limited supply of generator power;

CONSUMPTION:

- Long connections between the centers of generation and consumption, increased inductance and network capacities;
- Dynamic power surges

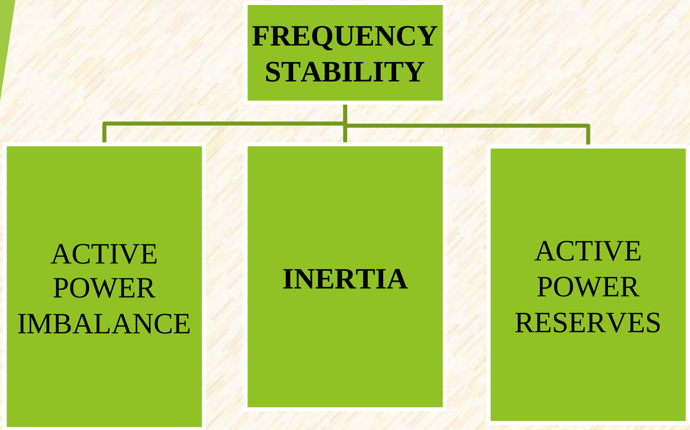
Redistribution of power flows

- Significant increase in currents and overload of individual sect;ions of the network/ lines
- Network bandwidth limitations;
- Redistribution with violation N-1 criteria;
- High cost of re-dispatching

Keeping the values of frequency, voltage and currents within acceptable limits during static and dynamic processes

theoretical background

One of the main factors contributing to the stability of the frequency of the power system, in addition to the magnitude of the imbalance of active power and available reserves, is the level of synchronously coupled ***kinetic energy (inertia)*** accumulated by rotating parts of large generators and industrial engines inside this system, which is released in the event of a change in its frequency.



Factors determining the stability of the power system frequency.

$$H = \frac{1}{2} \cdot \frac{I \cdot \omega^2}{S} = \frac{E_k}{S},$$

where $E_k = \frac{1}{2} I \cdot \omega^2$ - kinetic energy, *MW·s; I* – a moment of inertia, *J*; *ω* - angular frequency, *radians per second; S* - power, *MVA*, which is provided by the rotation of large mass generators and turbines in conventional power plants, thus allowing to smooth out frequency fluctuations

Increasing the power of the synchronous machine (SM) in the first seconds of the transition mode (***inertial response***) **ΔP_i** is a function of constant inertia, installed SM power, and system frequency. It is described by the following dependence:

$$\Delta P_i = H_i \cdot P_i \frac{\partial f_{sys}}{\partial t},$$

where H_i –inertia constant of the *j-th* generator, sec; P_i - installed power of the unit, MW; f_{sys} - system frequency, Hz.

Traditionally, ***inertia response*** has not been considered to be an extra service but has instead been considered as a natural characteristic of the power system. Inertia was provided by the rotation of generators, large-mass turbines at "traditional" power plants, and allows to smooth out frequency fluctuations.

With the evolution of power generation, inverter-based resources such as renewable power and battery storage are now connected to the grid. However, **these systems do not provide any inertia as both wind and solar energy are connected to the grid without a direct rotating mass, which is needed for the inertia**.

So what happens when the inertia decreases? As a basic rule, ***if the inertia is low, then the sudden changes that are experienced by the signal frequency are more significant, i.e. there may be larger difference or the change may be more rapid. This makes it more challenging to maintain the variation of the signal frequency in the normal range*.**

If an increasing share of electricity generation based on unconventional RES is added to power systems of this type, one of the consequences is ***a significant reduction in the equivalent inertia of the system.***

As a result, ***the same level of imbalance of electricity supply and demand will have a greater impact on the system frequency with low inertia rather than with high. In turn, the problem of the lack or absence of stored energy could become especially acute in the event of an emergency failure of large power plants, not allowing them to fill the lack of power quickly and temporarily.***

It should be noted that especially acute the problem of inertia conservation focus on ***small isolated systems***, the inertia of which is much lower than the inertia of large interconnected systems.

In addition, the ratio of the magnitude of the possible shutdown of generation to the total rotational power for such isolated systems is usually relatively large, and, as a result, they are ***more often subject to operational problems caused by large voltage surges from generators connected via frequency converters.***

Therefore, the issue of maintaining such network reliability by network operators remains extremely relevant. The irregular production of electricity from RES leads to a need of increasing both the flexibility of the remaining generation and the level of power reserves in the energy system.

At the same time, the massive integration of variable generation is related to the issue of reducing the total inertia of the power system, which has a great negative impact on the frequency management of the integrated renewable power system and its dynamic reliability at whole.

The consideration of the last highlighted concern is included in ENTSO-E Ten-Year Network Development Plan 2020 as one of the main topics.

IT WILL BE STRONGLY REFLECTED IN THE BALTIC REGION COUNTRIES, WHERE THE UNIFIED ENERGY POWER SYSTEM IN A LONG TERM WILL EXPERTISE MAJOR CHALLENGES CONSIDERING BOTH TECHNICAL AND ECONOMIC ISSUES.

STATEMENT OF THE PROBLEM

The Latvian electricity transmission system developed as a scarce power system until 2007.

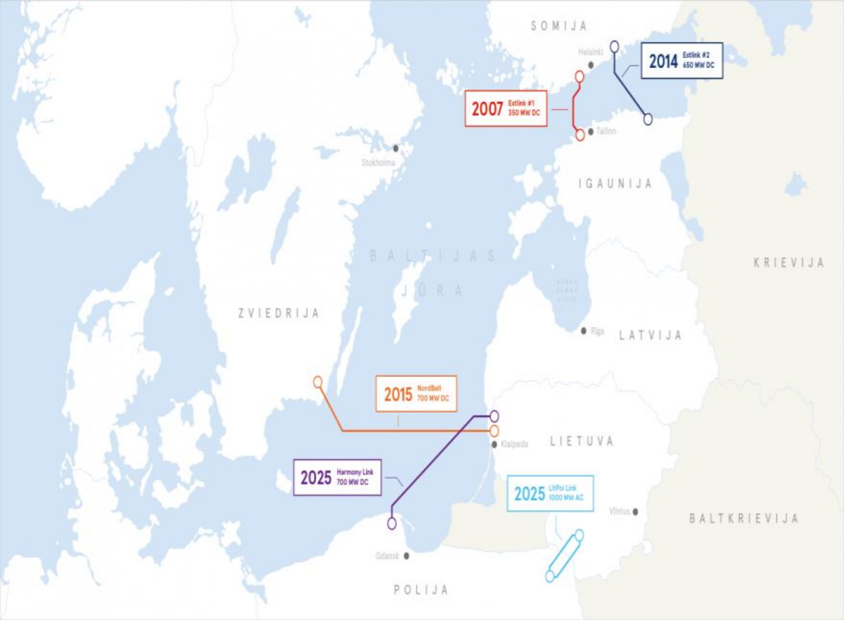
It was developing the expansion of the transmission network and paying less attention to the construction of new generating capacities since there was a constant opportunity to buy the necessary amounts of electricity from neighbouring power systems with sufficient capacity reserves, including for frequency regulation.

Preliminary operation scheme for Baltic countries system (BALTSO) in isolated model

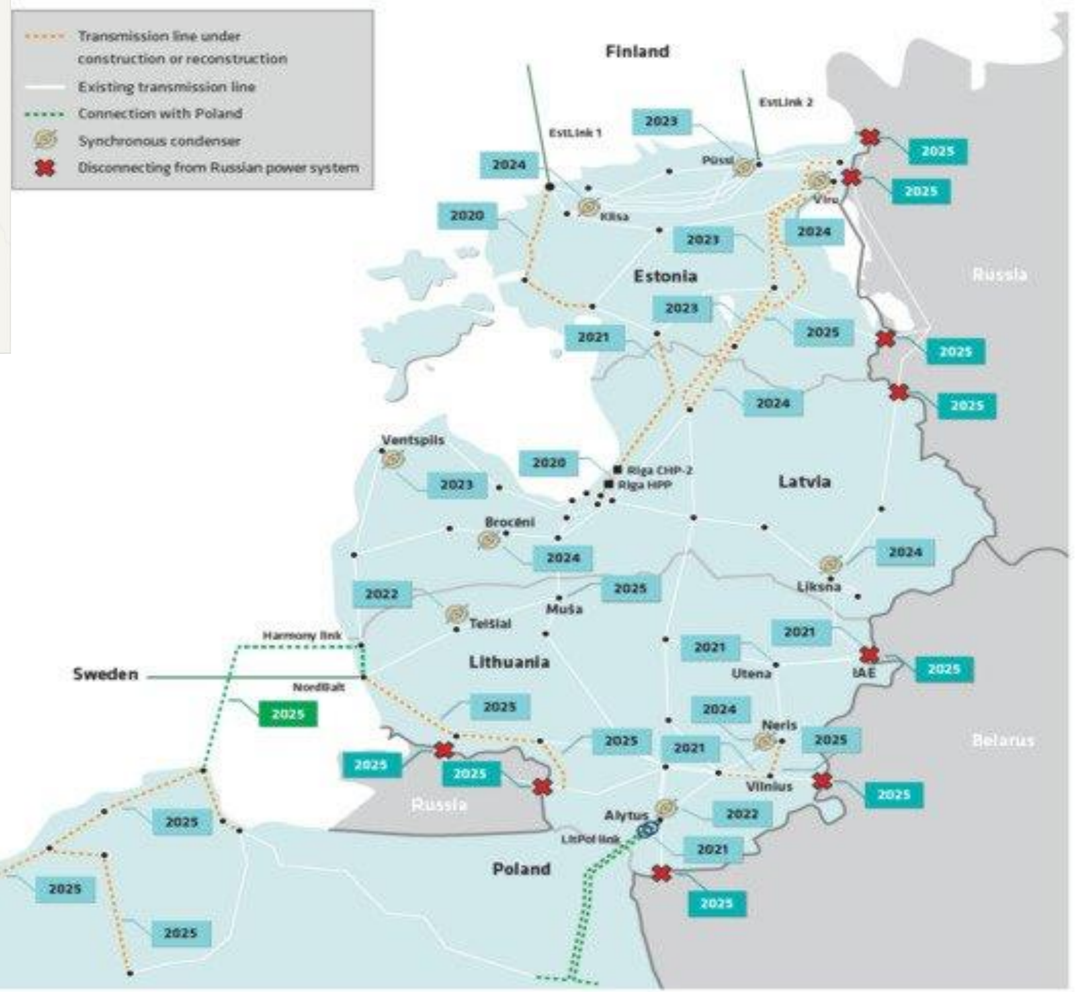
Desynchronization of the Baltic States' power system with the Unified Power System of Russia (UPS) synchronous area, followed by synchronization with the European Network of Transmission System Operators (ENTSO-E) is planned for 2025. However, in this regard it should be noted that this important step to national safety has also some negative aspects: ***it will increase the need for frequency and balancing reserves including concerns related to stopping the operation of uncompetitive thermal power plants.***

It will become a serious test of the Baltic States' power system readiness to independently provide the necessary inertia, as well as maintain a sufficient level of network frequency, ***especially acute of its operation in the island mode***: a transitional period during resynchronization as well as after the completion of the last - in case of planned or unplanned outages of the two-circuit synchronous connection between the Baltic power systems and ENTSO-E located on the Lithuania-Poland border.

Thus, to avoid a potential shortage of energy supply and to balance capacities after switching to synchronous operation with the continental European power system, the operators of the Baltic transmission system should be able to independently provide both load and frequency regulation by creating additional reserves for such purpose, and to avoid disruption of the stable operation of the whole power system.



Development of power transmission networks in the Baltic region up to 2025



POWER SYSTEM OPERATION

Stable

Frequency is regulated within strict limits of the requirements

Unstable

The frequency of the system will change at a rate initially determined by the inertia of the entire system

- *To assess the impact of the reduced synchronous inertia on the dynamics of the power system.*
- *To determine its critical minimum.*
- *To propose and take measures to increase the inertia.*

The problem of maintaining the balance of power and frequency within normal operating limits must be investigated.

To decrease the risk of electricity supply shortages in the near and long-term future potential solutions must be proposed.

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Evaluation of Inertial Response and Frequency Regulation in the Long-term Based on the Development Strategy of the Latvian Power System

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*The main aim of the investigation was to study **the problem of maintaining the balance of power and frequency within normal operating limits based on the example of a simplified model of the Latvian power system** developed in the Siemens PSS/E environment.*

The frequency response of the power system model has been investigated for both current and future development scenarios considering a significant increase in the share of generation from wind farms as well as the expected energy system synchronization of the Baltic States with the energy systems of continental Europe in 2025.

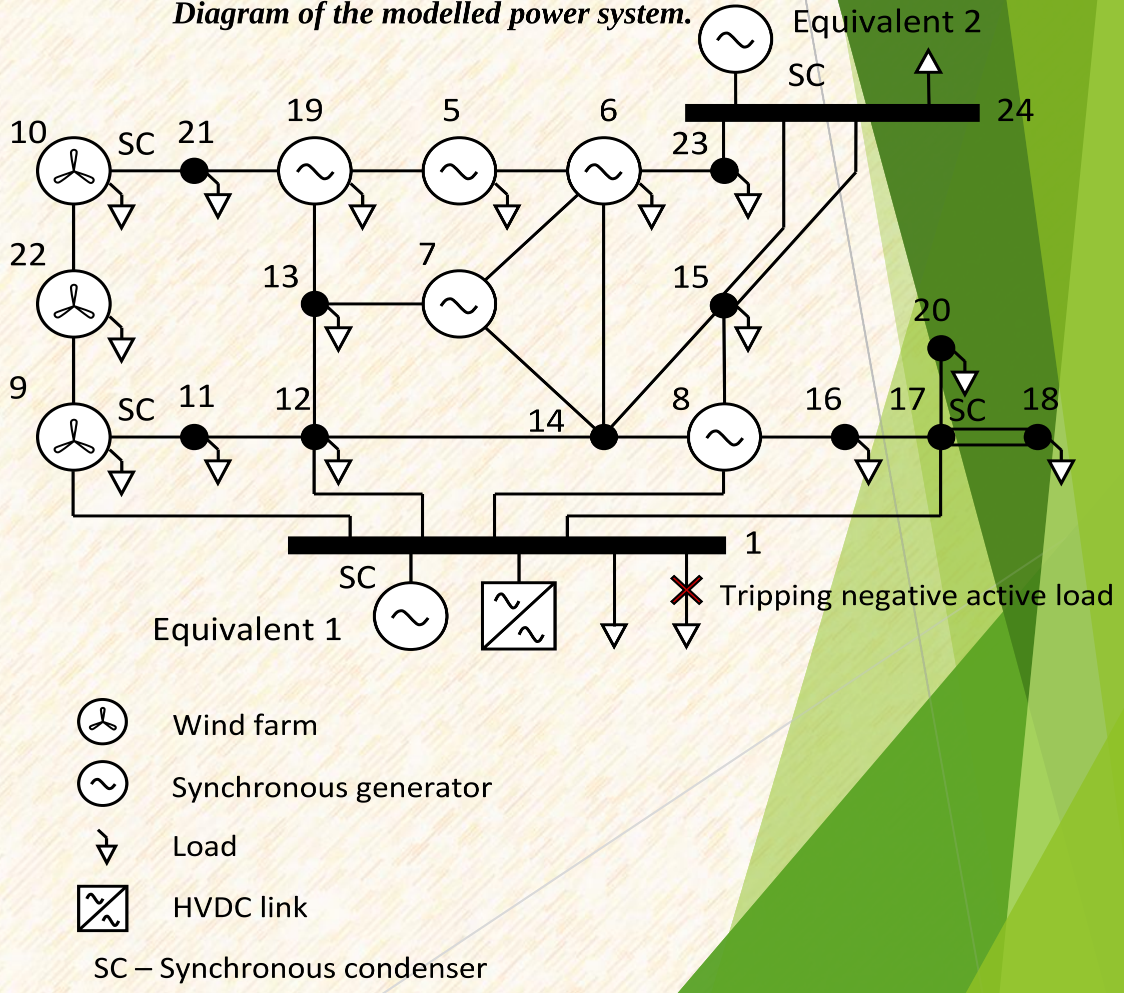
To ensure stable operation and management of a modern power system, it is necessary to assess not only the impact of this reduced synchronous inertia on the dynamics of the power system but also to determine the critical minimum, as well as propose and take measures to increase it.

In this study, as a solution, the combined use of synchronous capacitors and energy storage devices is proposed in case of sudden power changes in generation or load.

CASE STUDY BASED ON THE LATVIAN POWER ENERGY SYSTEM

The analysis is based on a long-term development strategy implying a significant increase in the share of wind generation (***construction of an offshore wind farm with a total capacity of 800 MW, which exceeds the current volume by fifteen times***).

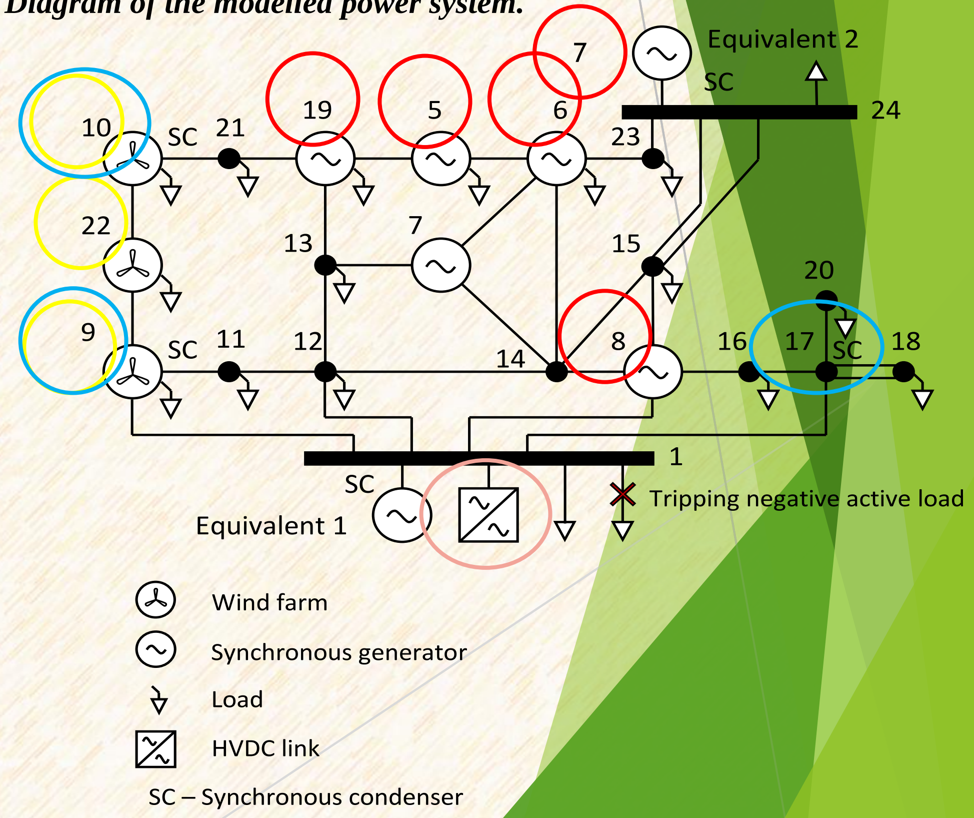
Diagram of the modelled power system.



The nodes of the model are marked with numbers. The model contains 24 nodes and 31 power lines of 330 kV, 5 conventional power plants at nodes 5, 6, 7, 8, and 19, three wind parks at nodes 9, 10, and 22, and three synchronous condensers at nodes 9, 10 and 17. Neighbouring power systems, Lithuanian and Estonian, are modelled by power system equivalents 1 and 2.

The equivalents contain synchronous generators, synchronous condensers, and loads. Additionally, the HVDC link representing HVDC interconnections with Nordic and Polish power systems is added at node 1. The output or the HVDC device is set to zero and only its transient response to frequency deviation is simulated. ***At node 1, a fictitious negative load of negative 400 MW is modelled***.

Diagram of the modelled power system.



The ***total load*** of the modelled power system is ***2069 MW*** and is shared among the ***Latvian power system*** (***995 MW***) and ***equivalents*** (***1074 MW***).

Synchronous generators of power plants and synchronous condensers have been modelled by ***standard dynamic models.***

The parameters used in the models are typical.The main parameters of power plants and synchronous condensers related to frequency response characteristics are listed in the next Table:

The main parameters of power plants and synchronous condensers

Bus Number	Technology	Apparent capacity (MVA)	Output power (MW)	Inertia H, s	Droop, p.u.
G1	Equivalent 1	1000	649	2.5	0.05
SC1	SC	600	-6	8	-
G5	CHP	16	10	2.5	0.05
G6	CHP	95	61	2.5	0.05
G7	HPP	192	123	4	0.05
G8	HPP	385	246	4	0.05
G9	WPP	310	197	-	-
SC9	SC	200	-2	8	-
G10	WPP	77	49	-	-
SC10	SC	200	-2	8	-
SC17	SC	200	-2	8	-
G19	CHP	8	3	2.5	0.05
G22	WPP	77	49	-	-
G24	Equivalent 2	864	700	2.5	0.05
SC24	SC	600	-6	8	-
Total synchronous generation		4360	1774		
Total non-synchronous generation		464	295		

THE MAIN PARAMETERS OF POWER PLANTS AND SYNCHRONOUS CONDENSERS

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SC9	SC	200	-2	8	-
G10	WPP	77	49	-	-
SC10	SC	200	-2	8	-
SC17	SC	200	-2	8	-
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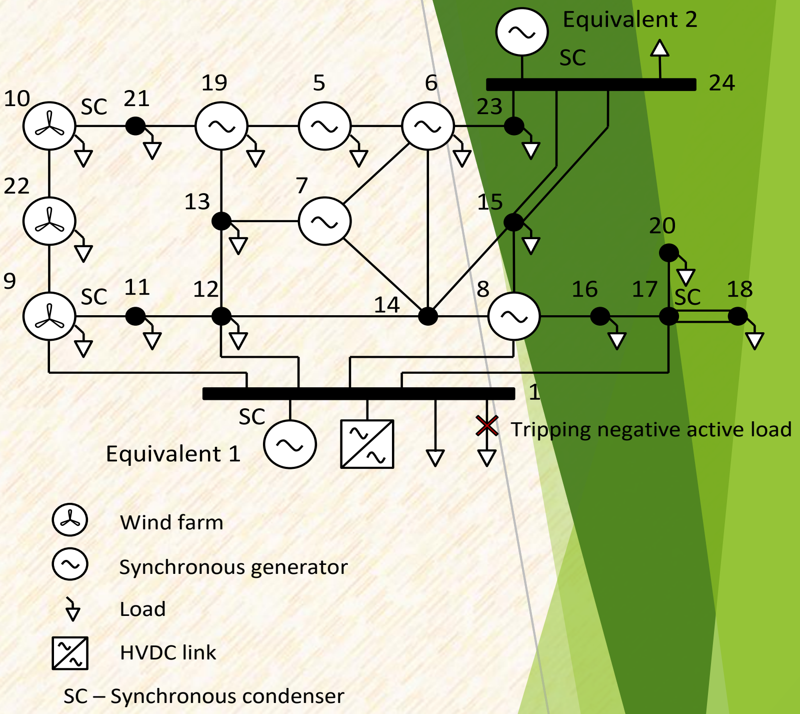


The capacity of the HVDC link at node 1 is ***700 MW***. It is assumed that the droop of the HVDC link is 2% and the maximum contribution to frequency response is ***50 MW***.

Additionally, contribution to frequency containment of energy storage system (ESS) is simulated.

In large-scale interconnected power systems, such as Continental European Synchronous Area, the Standard frequency range is ±50 mHz, maximum instantaneous frequency deviation is 800 mHz, and maximum steady-state frequency deviation is 200 mHz. This means that ***the frequency must not fall below 49.2 Hz during the transient caused by active power imbalance and must be at least 49.8 Hz after the activation of frequency containment reserve (FCR).*** However, such requirements are difficult to meet for a relatively small power system operating in island mode.

Following the example of Ireland and Nordic power systems, it is assumed that the requirements of the Baltic power system operating in island mode should be relaxed. ***Subsequent analysis assume that the minimal instantaneous frequency can be as low as 49.0 Hz and the quasi-steady-state value can be as low as 49.5 Hz.***

Nine cases corresponding to different penetration levels of non-synchronous generation (WPP) have been analyzed. ***The detailed parameters of all cases are provided in Table.*** **The base case, or case A,** represents a situation when conventional power plants in Latvia generate 443 MW, wind farms generate 295 MW, and synchronous generators of neighbouring countries generate 1359 MW. In this case, the penetration of wind generation is **14%.** Each other case (cases from B to I) represent situations with higher wind penetration in steps from 61 to 200 MW.

DESCRIPTION OF ANALYZED CASES

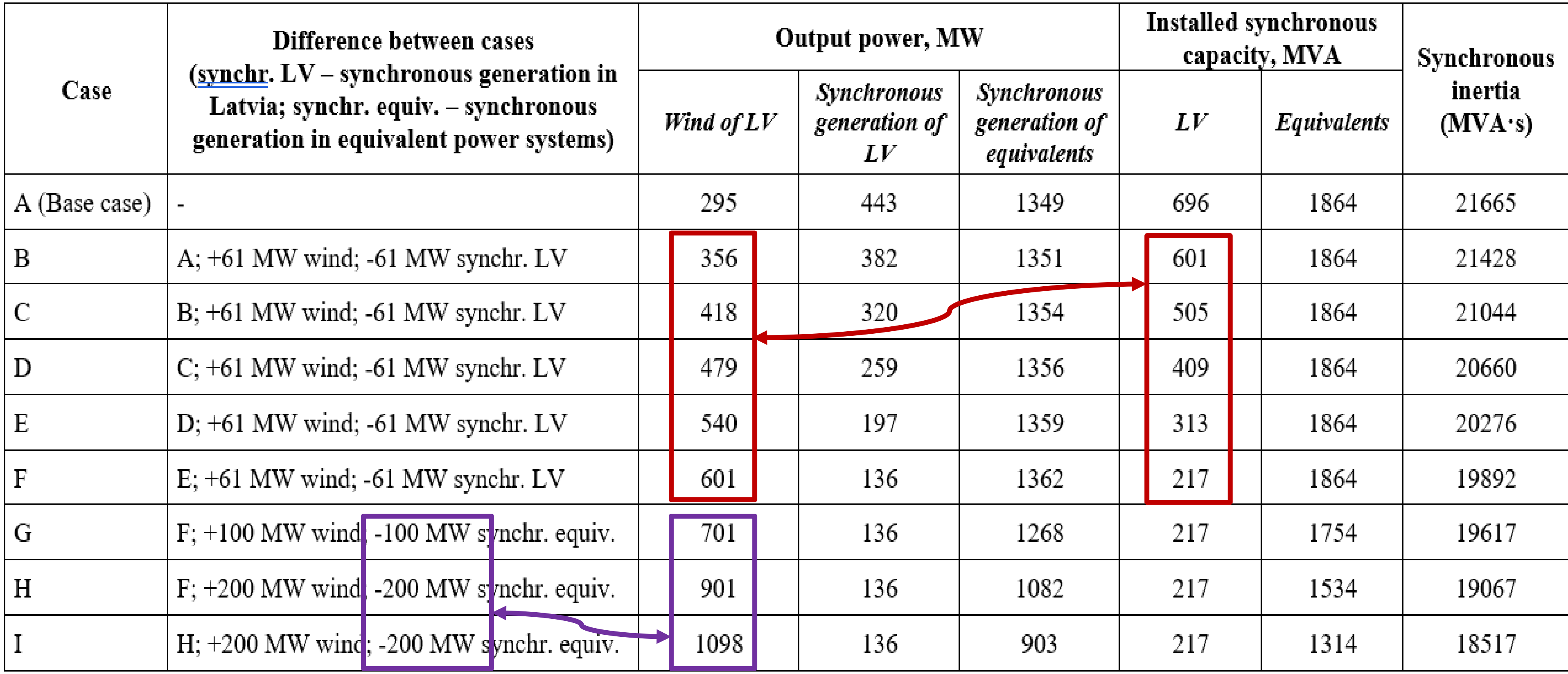
Case	Difference between cases (synchr. LV - synchronous generation in Latvia; synchr. equiv. - synchronous generation in equivalanet power systems)	Output power, MW			Installed synchronous capacity, MVA		Synchronous inertia (MVA·s)
		Wind of LV	Synchronous generation of LV	Synchronous generation of equivalents	LV	Equivalents	
A (Base case)	**-**	**295**	**443**	**1349**	**696**	**1864**	**21665**
B	A; +61 MW wind; -61 MW synchr. LV	356	382	1351	601	1864	21428
C	B; +61 MW wind; -61 MW synchr. LV	418	320	1354	505	1864	21044
D	C; +61 MW wind; -61 MW synchr. LV	479	259	1356	409	1864	20660
E	D; +61 MW wind; -61 MW synchr. LV	540	197	1359	313	1864	20276
F	E; +61 MW wind; -61 MW synchr. LV	601	136	1362	217	1864	19892
G	F; +100 MW wind; -100 MW synchr. equiv.	701	136	1268	217	1754	19617
H	F; +200 MW wind; -200 MW synchr. equiv.	901	136	1082	217	1534	19067
I	H; +200 MW wind; -200 MW synchr. equiv.	1098	136	903	217	1314	18517

Assumptions and Nine Scenarios of the Model:

- **B to F:** installed capacity and output power are ↓ in the Latvian power system that ↑ in wind generation
- **G to I:** it is assumed that additional power plants replace synchronous generation located in neighbouring power systems, and the installed capacity and generation are reduced at the equivalent nodes of the model.

In all cases the frequency transient excitation by the same initial power imbalance of 400 MW was examined.

This imbalance corresponds to the disconnection of the largest generating unit in the Baltic EPS.



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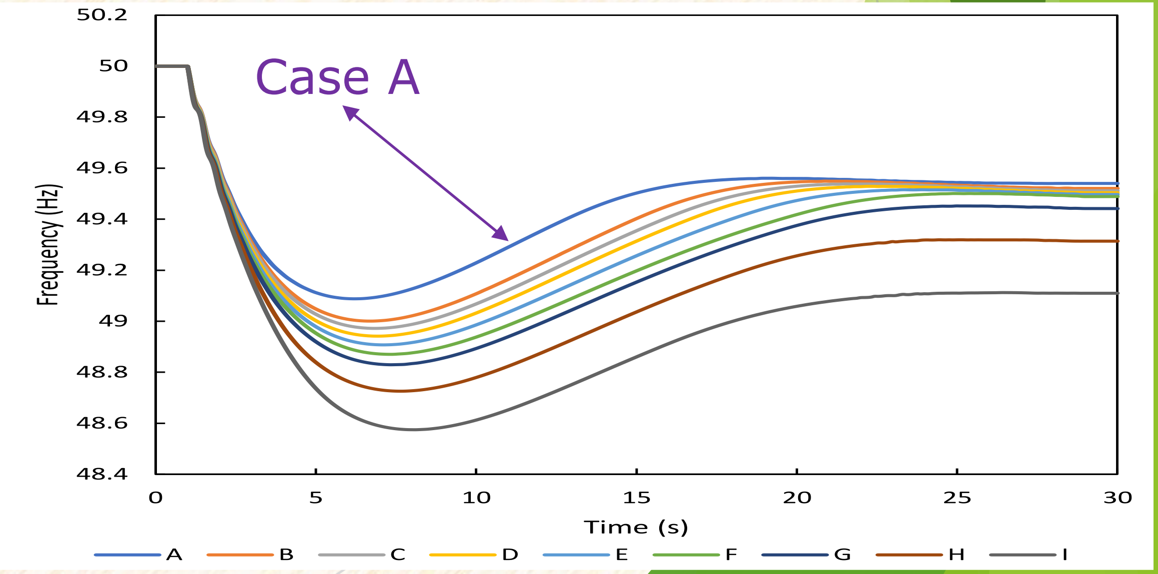
Frequency transients were simulated for two scenarios:

- ***Without an energy storage system;***
- ***With energy storage system contributing to frequency containment reserve.***

In case A (with a minimum wind power penetration of 295 MW), a sudden active power imbalance causes a frequency transient in which a temporary frequency drop of about ***49.1 Hz*** would occur. The frequency is contained in about 20 s, and after a transient process of 30 s, it would settle at a value higher than 49.5 Hz.

As the penetration of wind farms increases, the capacity of power plants that can participate in frequency containment reserve (FCR) decreases. As a result, a larger temporary decrease in frequency and a lower quasi-steady-state value are observed.

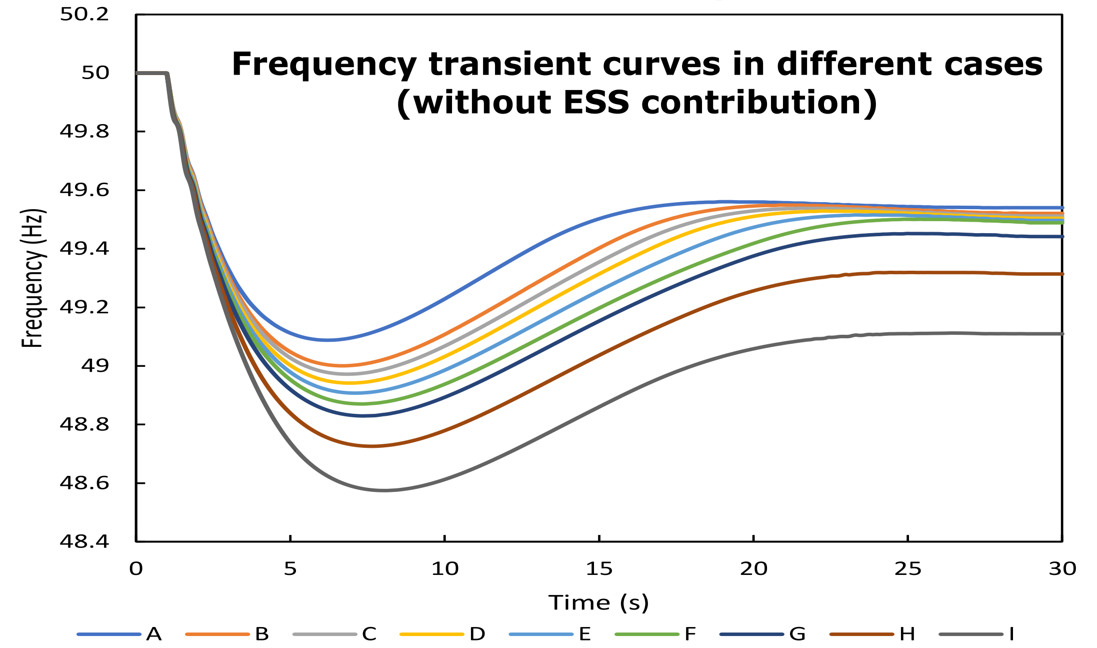


Frequency transient curves for ***cases A-I*** are presented in Figure, and characteristic values are given in Table. The simulation shows that the temporary minimum frequency value does not exceed the permissible limit of 49 Hz only in cases A and B when wind-generated power output ***doesn't exceed about 360 MW.***

Higher wind penetration would result in an insufficient system inertia value and response to frequency deviation, which could lead to the operation of load shedding poor frequency quality.

NUMERICAL VALUES OF FREQUENCY TRANSIENT SIMULATION RESULTS (WITHOUT EES CONTRIBUTION)

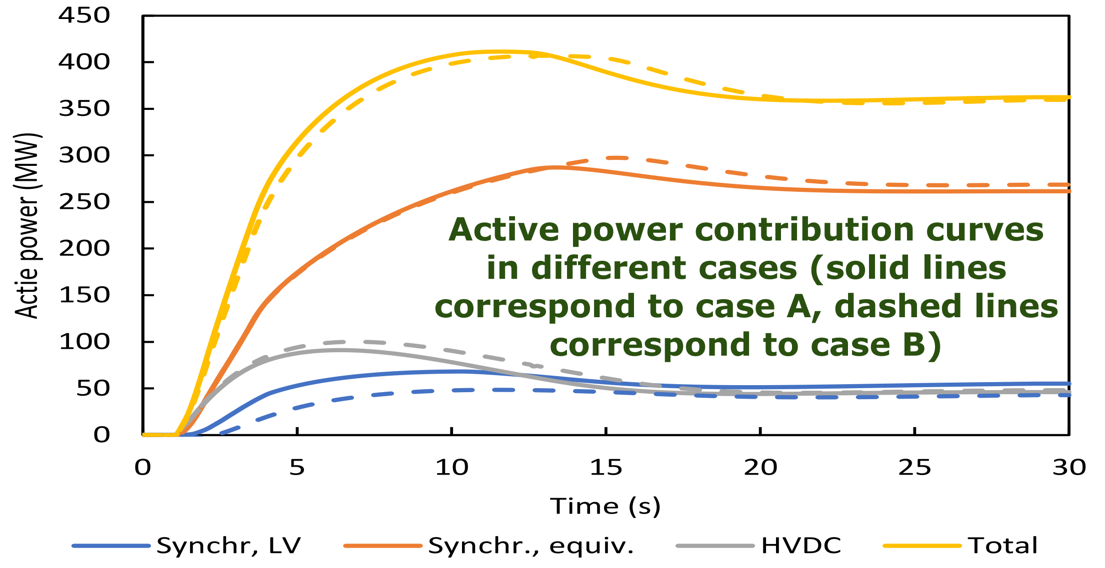
Case	f_{min} (Hz)	Time at f_{min} (s)	$f_{time=30}$ s (Hz)	Power system response (MW/Hz)
A (Base case)	49.09	5.22	49.54	362.5
B	49.00	5.67	49.52	359.5
C	48.97	5.89	49.51	358.7
D	48.94	6.00	49.50	356.8
E	48.91	6.11	49.50	355.6
F	48.87	6.33	49.49	354.8
G	48.83	6.33	49.44	355.9
H	48.73	6.66	49.31	357.9
I	48.57	7.11	49.11	359.4



- ***The response of conventional power plants and HVDC links to frequency change*** in ***cases A and B*** are illustrated in Figure. We can see that the fastest response belongs to HVDC and the power plant response is slower due to the inertia of servomotors, thermodynamic and hydrodynamic processes. In addition, an important indication is that the maximum contribution is in equivalents, i.e. neighbouring countries where higher installed synchronous capacity is modelled.

NUMERICAL VALUES OF FREQUENCY TRANSIENT SIMULATION RESULTS (WITHOUT EES CONTRIBUTION)

Case	f_{min} (Hz)	Time at f_{min} (s)	$f_{time=30\ s}$ (Hz)	Power system response (MW/Hz)
A (Base case)	49.09	5.22	49.54	362.5
B	49.00	5.67	49.52	359.5
C	48.97	5.89	49.51	358.7
D	48.94	6.00	49.50	356.8
E	48.91	6.11	49.50	355.6
F	48.87	6.33	49.49	354.8
G	48.83	6.33	49.44	355.9
H	48.73	6.66	49.31	357.9
I	48.57	7.11	49.11	359.4



Active power contribution curves in different cases (solid lines correspond to case A, dashed lines correspond to case B)

The percentage contribution of different sources to frequency control is shown in Figure. The contribution of equivalent power plants is about 70-80%, and with each scenario, as their synchronous capacity decreases in Latvia, their contribution to frequency management decreases. ***Cases G-I*** reduce the capacity of equivalent power plants, resulting in a significant reduction in their contribution and a relatively higher response of HVDC for frequency reduction.

NUMERICAL VALUES OF FREQUENCY TRANSIENT SIMULATION RESULTS (WITHOUT EES CONTRIBUTION)

Case	f_{min} (Hz)	Time at f_{min} (s)	$f_{time=30}$ s (Hz)	Power system response (MW/Hz)
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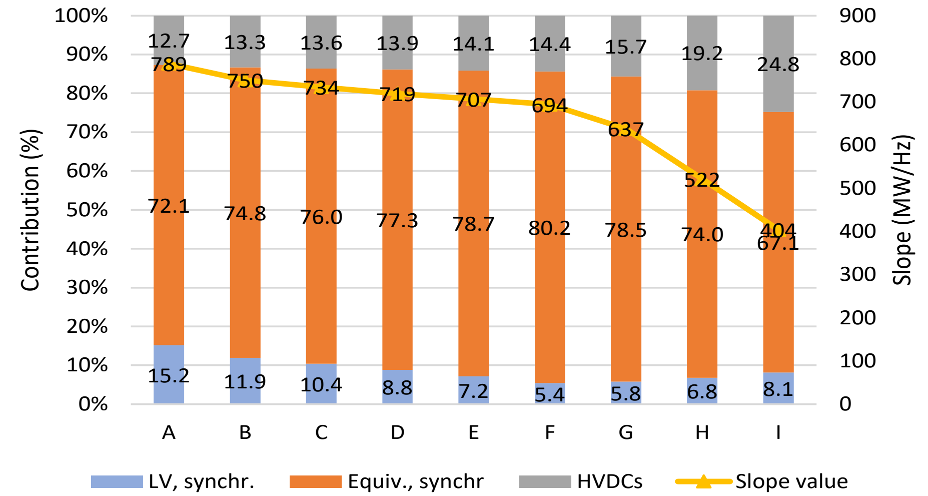
Percentage contribution of different sources to frequency control and frequency response in MW/Hz (without EES contribution)



As a measure of improving the quality of the frequency in the presence of high wind penetration, the effect of ***ESS usage*** is analyzed. The main criterion for selecting the necessary capacity of the ESS is keeping the temporary frequency deviation within the allowable range, i.e. frequency should not fall below 49 Hz during the transient. ***In cases A and B***, an ESS is not necessary, but from scenario ***C***, the use of an ESS can improve the quality of the frequency transients.

NUMERICAL VALUES OF FREQUENCY TRANSIENT SIMULATION RESULTS (WITHOUT EES CONTRIBUTION)

Case	f_{min} (Hz)	Time at f_{min} (s)	$f_{time=30\ s}$ (Hz)	Power system response (MW/Hz)
A (Base case)	49.09	5.22	49.54	362.5
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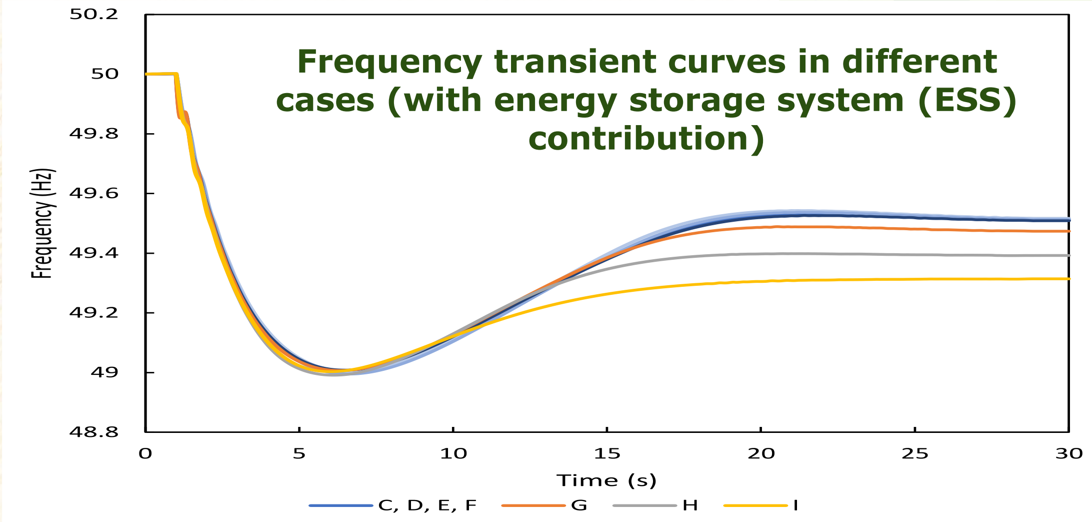

Frequency transient curves in different cases (with energy storage system (ESS) contribution)

CONCLUSIONS

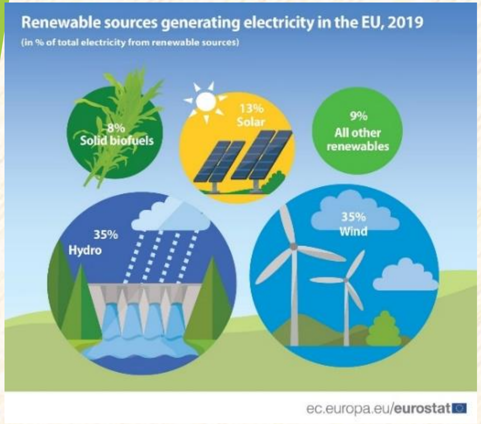
WHY DO WE NEED INERTIA IN THE POWER SYSTEM?

- **It is provided by the rotating mass of the rotors of all electric machines in the power system;**
- **Determines the system's response to a sudden imbalance of active power;**
- **Slows down frequency fluctuations in the system, prevents generators from falling out of sync and the development of fan outages.**

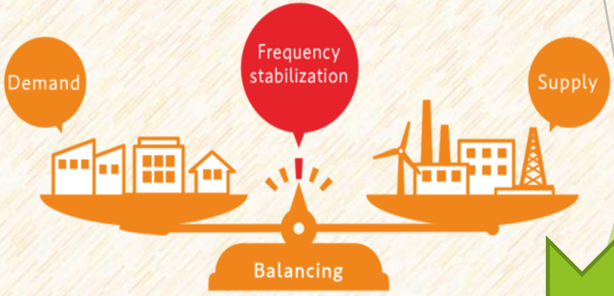
Nowadays, the renewable energy sector is experiencing phenomenal growth. The need to decarbonize the power energy system in support of renewable energy sources leads to their stability problems.

Balancing supply and demand in a situation where RES are integrated into the existing power systems in large volumes implies a significant grid restructuring.

↑ Use of renewable energy sources



Supply and demand balance



- **Frequency regulation**
- **Inertia consideration**

The balance of electricity consumption and frequency regulation is the main technical problem in power systems with a high share of renewable energy sources leading to reducing the network inertia.

The issue of maintaining such network reliability by network operators <u>remains extremely relevant.</u>

1. **Increasing levels of non-synchronous generation in power systems lead to increased difficulties in regulating the primary frequency. To overcome the high risks of power outages caused by interruptions in the operation of RES, a combined approach should be used. It should include the simultaneous use of additional energy storage devices with effective control and use of kinetic energy of rotating masses of synchronous compensators permanently connected to the grid, combined with the use of frequency control methods within integrated power systems. THE PROPOSED APPROACH ALLOWS TO EXCLUDE THE SHARPLY CHANGING NATURE OF GENERATION AND SIMPLIFIES THE MANAGEMENT OF ELECTRICITY FLOWS FROM RENEWABLE SOURCES. THE STUDY FOCUSES ON THE POWER SYSTEM OF THE BALTIC REGION OPERATING IN ISLAND MODE, WITH A HIGH PROPORTION OF WIND GENERATION INTERACTING WITH BATTERY ENERGY STORAGE SYSTEMS.**

2. The obtained results of such a study could contribute to the development of new methods of operation and management of other power systems to ensure stable operation of the system during periods of low inertia.

3. The model used for the analysis of frequency transients is simplified but shows trends in the dynamic characteristics of the power system.

4. The change in frequency does not depend on the installed capacity of the wind farms, but on the composition of the synchronous generators, their inertia, and their ability to participate in the frequency containment reserve (FCR). The analysis shows that a significant contribution to the FCR comes from neighbouring countries. In addition, the HVDC links and the ESS in neighbouring countries (the latter are not analyzed in this investigation) can make a significant contribution to frequency control.

5. Maintaining the same saldo in Latvian power system, the development of WPP replacing existing synchronous generators in Latvian PS has little effect on frequency change. Synchronous generation in Latvian PS cannot be switched off at all, as some of the power plants are hydroelectric and combined heat and power plants (CHP) operating according to heat demand.

6. The development of wind farms needs to be considered in other power systems of the synchronous block, and inertia and frequency control needs to be addressed regionally. The integration of the RES affects the dynamic characteristics of the entire PS, therefore measures to ensure frequency stability and inertia must be selected considering the development plans of the unified PS of the region and coordinated between the individual parts of the system.

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THANK YOU FOR YOUR ATTENTION!

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