VILNIUS GEDIMINAS TECHNICAL UNIVERSITY
FACULTY OF ELECTRONICS
DEPARTMENT OF ELECTRICAL ENGINEERING

LIUTAURAS VINGRAS

RESEARCH OF THE IMPACT OF THE NEW TRANSMISSION LINE ON THE ELECTRICITY MARKET

Master's thesis

Electrical Engineering study field

Electrical Energetics Systems Engineering study programme, state code 6211EX049

Electrical Power and Renewable Energy Engineering specialisation

Vilnius, 2024

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Supervisor ___Assoc. Prof. Audrius Grainys____
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(scientific title and degree, name, surname) (signature) (date)

Vilnius, 2024

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Electrical Engineering study field	APPROVED BY
Electrical Energetics Systems Engineering study programme, state code 6211EX049	Head of Department
Electrical Power and Renewable Energy Engineering specialisation	Sonata Tolvaišienė
	2024-05-07

OBJECTIVES FOR MASTER THESIS

No. EEIfmu-22–7657

Vilnius

For student Liutauras Vingras

Master Thesis title: Research of the Impact of the New Transmission Line on the Electricity Market

Deadline for completion of the final work according to the planned study schedule.

THE OBJECTIVES:

Description of the thesis. Aim: Esamos elektros rinkos analizė ir naujos perdavimo linijos įtakos elektros rinkai tyrimas.

Introduction: Elektros rinkos reikšmė. Naujų jungčių įtaka elektros rinkai.

Analytical part.: Elektros rinka, rinkos dalyviai, elektros rinkos analizė, veiksniai įtakojantys elektros rinką ir jos dalyvius. Perdavimo linijų įtaka elektros rinkai

Design - research part.: Išanalizuoti naujos perdavimo linijos įtaką elektros rinkai ir elektros kainai.

Explanatory letter. Drawings.: Brėžiniai, skaičiavimai, modeliavimo rezultatai

Analytical part.: Gautų tyrimo rezultatų apibendrinimas

Academic Supervisor Associated Professor Audrius Grainys

Vilniaus Gedimino technikos universitetas	
Elektronikos fakultetas	
Elektros inžinerijos katedra	

ISBN	ISSN
Egz. sk.	
Data .........-.....-.....	

Antrosios pakopos studijų **Elektros energetikos sistemų inžinerijos** programos magistro baigiamasis darbas	
Pavadinimas	**Naujos perdavimo linijos įtakos elektros rinkai tyrimas**
Autorius	**Liutauras Vingras**
Vadovas	**Audrius Grainys**

	Kalba: anglų

Anotacija

Baigiamajame magistro darbe nagrinėjama naujos aukštos įtampos oro perdavimo linijos įtakos Lietuvos elektros rinkai. Analitinėje literatūros apžvalgoje apžvelgiamas jau esamas elektros energijos perdavimo tinklas, elektros energijos rinka, planuojami nauji bei jau įgyvendinami projektai Lietuvoje. Išanalizuojamas bendras perdavimo linijų poveikis aplinkai. Naujos perdavimo linijos parametrai apskaičiuojami ir naudojami Balmorel modelyje tiriant poveikį elektros kainoms. Išanalizavus teorinius ir praktinius naujos perdavimo linijos tyrimo poveikio aspektus, pateikiamos baigiamojo darbo išvados.

Darbą sudaro: įvadas, analitinė literatūros apžvalgos dalis, 3 tiriamosios dalies skyriai, išvados, literatūros sarašas.

Darbo apimtis – 53 p. be priedų, 12 pav., 29 šaltinių.
Atskirai pridedami darbo priedai.

Prasminiai žodžiai: Elektros energijos perdavimo linija, elektros rinka, perdavimo tinklas, linijos parametrai, galios nuostoliai, energijos nuostoliai, elektros rinkos modeliavimas, linijos perdavimo pralaidumas, komercija, atsinaujinantys elektros energijos šaltiniai, sinchronizacija, rinkos modeliavimas, įtaka aplinkai.

Vilnius Gediminas Technical University	
Faculty of Electronics	
Department of Electrical Engineering	

ISBN	ISSN
Copies No.	
Date ..........-.....-.....	

Master Degree Studies **Electrical Energetics Systems Engineering** study programme Master Graduation Thesis	
Title	**Research of the Impact of the New Transmission Line on the Electricity Market**
Author	**Liutauras Vingras**
Academic supervisor	**Audrius Grainys**

	Thesis language: English

Annotation

The final master's thesis deals with the study of the impact that a new high voltage overhead transmission line has on the electricity market in Lithuania. The current grid and market situation in the region as well as overall impact of transmission lines are analyzed. Parameters of the new transmission line are calculated and used in Balmorel model to study the impact on the electricity prices. Having analyzed theoretical and practical aspects of the impact of the new transmission line study, the conclusions of the final thesis are presented.

Structure: introduction, analytical literature reviewing part, 3 research part chapters, conclusions, references.

Thesis consists of 53 p. without appendixes, 12 figures of pictures, 29 entries.
Appendixes included separately.

Keywords: high voltage transmission line, transmission grid, line parameters, power loss, energy loss, electricity market, commerce, market modelling, environmental impact, renewable energy sources, transmission capacity, synchronization.

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	(Studijų programa, akademinė grupė)	

BAIGIAMOJO DARBO (PROJEKTO)
SĄŽININGUMO DEKLARACIJA

2024 m. gegužės 22 d.

Patvirtinu, kad mano baigiamasis darbas tema „Naujos perdavimo linijos įtakos elektros rinkai tyrimas“ yra savarankiškai parašytas. Šiame darbe pateikta medžiaga nėra plagijuota. Tiesiogiai ar netiesiogiai panaudotos kitų šaltinių citatos pažymėtos literatūros nuorodose.

Mano darbo vadovas docentas daktaras Audrius Grainys.

Kitų asmenų indėlio į parengtą baigiamąjį darbą nėra. Jokių įstatymų nenumatytų piniginių sumų už šį darbą niekam nesu mokėjęs (-usi).

			Liutauras Vingras
	(Parašas)		(Vardas ir pavardė)

TABLE OF CONTENTS

ABBREVATIONS

HPSPP – Hydro pumped storage power plant

BRELL – Power system of Belarus, Russia, Estonia, Latvia and Lithuania

IPS/UPS – Integrated power system/Unified power system of Russia

TSO – Transmission system operator

PS – Power System

RES – Renewable energy sources

LT – Lithuania

LV – Latvia

EU – European Union

CESA – Continental European Synchronous area

MAPS - market assessment and portfolio strategies

MMOPF - multi-commodity, multi-area optimal power flow

DC – direct current

AC – altering current

CE – Central European

INTRODUCTION

Over the years the electricity grid has developed extraordinarily. That brings both benefits and challenges. While customers can enjoy being supplied with stable electrical energy all the time, the only thing everyone is concerned about nowadays is the price that they must pay for this energy. And to ensure this comfortability there must be a lot of things processed and taken care of in the background. Demand of electricity, transmission and distribution grid's stability, day-ahead and intraday market are only a few of those background processes and they have many subtopics of their own. Yet the main talking point that connects all is the electricity grid. In this case it is the transmission grid.

In this paper most of the topics of transmission grid will be touched but the focus will be pointed towards modelling a new transmission line in Lithuanian energy system and its impact on the market. Bearing in mind that nothing is permanent, the system requires constant development and reconstruction to keep the grid safe and reliable. Constructing or reconstructing new transmission lines will always be relevant especially for Lithuania because of its rapid development of renewable energy and synchronization with CESA plans.

1. LITERATURE REVIEW

1. 1. Relevance of the topic

The relevance of this research topic is based on the Lithuanian electricity transmission system development strategy. High-voltage transmission lines are currently being built not only as reconstruction projects for existing connections, but also based on new needs for synchronization with the continental European network. Newly constructed transmission lines' integration in the current grid will not only bring better stability, safety and efficiency but also will have an impact on the energy market and prices.

Currently one of the main strategies is to reach a complete independence from IPS/UPS grid which means disconnection from third countries. According to Lithuanian National Energy Independence Strategy, disconnection of the Lithuanian electricity system from synchronous operation with the IPS / UPS system and synchronization of the electricity system with the continental European electricity system an energy system is essential to ensure and maintain energy security.

Although the frequency of the IPS / UPS network is the same as that of the European network, i.e. 50Hz, the timing is different, which is why synchronous operation between the two systems is not possible. The LitPol Link connection with Poland, which currently connects Lithuania with Europe, is compatible at the Alytus converter station, where the frequency for the European network is compatible.

Since the main strategic goal is the desynchronization from IPS/UPS network and the synchronization to the European Continental Grid, interconnection of Baltic power system grid ought to be strengthened which brings the demand of new transmission lines. For example, a new submarine cable is being constructed called "Harmony Link".

Harmony Link is a new electricity connection between Lithuania and Poland, which will connect the Zarnoviec substation in the Polish Pomeranian region with the Darbėnai substation in the Kretinga district of Lithuania. The most important component of the connection is a 700 MW high voltage direct current (DC) cable. The electricity connection will be about 350 km long, of which about 300 km will be offshore.

The submarine cable would improve the energy security of the region, enabling the synchronization of the Lithuanian, Latvian and Estonian electricity systems with the synchronous zone of continental Europe. Harmony Link will increase the security of energy supply to consumers across the region and give market participants more opportunities to trade electricity in Europe.

Preparatory work for Harmony Link has been ongoing since the beginning of 2019. Construction of the connection is scheduled to be completed in 2028.

As of now, there are official discussions about building this cable inlands which would significantly reduce the cost of the project.

The investors of the project are Polish and Lithuanian electricity transmission system operators - Polskie Sieci Elektroenergetyczne SA and Litgrid. [8]

To ensure the reliability of the transmission grid and increase the security of electricity supply by constructing a 330 kV switchyard Darbėnai, which is important for the synchronous operation of the Lithuanian electricity system with the continental European electricity grid. [25]

The new transmission line that is researched in this paper could be built to connect all these new projects and strategies. To be precise, the line should be built connecting Darbėnai with another Latvian substation. In this way the interconnection grid between Lithuania and Latvia will be strengthened while also dividing the load from flow of the new Harmony Link connection in the Darbėnai switchyard. In this paper the new transmission line is expected to be between Darbėnai and Ventspils.

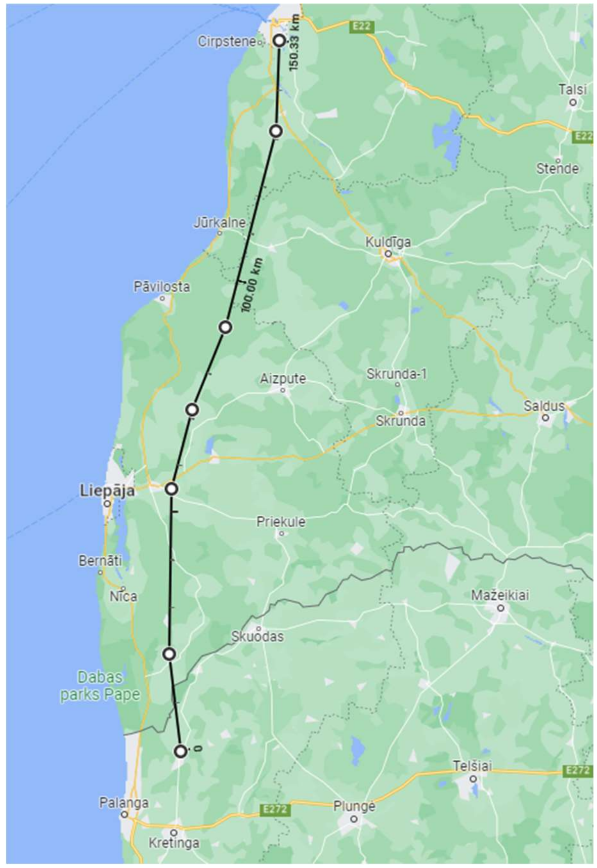

Figure 1. Representation of approximate line location

As stated in [25] Synchronization with the networks of continental Europe is the last step towards Lithuania's energy independence. Currently, our electricity system is still dependent on frequency control in Russia, but already in 2025, it will operate in one synchronous area together with the systems of other European countries.

The 330 kV switchyard Darbėnai is one of the synchronization projects, the implementation of which will increase the reliability of electricity supply in the Lithuanian electricity system, as well as ensure the integration of a new direct current connection with Poland Harmony Link.

1. 2. Power system review

1. 2. 1. Transmission system operator "Litgrid"

Litgrid, Lithuanian electricity transmission system operator, maintains stable operation of the national power system, controls electricity flows and enables competition in an open domestic electricity market. Litgrid is responsible for integrating the national power system into the European power infrastructure and electricity market. The company has built strategic electricity cross-border links, namely, NordBalt

(Lithuania-Sweden) and LitPol Link (Lithuania-Poland). While implementing the ultimate goal of Lithuania - independence in energy sector, we promote such values as responsibility, creativity and dialogue. [9]

Pursuant to the Law on Electricity of the Republic of Lithuania, the electricity transmission system operator (TSO) is responsible for the stability and reliability of operation of the electric power system, the performance of the national balancing function and the provision of system services in the territory of the Republic of Lithuania, operation, maintenance, management and development of the transmission network of the power system (PS) and interconnectors with the power systems of other countries, reducing the capacity constraints in the transmission networks and taking into account the needs of the power system and electricity network users. Operator of the electricity transmission system must also forecast the long-term power balance of the electricity system and provide market participants with information on the expected shortage or limitation of the generation or transmission capacity. [4]

Litgrid as the TSO continuously provides information about the power system. Their website provides you with the real-time data on intersystem flows, consumption and generation of electricity, generation at wind farms, scheduled/actual outages of the generation sources etc.

The information provided here has been recorded not earlier than 30 minutes ago. Their aim is to ensure that it is always accessible without any interruption, in the most user-friendly manner. The grid data is structured in the form of tables and graphs for greater clarity. [26]

The main function of the company is to ensure the efficient and reliable operation of the national power system. While performing this function, the company looks after the integrity of the power system and control, operate and develop the transmission network and the lines connecting the national system with the other power systems.

1. 2. 2. Transmission grid.

Litgrid as the transmission system operator (TSO) is responsible for the control, maintenance, and development of the national power transmission grid.

The main function of the company is to ensure the efficient and reliable operation of the national power system. While performing this function, we look after the integrity of the power system and control, operate, and develop the transmission network and the lines connecting the national system with the other power systems.

The 330-110 kV power transmission grid of Lithuania includes 239 transformer substations and switchyards as well as 7289,3 km of power transmission lines. The installed capacity of the 400 kV transformers totals 3163,5 MW, 330 kV transformers totals 5448,5 MW and that of the 110 kV transformers totals 92,6 MW. [26]

1. 2. 3. Transmission grid control and development

Litgrid provides the power transmission service to the users of the high-voltage grid and ensure equal conditions for the connection to and use of the grid. Furthermore, they organize connection of the customers‘, distribution companies‘ and power plants‘ equipment to the transmission grid and carry out and supervise the accounting for electricity in the transmission grid.

Litgrid is responsible for the reliable operation of the transmission grid, connecting lines, and other electric equipment. They carry out the real-time control of the national power balance and ensure the quality of electricity in the transmission grid. The transmission grid of Lithuania is well connected with some of the neighboring power systems: by four 330 kV lines and three 110 kV lines with Latvia, five 330 kV lines and seven 110 kV lines with Belarus, and three 330 kV and three 110 kV lines with the Kaliningrad Region.

The company provides additional services that are required for the safe and reliable operation of the power system. The TSO performs the planning and coordination of the transmission network topology, implements measures to prevent failures and emergencies, and takes emergency response actions when necessary. Litgrid ensures that the quality of the electricity transmitted via the grid meets the applicable standards.

The TSO operates in such a way that the transmission network in Lithuania functions in an effective, reliable and environmentally friendly way.

Litgrid prepares plans for the development of the power transmission grid, carries out grid reconstruction and maintenance works including the high-voltage power transmission lines and transformer substations, builds new overhead and cable power lines, implements the strategic projects on power links with Poland (LitPol Link) and Sweden (NordBalt).[1]

The Company transmits high-quality electricity in accordance with the requirements of international quality standards (LST EN 50160) and in line with the description of permissible frequency and voltage quality parameters of the high-voltage (330 kV and higher) transmission network prepared by Litgrid separately. These documents define the limit parameters that must not be exceeded and maintained by all users connected to the network, specify the frequency and voltage limits, voltage dips and interruptions, harmonics and asymmetry. It should be noted that very short (up to a second) voltage interruptions in 110 kV and higher grids occur due to electrical network accidents (short circuits), which are usually caused by natural phenomena (lightning, storms, hurricanes, migratory birds, etc.). Electric power transmission networks shall be designed to eliminate such failures within <150 ms of the main protection and <250 ms of the backup protection. In reality, short circuits are removed even faster (in about 100 ms) when the basic protections are applied. In addition to the operation time of the additional disconnection logic, the operation of the switching equipment itself takes about 70-80 ms, therefore it is technically impossible to eliminate voltage interruptions in the high-voltage grid or it would cost unreasonably large money. In order to ensure the operation of consumers who are very sensitive to the quality of electricity, special reservation measures must be installed on the consumer‘s own farm or in low-voltage networks. [4]

1. 2. 4. Lithuania’s National electricity demand and generation

The final electricity consumption in Lithuania totaled 10,957 terawatt hours (TWh) in 2023, a 2 % decrease compared to 2022 (11,192 TWh).

In 2023 total generation was 5,664 TWh, that is 75% higher than in 2022 due to the fact that wind generation increased from 1,513 TWh to 2,524 TWh in one year. Solar generation also increased significantly from 0,273 TWh to 0,633 TWh.[3]

The main generation consists of thermal power plants, hydroelectric power plants, “Kruonis” HPSPP, winds farms which include wind farms in both transmission grid and distribution grid, and other renewable energy sources that include biomass, biogas, solar energy and waste incineration plants.

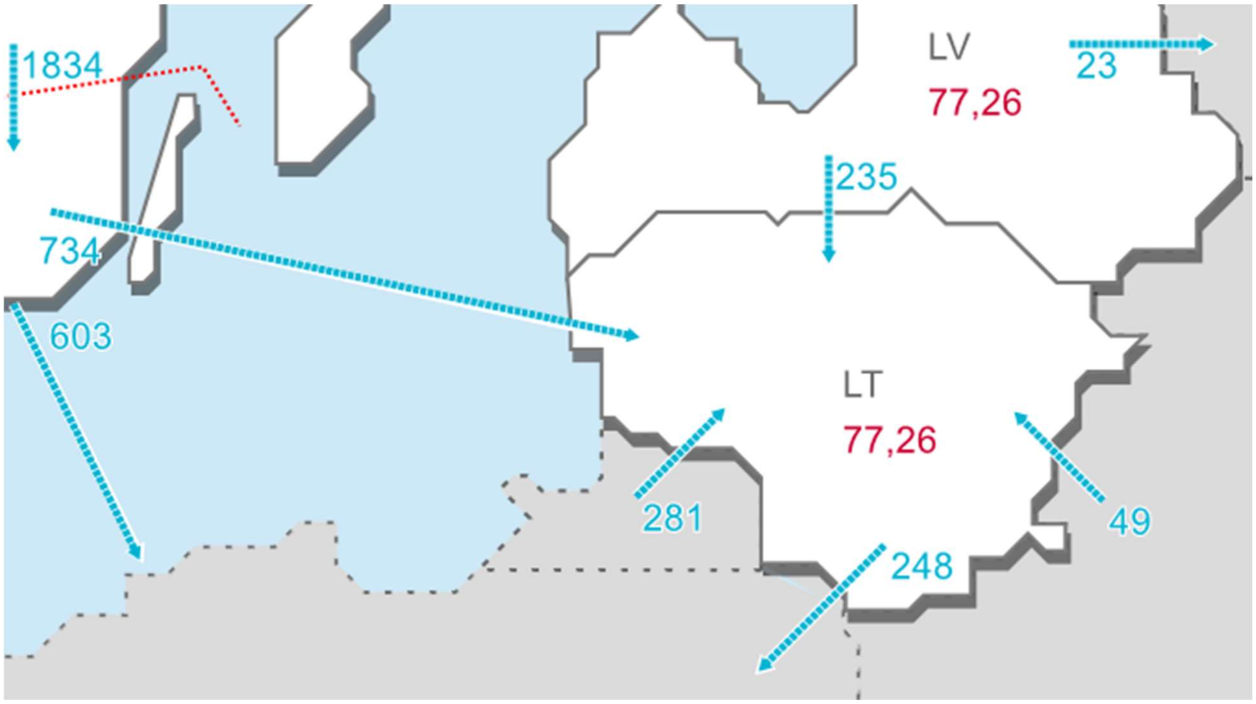

Figure 2. 2022-04-24 STATE OF THE NORDIC POWER SYSTEM; ●Flow(MW) and ●Price(MWh). [2](https://www.litgrid.eu/index.php/state-of-the-nordic-power-system/2846)

1. 2. 5. Baltic load frequency control block

In preparation for connecting Lithuanian, Latvian and Estonian electricity power systems to the synchronously operated area of the Continental Europe, three Baltic transmission system operators – Litgrid AB, AS "Augstsprieguma tīkls" and Elering AS – have signed Memorandum of understanding for Baltic Load Frequency Control (LFC) Block development in order to establish common principles for frequency and balance control of three Baltic power systems.

Taking into consideration that desynchronization of the power systems of the Baltic States from the synchronous area of IPS/UPS and their synchronization with the Continental Europe Synchronous Area (hereinafter referred to as CESA) requires Baltic TSO's to develop and start operating the LFC process pursuant to the Synchronous Area Framework Agreement of CESA and other relevant arrangements, Baltic TSO's have agreed to enter into Memorandum of understanding in order to highlight the key concepts, principles and actions to establish a framework for development of an effectively functioning Baltic LFC process, which will also open the Baltic power market for a new type of reserves and make it more attractive for the new market participants. The Memorandum envisages Baltic TSOs aim for the creation of a common reserve market in the Baltics, which will increase market liquidity and competition thus ensuring most efficient procurement of balancing capacities within Baltics.

As a result of Memorandum, Baltic TSO's will commonly develop the LFC Concept document for the key principles stipulated herein to be elaborated in due detail to cover necessary reserves as well as organizational arrangements for the LFC block cooperation which shall be consulted with the stakeholders. The public consultation is set to be conducted in the autumn of 2020.

Based on the LFC Concept document the Baltic TSO's commit to draft and conclude all the arrangements and methodologies within the LFC Block Operational Agreement to comply with Article 119 of the Commission Regulation (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation. These actions will be concluded before the synchronization of Baltic Power systems with CESA. [26]

1. 3. Electrical power system legal guidelines

1. 3. 1. National Energy Independence Strategy

The National Energy Independence strategy states that the goal of Lithuanian energy is to ensure the energy needs of the Lithuanian state, its population and business. The National Energy Independence Strategy sets out the vision of the Lithuanian energy sector, the principles of its implementation, strategic directions, goals and objectives.

The strategy envisages the vision of the Lithuanian energy sector - progressive energy that creates added value for the state and consumers, reliably supplies environmentally friendly energy at a competitive price.

Its implementation will be detailed in the 2020, 2030 and 2050 action plans. The strategy will be implemented through the following four strategic directions: competitiveness, reliability, reduction of the impact on climate change and ambient air pollution, and participation of the country's business in achieving energy progress. [6]

The strategy is implemented in the following four strategic directions:

1. Competitiveness. Energy costs account for a significant share of industrial spending and household budgets. Global trends - reduction of the energy sector's dependence on fossil fuels, market integration, digitalization, urbanization, the need to rapidly increase energy efficiency, the development of renewable energy production and energy distribution technologies - necessitate changes in the energy sector. Therefore, the state will strive to ensure that energy is in line with these global trends, ensuring the implementation of the energy interests of the population and businesses.

Energy prices will be formed in an efficient, common market of the European Union member states. The country's energy infrastructure will be used efficiently, which will ensure that the cost of maintaining this infrastructure in relation to the final energy price does not exceed the average of the EU Member States, and that the tariff structure will allow for increased investment in industry.

2. Reliability. The security and competitiveness of the state, the growth of the economy, and the well-being of all the country's citizens depend on a reliable supply of energy. Lithuania is part of the emerging European North-South Energy Corridor, which runs from Finland to Central European countries. Energy security is ensured by being part of the EU's energy infrastructure, markets and systems, having the necessary power to generate electricity and alternative sources of gas supply.

3. Reducing the impact on climate change and environmental air pollution (energy saving and green energy). Energy efficiency improves the financial condition of the state's population, increases business competitiveness, reduces greenhouse gas emissions and ambient air pollutants, and improves environmental air quality. Improving energy efficiency and the use of renewable energy sources will be a daily feature of every household, business or industry purchasing electricity, gas, biofuels or other fuels or raw materials. Renewable energy sources are the most promising energy source for expanding domestic energy production, and the further development of renewable energy sources and energy efficiency, combined with the reduction of environmental air pollution, will be encouraged through financial and non-financial measures.

4. Involvement of the country's business in energy progress. Lithuania from an energy importing country must become an energy technology developing and exporting country. Improving energy efficiency through building renovation programs and increasing the efficiency of manufacturing industries, promoting the use of renewable energy sources creates a large market for these services and the opportunity to create jobs, develop innovative low-emission and low-emission technologies and human resources. [5]

1. 4. Electrical energy market review

1. 4. 1. Electricity market

The electricity market is the entirety of relationships formed between entities in the process of trading in electricity. The specific character of this market is related to the fact that electricity cannot be stored – it must be consumed when it is produced, and transmission of electricity must take place under strict control of its parameters.

The electricity market consists of wholesale and retail trade in electricity. Power generating companies that sell electricity to suppliers take part in wholesale trade. This market also includes transmission and distributions systems‘ operators that purchase electricity to compensate for production losses in the transmission and distribution grids. Participants of the wholesale trade may enter into bilateral agreements directly or conclude purchase/sale transactions on an electricity exchange.

Power suppliers and customers that have concluded bilateral electricity sale-purchase agreements with suppliers take part in retail trading.

The transmission system operator (TSO) is responsible for securing national power generation and consumption balance and for the administration of the regulation and balancing power in the market. [26]

Lithuania currently is a part of Nord Pool power market.

Nord Pool is Europe's leading power market and offers trading, clearing, settlement and associated services in both day-ahead and intraday markets across 16 European countries.

Their product is a transparent and reliable power price produced within our markets every hour, every day.

Nord Pool provides liquid, efficient and secure day-ahead and intraday markets to their customers. They are committed to simple, straight-through trading for all their customers regardless of their size or where they trade from. They are the counterparty for all trades, guaranteeing settlement and delivery.

360 companies from 20 countries trade on their markets in the Nordic and Baltic regions, the UK, Central Western Europe (covering Austria, Belgium, France, Germany, Luxembourg and The Netherlands) and Poland.

Nord Pool’s team is absolutely committed to excellence, problem-solving and making their customers’ lives simpler. Their markets are operated from offices in Oslo, Stockholm, Helsinki, Tallinn, Berlin and London. [7]

Nord Pool is appointed as a Nominated Electricity Market Operator (NEMO) in Austria, Belgium, Denmark, Estonia, Finland, France, Germany, Great Britain, Ireland, Latvia, Lithuania, Luxembourg, the Netherlands, Poland and Sweden which signifies Nord Pool’s ability to meet the new Network Guidelines on Capacity Allocation and Congestion Management (CACM), which came into force on 14 August 2015.

During 2021 a total of 963 TWh of power was traded through Nord Pool (made up of buy volume of 462 TWh and sell volume of 501 TWh).

The Nordic and Baltic day-ahead market traded 722.5 TWh and the UK day-ahead market 147.3 TWh, while Nord Pool's central European (CE) day-ahead market (covering Austria, Belgium, France, Germany, Luxembourg, The Netherlands and Poland) achieved 68.2 TWh of power traded by year end. Total intraday trading, across all markets, for the year stood at 25.18 TWh. [7]

The electricity market is special in the way that Electricity, as a product, must be used in real time, electricity cannot be stored somewhere until demand, let alone energy storage facilities.

Every day, the transmission system operator buys electricity from the exchange. Prices in the region are based on the most expensive supplier price in the region, which means that even if we bought very cheap energy from existing exchanges, it would just run out. In that case it would require to run local sources, such as thermal power plants, which offer to sell their energy at a very high cost compared to power exchanges, so the price in our region and will be the one offered by the most expensive supplier, in this case - thermal power plants.

Trading is usually based on bilateral agreements between market participants who wish to trade directly under the terms of the agreement (prices, quantities, settlement terms, etc.). This is considered a fixed price.

Power Exchange Trading: A public trading venue where participants purchase or sell electricity without prior agreement. This is considered a variable price.

Electricity through connections always flows from a cheaper area to a more expensive one, as long as enough cheaper electricity flows through to equalize the different prices in the regions. Cheap prices are hampered by existing capacity, which is often insufficient to meet energy needs from one country.

Another important part of the market is the capabilities of the capacity between borders. When considering Lithuania, currently the country imports most of its electricity from abroad which makes capacities between borders even more relevant.

As it is stated in Litgrid's official site, the main flows of electricity into Lithuania are coming:

1. via NordBalt DC interconnector with Sweden (SE4 > LT 700 MW)
2. via LitPol Link DC interconnector with Poland (PL > LT 492 MW)
3. via AC interconnector with Latvia (LV > LT 1201 MW)

The interconnectors with Latvia play a big role for the transition of the electricity generated not only in Latvia, but also in Estonia, Finland. It reaches Lithuanian power system via the Estlink 1 and Estlink 2 DC interconnectors Finland-Estonia (FI > EE 1016 MW), also the AC interconnector Estonia-Latvia (EE > LV 1447 MW).

Lithuanian electricity price is strongly influenced by the interconnection capacities - the maximum amounts of electricity that can be transmitted through interconnectors, set by the Baltic TSOs. As the wholesale electricity market prices are formed on a demand-supply basis, with limited capacity and demand exceeding available supply, there is a price differential between individual systems (price zones or countries) on the wholesale electricity exchange. [27]

1. 4. 2. Market development in Baltic region

One of the responsibilities of the electricity transmission system operator is electricity market development and Lithuanian electricity market integration into the single European power market.

The Lithuanian bidding area of Nord Pool Spot, the leading Nordic and Baltic power exchange in Europe, has been functioning since June 2012, and the Elbas intraday market was launched in December 2013. Market participants may trade in electricity in both day-ahead and hour-ahead markets. Short-term plans include the development of a financial market that will enable management of the risk of long-term trading in electricity. Market participants will be able to secure themselves against electricity price fluctuations in advance and fix the price of electricity they are planning to trade in the future.

The new power links with Sweden and Poland, construction whereof is currently in progress and operation whereof is scheduled to start at the end of 2015, will connect the power infrastructures of the Baltic States, North-Western Europe. Thus, electricity import opportunities will increase and alternative electricity trading channels between Lithuania, Scandinavia and North-Western European countries will be created.

The national methodology for capacity allocation of electricity transmission links between Lithuania and neighbouring countries in the market became effective on 1 January 2014. The key requirement of the methodology is to efficiently allocate and operate Lithuanian power links with Latvia, Belarus and Kaliningrad while keeping to the electricity transmission security requirements and to ensure power system reliability as well as maximum infrastructure availability for the market. System reserve power will also be assessed from the above date when identifying maximum electricity flows able to get into the Lithuanian power system. This will increase electricity import opportunities during the months of the greatest physical restrictions for electricity import due to technical reasons (line and generator repairs).

In February 2014 the first step was taken towards a common rules on cross - border capacity calculation and allocation between Baltic countries. Lithuanian and Latvian electricity transmission systems operators Litgrid and Augstsprieguma tīkls signed the agreement on principles of calculation and allocation of the Cross-border trading capacities, which is published below.

On 17 June 2009, the President of the European Commission (EC) and the Prime Ministers of the States of the Baltic Sea Region signed a memorandum on the basis of which a detailed plan on the integration of the Baltic electricity markets (Baltic Energy Market Interconnection Plan, BEMIP) was drawn up.

The main purpose of BEMIP is to create a duly operating, integrated energy market and to secure the requisite energy infrastructure as a prerequisite for a competitive, sustainable and secure energy market in the Baltic Sea Region.

A number of strategic energy projects implemented in the Baltic region are aimed at elimination of the Baltic countries‘ energy isolation and at sustainable development of the energy sector in the BEMIP area.

Litgrid, which is responsible for the development of the electricity market and the implementation of the international power links‘ projects, submits reports on implementation of BEMIP to the EC and makes proposals for the inclusion of the cross-border links in the List of Projects of Common Interest (PCI). [26]

1. 4. 3. Internal EU electricity market

European Union needs a competitive, integrated and flexible single energy market. Energy has to be a common competitive commodity that reaches customers at places where there is a demand for it.

The European Heads of State and Government set a clear deadline of 2014 for the completion of the internal European energy market.

ENTSO-E and European electricity exchanges are intensively developing an internal market for electricity by implementing the project on the price coupling of regions (PCR).

The Nord Pool Spot electricity exchange, which is successfully operating also in Lithuania, is an active participant in this project. By creating a common electricity market of the Baltic States and integrating it into the Nordic electricity market, by constructing the power links with Sweden and Poland, and by implementing the Grid Codes, we will become an integral part of PCR and the internal market for electricity. The internal European electricity market will help enhance liquidity, efficiency, and social welfare. [26]

1. 5. Parameters of the new transmission line

The parameters of the new transmission line that is researched in this paper will be the developed line in my own bachelor's paper. It is a double conductor per phase ACSR 350 mm2, 54/7 BISON line. The primary parameters required for further parameters calculation are lister in the table below:

Line voltage, V	330 kV
Line length, l	150 km
Line inductivity, L	1,06302 mH/km/phase
Line capacitance, C	0,01076 μF/km/phase
Line resistance, R	0,033698 Ω/km/phase
Current rating, I	1360A/phase
Line power rating, S	760 MVA

Active resistance of the line:

$$R_{line} = l \ast R = 150\,km \ast 0{,}033698\,\Omega/km = 5{,}05\,\Omega;$$

Inductive resistance of the line:

$$X_{L_{line}} = X_{0L} \ast l = 2\pi f L \ast l = 2 \ast 3{,}14 \ast 50\,Hz \ast 1{,}06302\frac{mH}{km} \ast 150\,km = 50068.24\,mH = 50{,}07\,\Omega;$$

Capacitive resistance of the line:

$$\mathrm{X_{C_{line}}} = \mathrm{X_{0C}} \ast \mathrm{l} = \frac{1}{2\pi f C} \ast \mathrm{l} = \frac{1}{2 \ast 3{,}14 \ast 50 \ast 0{,}033698\frac{\Omega}{km}} \ast 150\ \mathrm{km} = 14{,}18\ \Omega;$$

$$\mathrm{Z_{line}} = \sqrt{\mathrm{R_{line}^2} + \mathrm{jX_{L_{line}}}^2} = \sqrt{5{,}0547^2 + 50{,}068^2} = 50{,}32\ \Omega;$$

Complex impedance:

$$\mathrm{Z} = \mathrm{R_{line}} + \mathrm{j}\omega\mathrm{Ll} = \mathrm{R_{line}} + \mathrm{j}2\pi\mathrm{fLl}$$

Where $L \ast l$, is the line's inductivity per kilometer L multiplied by line's length l.

$$\mathrm{Z} = 5{,}05 + \mathrm{j} \ast 2 \ast 3{,}14 \ast 50 \ast 1{,}06302 \ast 150 = 5{,}05 + \mathrm{j}50{,}07 = 50{,}32\mathrm{e}^{\mathrm{j}5{,}76^\circ}$$

Line's current:

$$I = \frac{S}{\sqrt{3} * U}$$

Where S – power flow through the line: 300MVA, o U – 330 kV

$$I = \frac{300000 \text{ kVA}}{\sqrt{3} * 330 \text{ kV}} = 524{,}86 \text{ A}$$

For further parameter calculation the line's scheme was replaced with points of reactance instead of existing line's equipment.

Line's power losses.

Power losses are calculated using these formulas:

$$\Delta P_L = 3 * I_2^2 * R$$

$$\Delta Q_L = 3 * I_2^2 * X$$

$$\Delta S_L = 3 * I_2^2 * Z$$

here ΔP_L, ΔQ_L, ΔS_L – power losses in the line;

I_2 – receiving end's line current, A;

U_2 – receiving end's line voltage, V;

R – line's active resistance, Ω;

X – line's reactance, Ω;

Z – line's impedance, Ω;

Active power losses:

$$\Delta P_L = 3 * I_2^2 * R_{line};$$

$$\Delta P_L = 3 * 524{,}86^2 \text{A} * 5{,}05\ \Omega = 4{,}17 \text{ MW};$$

Reactive power losses:

$$\Delta Q_L = 3 * I_2^2 * X_{L_{line}}$$

$$\Delta Q_L = 3 * 524{,}86^2 \text{A} * 50{,}07\ \Omega = 41{,}38 \text{ MVAr}$$

Apparent power losses:

$$\Delta S_L = 3 * I_2^2 * Z_{line}$$

$$\Delta S_L = 3 * 524{,}86^2 A * 50{,}32\ \Omega = 41{,}59\ MVA$$

Energy losses in the line.

Energy losses can be calculated using the following formula:

$$\Delta A_{LP} = 3 * I_2 * R * \tau_{\ max} = \frac{S_2}{U_1} * R * \tau_{\ max}$$

$$\tau_{\ max} = \left(0.124 + \frac{T_{max}}{10000}\right)^2 * 8760$$

here ΔA_{LP} – active energy losses in the line;

S_2 – apparent power in the receiving end, kVA.

U_1 – voltage of the sending end, kV.

I_2 – receiving end's current, A.

T_{max} – yearly number of hours when the line is at maximum load, h;

τ_{max} – yearly amount of time when the line works with maximum load, h.

R – active line's resistance, Ω;

T_{max} will be measured as 5000 h. This measurement is chosen having in mind that from all 8760 hours in the year, the line will not be working during faults, reconstructions, repair, testing periods, connection of new equipment or sources of renewable energy since they are becoming especially popular in that area of Lithuania. So τ_{max} is calculated like this:

$$\tau_{\ max} = \left(0.124 + \frac{5000}{10000}\right)^2 * 8760 = 3410{,}93\ (h)$$

While the yearly energy losses are equal to:

$$\Delta A_{LP} = 3 * I_2 * R * \tau_{\ max} = 3 * 524{,}86^2 * \ 5{,}05 * 3410.93 = 14{,}23\ GW$$

Short circuit currents.

In this case the are two scenarios, when the short circuit occurs in both ends, in both cases the fault is phase-to-ground.

Short circuit current is calculated using the following formula:

$$I_{S.C}^{(x)} = \frac{E}{(3X_0)\sqrt{3}}$$

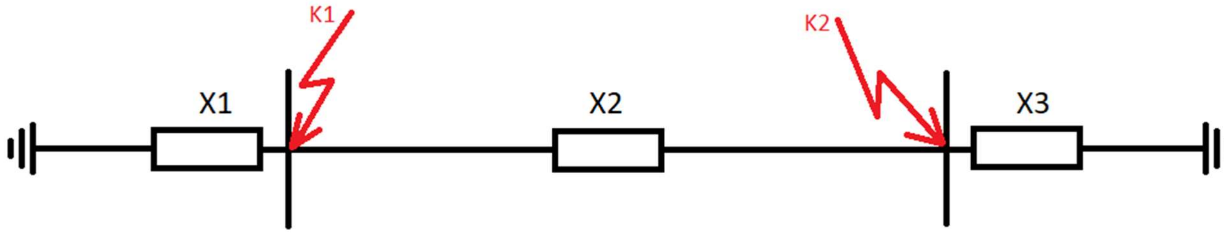

Figure 3. Changed line diagram with short circuit points K1 and K2

X2 value was already calculated:

$X_{L_{line}} = 50{,}07\ \Omega;$

X1 and X3 values are calculated using data from table below:

Reactance	Darbėnai (330 kV)	Ventspils (330kV)
$\sum X_{0max} =$	18,56 Ω	21,30 Ω
$\sum X_{0min} =$	29,40 Ω	29,40 Ω

Minimal load

All three values of the minimal load will be from the table above:

$X1 = \Sigma X_{0min} = 29.40\ \Omega;$

$X2 = 50.07\ \Omega;$

$X3 = \Sigma X_{0min} = 29.40\ \Omega;$

K1 short circuit current calculation using minimal load:

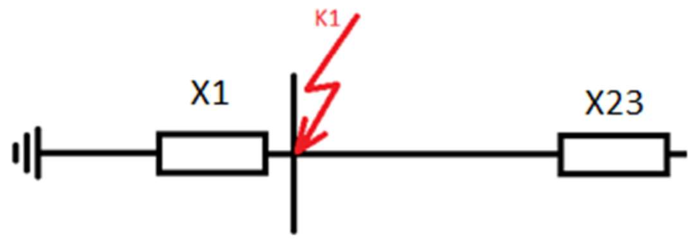

Figure 4. K1 short circuit in transmission line

$X1 = \Sigma X_{0min} = 29.40\ \Omega;$

$X23 = X2 + X3 = 50{,}07\ \Omega + 29.40\ \Omega = 79.47\ \Omega;$

$$X_{\Sigma K1} = \frac{X1 * X23}{X1 + X23} = \frac{29.40\ \Omega * 79.47\ \Omega}{29.40\ \Omega + 79.47\ \Omega} = \frac{2336.42\ \Omega}{108.87\ \Omega} = 21.46\ \Omega$$

$$I_{S.C}^{(1)} = \frac{E}{(3X_0)\sqrt{3}} = \frac{330000\ V}{(3 * 21.46\ \Omega)\sqrt{3}} = 2959.39\ A;$$

$$I_{S.CX_1}^{(1)} = \frac{E}{(3X_1)\sqrt{3}} = \frac{330000\ V}{(3 * 29.40\ \Omega)\sqrt{3}} = 2160.15\ A;$$

$$I_{S.CX_{23}}^{(1)} = \frac{E}{(3X_{23})\sqrt{3}} = \frac{330000\ V}{(3 * 79.47\ \Omega)\sqrt{3}} = 799.15\ A;$$

K2 short circuit current calculation using minimal load:

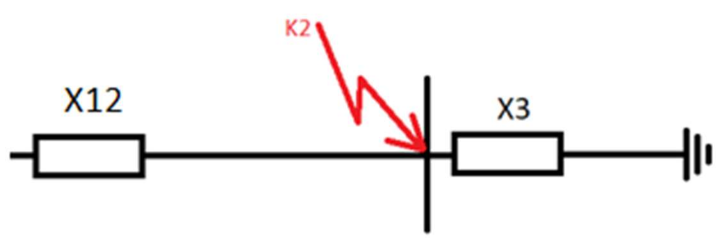

Figure 5. K2 short circuit in transmission line

$X3 = \Sigma X_{0min} = 29.40\ \Omega;$

$X12 = X1 + X2 = 29.40\ \Omega + \ 50{,}07\ \Omega = 79.47\ \Omega;$

$$X_{\Sigma K2} = \frac{X3 * X12}{X3 + X12} = \frac{29.40\ \Omega * 79.47\ \Omega}{29.40\ \Omega + 79.47\ \Omega} = \frac{2336.42\ \Omega}{108.87\ \Omega} = 21.46\ \Omega$$

$$I_{S.C}^{(1)} = \frac{E}{(3X_0)\sqrt{3}} = \frac{330000\ V}{(3 * 21.46\ \Omega)\sqrt{3}} = 2959.39\ A;$$

$$I_{S.CX_3}^{(1)} = \frac{E}{(3X_3)\sqrt{3}} = \frac{330000\ V}{(3 * 29.40\ \Omega)\sqrt{3}} = 2160.15\ A;$$

$$I_{S.CX_{12}}^{(1)} = \frac{E}{(3X_{12})\sqrt{3}} = \frac{330000\ V}{(3 * 79.47\ \Omega)\sqrt{3}} = 799.15\ A;$$

Maximum load

All three values of the maximum load will be from the table above:

$X1 = \Sigma X_{0max} = 18.56\ \Omega;$

$X2 = 50.07\ \Omega;$

$X3 = \ \Sigma X_{0max} = 21.30\ \Omega;$

K1 short circuit current calculation using maximum load:

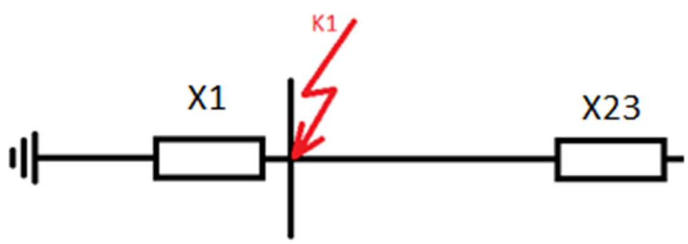

Figure 6. K1 short circuit in transmission line

$X1 = \Sigma X_{0max} = 18.56\ \Omega;$

$X23 = X2 + X3 = 50{,}07\ \Omega + 21.30\ \Omega = 71.37\ \Omega;$

$$X_{\Sigma K1} = \frac{X1 * X23}{X1 + X23} = \frac{21.30\ \Omega * 71.37\ \Omega}{21.30\ \Omega + 71.37\ \Omega} = \frac{1520.18\ \Omega}{92.67\ \Omega} = 16.40\ \Omega$$

$$I_{S.C}^{(1)} = \frac{E}{(3X_0)\sqrt{3}} = \frac{330000\ V}{(3 * 16.40\ \Omega)\sqrt{3}} = 3872.47\ A;$$

$$I_{S.CX_1}^{(1)} = \frac{E}{(3X_1)\sqrt{3}} = \frac{330000\ V}{(3 * 18.56\ \Omega)\sqrt{3}} = 3421.79\ A;$$

$$I_{S.CX_{23}}^{(1)} = \frac{E}{(3X_{23})\sqrt{3}} = \frac{330000\ V}{(3 * 71.37\ \Omega)\sqrt{3}} = 889.85\ A;$$

K2 short circuit current calculation using maximum load:

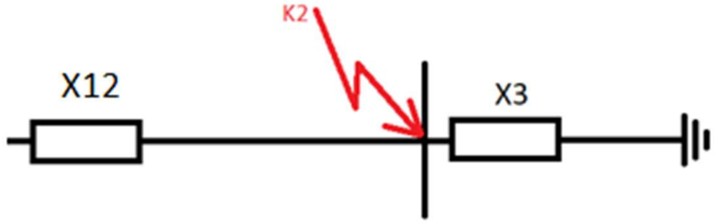

Figure 7. K2 short circuit in transmission line

$X3 = \Sigma X_{0max} = 21.30\ \Omega$;

$X12 = X1 + X2 = 18.56\ \Omega + 50{,}07\ \Omega = 68.63\ \Omega$;

$$X_{\Sigma K1} = \frac{X3 * X12}{X3 + X12} = \frac{21.30\ \Omega * 68.63\ \Omega}{21.30\ \Omega + 68.63\ \Omega} = \frac{1461.82\ \Omega}{89.93\ \Omega} = 16.26\ \Omega$$

$$I_{\text{S.C}}^{(1)} = \frac{E}{(3X_0)\sqrt{3}} = \frac{330000\ V}{(3 * 16.26\ \Omega)\sqrt{3}} = 3905.81\ A;$$

$$I_{\text{S.C}X_3}^{(1)} = \frac{E}{(3X_3)\sqrt{3}} = \frac{330000\ V}{(3 * 21.30\ \Omega)\sqrt{3}} = 2981.62\ A;$$

$$I_{\text{S.C}X_{12}}^{(1)} = \frac{E}{(3X_{12})\sqrt{3}} = \frac{330000\ V}{(3 * 68.63\ \Omega)\sqrt{3}} = 925.38\ A;$$

1. 6. Overall impact of a new transmission line

1. 6. 1. Impact on the environment

Two key concepts are associated with the long-term presence of transmission line rights-of-way in wildlife habitat: edge effect and habitat fragmentation. While the mixture of habitats created by rights-of-way can allow greater density and diversity of wildlife to be present, transmission lines may also produce a negative edge effect for some species which require large, undisturbed habitat. Rights-of-way can create an edge effect, which refers to the border between different types of habitats and it is regarded as an important component of wildlife habitat. Vegetation composition changes in the newly created edge because plant species that do well in high light conditions become more widespread and abundant while interior species not accustomed to higher light intensity are eliminated. [12]

Habitat fragmentation refers to plant communities that have become divided or isolated. Individual transmission line projects may fragment the landscape by dividing large blocks of forested habitat into smaller blocks which can result in a decline in species within the remaining forests. The northern spotted owl is one example of a raptor dependent on old growth forest that is negatively affected by fragmentation. Woodland caribou, which require large tracts of relatively undisturbed habitat may also be negatively affected by any habitat fragmentation effects caused by transmission line rights-of-way. [12]

Over the long-term, the right-of-way will provide winter access and limited summer access depending on the type of terrain the right-of-way crosses. An increase in hunting may occur due to the presence of a transmission line. Long-term access could have a small, local negative effect on animal populations. For example, birds of prey such as eagles are more vulnerable to increased harassment along some accessible rights-of-way.

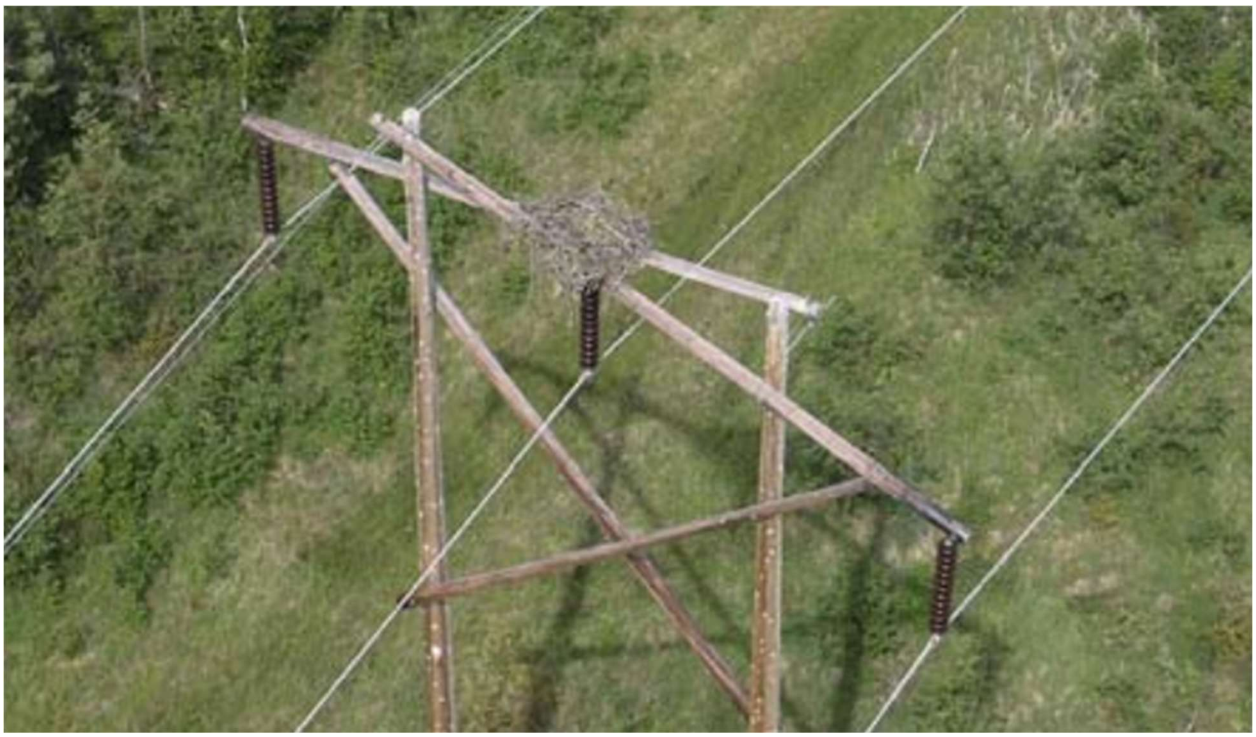

Figure 8. An osprey nest on a transmission line structure. [12]

Many navigable waterways have access points, and a stream or river could be fished along its length regardless of a new access point created by the line. However, new transmission lines could increase access in previously inaccessible fishing areas and potential for increased access could increase the harvest of fish. [12]

Lithuanian transmission grid operator Litgrid has strong belief that harmony with the environment in which we live and work forms the basis for successful activities and development of the company.

Principles of Litgrid environmental protection policy:

Planning of routes of new power transmission lines in such a way that the impact on people's economic activities and nature is as low as possible.

Designs of construction/reconstruction of energy facilities involve the provision for preventive measures to protect the environment, environmentally-friendly technologies, and facilities ensuring energy efficiency.

Contributing to the 20/20/20 plan on promotion of alternative energy sources by the year 2020, which provides for a 20% reduction of greenhouse gas emissions (compared with 1990), a 20% increase in the generation of energy from renewable energy sources, and a 20% increase in energy efficiency of the generation from conventional sources. [9]

1. 6. 2. Impact on property values

Understanding the impact is important to electricity suppliers in planning routes and determining fair compensation in cases of full or partial resumption of private land. Those affected by the establishment or extension of transmission infrastructure also want greater certainty about the process and outcomes and how their economic or domestic operations are likely to be affected. Years of international practice in compensation raise the issue of the exact nature of the affliction created by power lines and equipment.

Electromagnetic fields and the effect of differing kinds of radiation on humans are matters of mounting concern, abetted by recent dilemmas surrounding mobile telephones and their towers. The focal health outcome is, naturally, cancer and a fairly copious literature has emerged. Associated writing probes the effect of EMF on livestock, with obvious implications for rural property valuations near power lines. [10]

Health implications of Electric Magnetic Fields (EMFs) as the most likely high voltage overhead transmission lines (HVOTL) risk attribute to attract concern and the consequential risk of a possible reduction in property value often became evident in discussions about EMF and, in fact, most other transmission effects. All effects bear directly on the homeowner but EMF risk in particular has the potential to amplify indirectly (i.e. 'ripple') among the community and in the property market in a process known as 'consumption depreciation.' Residential real estate is both a consumption good and investment asset and is sensitive to social settings and planning regimes and practices.

When HVOTLs are involved, purchase decisions factor in not only a resident's perceived loss of utility in foregone views and compatibility of adjacent land uses, but also in a reduction of investment value if prospective purchasers perceive a place as stigmatized. The environmental stigma arising from HVOTL is the perception of potential buyers and sellers of real estate in proximity to HVOTL who consider that the real estate is compromised in its utility by risk attributes and consequently diminished in value. Numerous factors affect market perceptions of utility. [11]

Although HVOTLs have existed for over 100 years, many people, and homeowners in particular, are still wary of them. Research into public reactions to the provision of lines has reinforced the finding of negative perceptions, albeit with substantial variation in intensity caused by measurement differences across studies, as well as disparities in socio-economic status and the choice of environmental variables. Public perceptions of risk initially focused on aesthetic and engineering qualities. The year 1979 was a turning point, suggesting the first relation of EMF exposure to possible human health effects. Whilst such a link remains unproven, fears of transmission facilities have since been repeated. Issues of safety and environmental damage, as well as interference with property rights, abet the negativity. Proposals of new lines can foster apprehension about local residents' wealth and financial security, due to resumption procedures and associated compensation rights which could appear complex and threatening. The few recorded papers appear amongst studies of 'difficult' industrial land uses and other forms of infrastructure (e.g. railways) and airports. [11]

2. MODELING OF ELECTRICITY MARKET

2. 1. Electricity market and price forecast models

Electricity systems models are software tools used to manage electricity demand and the electricity systems, to trade electricity and for generation expansion planning purposes. Various portfolios and scenarios are modelled in order to compare the effects of decision making in policy and on business development plans in electricity systems so as to best advise governments and industry on the least cost economic and environmental approach to electricity supply, while maintaining a secure supply of sufficient quality electricity. The modelling techniques developed to study vertically integrated state monopolies are now applied in liberalized markets where the issues and constraints are more complex.

The development of liberalized electricity markets and the rapid growth of variable renewable power sources have seen the development of a number of proprietary off the shelf type and custom-built electricity market models in the last 10 years. This modelling has been predominantly in the United States of America (USA), New Zealand and Europe, where issues associated with the increased levels of wind power penetration have led to concerns by regulators and system operators regarding additional system balancing and reserve costs. However, academics and electricity utility companies began electricity modelling in earnest in the 1950's using linear programming techniques, mostly in capacity expansion, usually to plan new generators to meet increased electricity demand, the so-called capacity expansion problem. Prior to the 1973 oil crisis, electricity planning was reasonably uncomplicated due to the fairly predictable increases in electricity demand with a shift to predominantly larger generating plants. Electricity systems models are tools used by electricity analysts such as engineers, economists and planners to manage and plan the electricity system, to trade electricity and for generation expansion planning purposes. In Integrated Resources Planning (IRP) electricity systems are modelled in order to compare the effects of decision making, policy and business development plans to best guide governments and industry on the least cost economic and environmental approach to electricity supply, while maintaining a secure supply of sufficient quality electricity. Issues and constraints in electricity systems modelling not only include available fuel source availability and cost, regulation, grid and generators limitations but market forces, changes in demand patterns, technological advances and more importantly the environment. Electricity systems' modelling is now far more complex and thus requires new techniques. [14]

Research developments follow three main trends: optimization models, equilibrium models and simulation models. Optimization models focus on the profit maximization problem for one of the firms competing in the market, while equilibrium models represent the overall market behavior taking into consideration competition among all participants. Simulation models are an alternative to equilibrium models when the problem under consideration is too complex to be addressed within a formal equilibrium framework.

Although there are many other possible classifications based on more specific attributes, the different mathematical structures of these three modeling trends establish a clearer division. Their various purposes and scopes also imply distinctions related to market modeling, computational tractability and main uses. [15]

The level of understanding of the electricity system by the analyst and level of expertise of the modeler is also very important in electricity systems modelling because models can be constraint to operate in different ways. The analysts must fully understand the implications of generator operational characteristics and other system and market data such as capital cost, operation and maintenance costs, dispatch rules, market rules, VoLL, LOLP, ENS, efficiency and so forth in order to ensure the electricity system is operating efficiently. The SO and DP techniques used in stochastic programming were also presented and the literature review identified that there are many techniques used to model the different components and aspects of the electricity system. A number of proprietary electricity systems models used in the USA and Europe including AURORAxmp, EMCAS, GTMax, PLEXOS, UPLAN, WASP IV and WILMAR were presented in order to inform electricity analysts in the choice of model to investigate different aspects of the electricity system. Once again it was obvious that these models even though similar in some regard can be very different in others. Thus the choice of model to study electricity systems is critical and should be fully scoped prior to selecting any proprietary software tools. Electricity system planning and assessment is a dynamic iterative process with stochastic elements, which requires multiple inputs, constraints and decision paths to assess possible future changes and developments in the electricity system and market due to economic market forces and technological advancements, social demands and government policy. All the issues, risks and uncertainties add another layer of complexity to electricity systems modelling and that any one outcome from a model is only one of a number of possible outcomes, which are only meant to guide the decision making process. [14]

2. 1. 1. Simulation models

Simulation models are an alternative when the problem under consideration is too complex to be addressed within a formal equilibrium framework. Simulation models typically represent each agent's strategic decision dynamics by a set of sequential rules that can range from scheduling generation units to constructing offer curves that include a reaction to previous offers submitted by competitors. The great advantage of a simulation approach lies in the flexibility it provides to implement almost any kind of strategic behavior. However, this freedom also requires that the assumptions embedded in the simulation be theoretically justified. [15]

In many cases, simulation models are closely related to one of the families of equilibrium models. For example, when in a simulation model firms are assumed to take their decisions in the form of quantities, the authors will typically refer to the Cournot equilibrium model in order to support the adequacy of their approach.

These models form the second class of price-forecasting techniques, where an exact model of the system is built, and the solution is found using algorithms that consider the physical phenomenon that governs the process. Then, based on the model and the procedure, the simulation method establishes mathematical models and solves them for price forecasting. Price forecasting by simulation methods mimics the actual dispatch with system operating requirements and constraints. It intends to solve a security constrained optimal power flow (SCOPF) with the entire system range. Two kinds of simulation models have been analyzed in this paper. One is market assessment and portfolio strategies (MAPS) algorithm developed by GE Power Systems Energy Consulting and the other is UPLAN software developed by LCG Consulting. [16]

MAPS is used to capture hour-by-hour market dynamics while simulating the transmission constraints on the power system. Inputs to MAPS are detailed load, transmission and generation units' data. Where as the outputs are complete unit dispatch information, LMP prices at generator buses, load buses and transmission flow information. UPLAN, a structural multi-commodity, multi-area optimal power flow (MMOPF) type model, performs Monte Carlo simulation to take into account all major price drivers. UPLAN is used to forecast electricity prices and to simulate the participants' behavior in the energy and other electricity markets like ancillary service market, emission allowance market. The inputs to MMOPF are competitive bidding behavior, generation units' data, the transmission network data, hydrological conditions, fuel prices and demand forecasts. These are almost comparable to the input variables of MAPS. The outputs are forecast of prices and their probability distribution across different energy markets. The dynamic effect of drivers on market behavior has also been captured. Both UPLAN and MAPS may be used for long as well as short range planning.

Simulation methods are intended to provide detailed insights into system prices. However, these methods suffer from two drawbacks. First, they require detailed system operation data and second, simulation methods are complicated to implement and their computational cost is very high. [16]

2. 1. 2. Game theory-based models

In energy sector, game theory has been widely used in modeling interactions. Interaction model between utility company (UC) and consumers has been discussed extensively and is usually constructed by Stackelberg game to balance supply and demand or achieve a win–win situation, such as leader-followers game and multi-leaders and multi-followers game. Besides, the interaction between distribution market operator (DMO) and demand response aggregators (DRAs) is also established by Stackelberg game. In addition, the interactions model among UCs, price makers, are investigated by constructing a non-cooperative static game. [21]

Game theory-based models can be used to explore relevant aspects of the design and regulation of liberalized energy markets. [15]

In [17] the electricity market as a Cournot game was modeled. Even though other approaches are possible such as conjectural variations, Bertrand games, or supply functions, it was found that the simpler Cournot model with capacity constraints provides useful and novel insights into the main characteristics of oligopolistic strategic behavior within a portfolio setting.

Two different hypotheses for these Cournot games have been adopted and analyzed in [17]: a single-clearing Cournot game in which there is a single-clearing price for each hour of the day (which attempts to replicate the conditions of electricity trading in pool like systems), as distinct from a multi-clearing Cournot game in which there are different clearing prices for different markets, over certain times of the day (which attempts to replicate the conditions of electricity trading in bilateral markets). Therefore, these clearing-mechanisms define a theoretical model of prices and loads in electricity markets in which the behavior of a generator is a function of the industry structure and of his portfolio of plants. Further, each one of the models captures the following stylized facts: A generator's supply function is step-shaped. A generator may receive different prices for his generation from different plants, even if these are identical. Different generators may price the same type of plant differently. A generator aims at maximizing the value of his portfolio of plants as a whole. [17]

The plant trading game represents the interaction between electricity companies that trade generating plants. The electricity market game formulates the daily electricity market prices by assuming Cournot players. [17]

2. 1. 3. Supply function models

The Supply Function Equilibrium (SFE) introduced by Klemperer and Meyer in [20] is a way of modeling how competitors could maximize profits in the marketplace under conditions of uncertain demand; this method has also been applied to the electricity industry reforms in England and Wales pool market. The SFE concept offers an appropriate model of competitive behavior of multiple suppliers of a single product in which the existence of the Nash equilibrium does not require the demand to be elastic; in fact, the representation of the behavior of suppliers by means of supply functions, creates elasticity of the residual demand faced by each player and could result in an equilibrium outcome even if the demand is non-responsive to price. The on-going deregulation of the electric industry over the last decade in various countries of the world prompted industry analysts and consultants to study the SFE concept as a mean for modeling strategic behavior in electricity markets. Different application of this model has been proposed ranging from market power assessment of the impact of strategic behavior on electricity prices to the evaluation of generating assets.

Klemperer and Meyer in [20] showed that, in the absence of uncertainty and given the competitors' strategic variables (quantities or prices), each firm has no preference between expressing its decisions in terms of a quantity or a price, because it faces a unique residual demand. On the contrary, when a firm faces a range of possible residual demand curves, it expects, in general, a bigger profit expressing its decisions in terms of a supply function that indicates the price at which it offers different quantities to the market. This is the SFE approach which, originally developed by Klemperer and Meyer in [20], has proven to be an extremely attractive line of research for the analysis of equilibrium in wholesale electricity markets.

Calculating an SFE requires solving a set of differential equations, instead of the typical set of algebraic equations that arises in traditional equilibrium models, where strategic variables take the form of quantities or prices. SFE models have thus considerable limitations concerning their numerical tractability. In particular, they rarely include a detailed representation of the generation system under consideration. The publications devoted to these models concentrate on four topics: market power analysis, representation of electricity pricing, linearization of the SFE model and evaluation of the impact of the electric power network. [15]

2. 1. 4. Agent-based models

A typical agent-based model has three elements:

1. A set of agents, their attributes and behaviors.

2. A set of agent relationships and methods of interaction: An underlying topology of connectedness defines how and with whom agents interact.

3. The agents’ environment: Agents interact with their environment in addition to other agents.

A model developer must identify, model, and program these elements to create an agent-based model. A computational engine for simulating agent behaviors and agent interactions is then needed to make the model run. An agent-based modeling toolkit, programming language or other implementation provides this capability. To run an agent-based model is to have agents repeatedly execute their behaviors and interactions. This process often does, but is not necessarily modeled to, operate over a timeline, as in time-stepped, activity-based, or discrete-event simulation structures. [18]

Simulation provides a more flexible framework to explore the influence that the repetitive interaction of participants exerts on the evolution of wholesale electricity markets. Static models seem to neglect the fact that agents base their decisions on the historic information accumulated due to the daily operation of market mechanisms. In other words, agents learn from past experience, improve their decision-making and adapt to changes in the environment (e.g.,competitors’ moves, demand variations or uncertain hydroinflows). This suggests that adaptive agent-based simulation techniques can shed light on features of electricity markets that static models ignore.

In an agent-based simulation model, generation companies are represented as autonomous adaptive agents that participate in a repetitive daily market and search for strategies that maximize their profit based on the results obtained in the previous session. Each company expresses its strategic decisions by means of the prices at which it offers the output of its plants. Every day, companies are assumed to pursue two main objectives: a minimum rate of utilization for their generation portfolio and a higher profit than that of the previous day. The only information available to each generation company consists of its own profits and the hourly output of its generating units. As usual in these models, demand side is simply represented by a linear demand curve. This setting allows the authors to test a number of market designs relevant for the changes that have recently taken place in E&W wholesale electricity market. In particular, they compare the market outcome that results under the pay-as-bid rule to that obtained when uniform pricing is assumed. Additionally, they evaluate the influence of allowing companies to submit different offers for each hour, instead of keeping them unchanged for the whole day. The conclusion is that daily bidding together with uniform pricing yields the lowest prices, whereas hourly bidding under the pay-as-bid rule leads to the highest prices. [15]

Within the new liberalized markets, and due to the decentralization of the long-term decisions, the investment problem is now very different from the capacity planning formulations that characterized power system economics for so long. The privatized market presents an increased risk due to price and demand uncertainty and due to competition (the investment projects are private). The investment problem in oligopolistic electricity markets using stochastic prices, to perform simulation-based valuation of generation assets, taking into account start-up and shutdown costs. [17]

2. 1. 5. Fundamental models

Fundamental, also known as structural, models are designed to establish the relationship between physical and economic factors that can be observed in electricity markets. These relationships are often described by nonlinear, complex equations designed to assess how fundamental factors (energy demand, weather conditions, water levels in rivers or reservoirs, and others) affect the price of electricity on the exchange. [23]

Structural models assume complete knowledge of a very detailed information set, akin to that held by the firm's managers. In most cases, this informational assumption implies that a firm's default time is predictable. [24]

An approach for improved design and lifetime evaluation of environmental cracking is presented based on fundamental modeling of the underlying processes operative in crack advance. In outlining this approach and its application in energy industries, the requirements for a life prediction methodology will be highlighted and the shortcomings of the existing design and lifetime evaluation codes will be discussed. [22]

Just as this modeling was implemented in [22], it also, as mentioned, can be implemented in the energy industries. More about the techniques of this type of modeling implemented for environmental cracking is as follows: Essential ingredients to any comprehensive life prediction methodology include the following: treatment of the continuum in material and condition, environment, and stress; treatment of time-dependent crack growth to encompass the continuum from static to cyclic loading; unified approach for crack initiation and growth, which requires understanding of short crack behavior; fracture mechanics and crack chemistry similitude for relevance to varying component geometries and loading conditions; calculational approaches for complex service conditions which require accounting for the time and through-thickness variations in properties and the use of distributions in properties as well as probabilistic approaches; integrated predictive modeling and monitoring of on-line system behavior; and extensibility into related cracking systems. [22]

Pure reference models are commonly used for medium-term forecasts. By combining these models with time series, regression, and neural network models, the resulting hybrid models can also be used for short-term price predictions. In addition, these models are usually price-oriented and therefore do not provide

detailed electricity market information: electricity generation by fuel type and different power plants, energy flows, CO2 emissions, etc. For this reason, these models are not suitable for this study. [23]

2. 1. 6. Other models

Another type of modeling is called reduced form models, often compared with structural modeling. They assume knowledge of a less detailed information set, akin to that observed by the market. In most cases, this informational assumption implies that the firm's default time is inaccessible. Given this insight, one sees that the key distinction between structural and reduced form models is not in the characteristic of the default time (predictable versus inaccessible), but in the information set available to the modeler. Indeed, structural models can be transformed into reduced form models as the information set changes and becomes less refined, from that observable by the firm's management to that which is observed by the market. [24]

Rather than debating which model type is best in terms of forecasting performance, the debate should be focused on whether the model should be based on the information set observed by the market or not. For pricing and hedging credit risk, we believe that the information set observed by the market is the relevant one. This is the information set used by the market, in equilibrium, to determine prices. Given this belief, a reduced form model should be employed. As a corollary of this information structure, the characteristic of the firm's default time is determined—whether it is a predictable or totally inaccessible stopping time. [24]

2. 2. Suitable modelling tool

All the models listed in 2. 1. chapter are used in market modeling and price forecasting. They can be open-source models or commercial products. The latter is not suitable for this case since the price is usually not worth spending for a single master thesis student paper. Furthermore, not only those models can be price but also not approachable on academic level. Therefore, we will turn to open-source models for this study since they are non-commercial and free. Although, the described models in 2. 1. chapter are of a different implementation range. Having in mind a specific case of this paper, only certain models for be applied for this study.

Modeling of a new transmission line impact on market was compared in [23] and can be applied in this paper.

From the model presented in the above-mentioned work, seven models can be selected, which are adapted to model international electricity markets and which, among other models, also have simulation models for long-term electricity market forecasts. These models are: Balmorel, EMPS, MESSAGE, MiniCAM, PERSEUS, RAMSES and WILMAR Planning Tool. Among them, only three models (Balmorel, MiniCAM and MESSAGE) are free for academic activities.

MiniCAM is not focused on electricity market prices, but on the assessment of greenhouse gas emissions, so it does not fully meet the objectives of this work.

MESSAGE and Balmorel are optimization models for medium- and long-term planning of energy systems. Both models require detailed data on the structure of production and are suitable for assessing both national and regional scenarios. On the other hand, out of these two modeling tools, the Balmorel model was developed exclusively for modeling the electricity market in the Baltic Sea region. Also, unlike MESSAGE, Balmorel is an open source program and can be freely customized. For these reasons, the Balmorel model will be used in this work. [23]

3. METHODOLOGY

3. 1. “Balmorel” model

3. 1. 1. About “Balmorel” model

“Balmorel” is an open-source model written in “GAMS” language.

“Balmorel” is a partial equilibrium model for analyzing the electricity and combined heat and power sectors in an international perspective. It is highly versatile and may be applied for long range planning as well as shorter time operational analysis. “Balmorel” is implemented as a mainly linear programming optimization problem.

The model is developed in a model language, and the source code is readily available under open source conditions, thus providing complete documentation of the functionalities. Moreover, the user may modify the model according to specific requirements, making the model suited for any purpose within the focus parts of the energy system.

The “Balmorel” model has been applied in projects or other activities in a number of countries, e.g., in Denmark, Norway, Sweden, Estonia, Latvia, Lithuania, Poland, Germany, Austria, Ghana, Mauritius, Canada and China. It has been used for analyses of, i.e., security of electricity supply, the role of flexible electricity demand, hydrogen technologies, wind power development, the role of natural gas, development of international electricity markets, market power, heat transmission and pricing, expansion of electricity transmission, international markets for green certificates and emission trading, electric vehicles in the energy system, environmental policy evaluation. [13]

The Balmorel model, when examining the development of the electricity market, assumes that the electricity market is fully liberalized and well developed, so that there is ideal competition between market producers. The market price calculated in this way is ideally suited to the cost of production incurred. It should be noted, however, that the model emphasizes precisely generating one’s technologies, and the consumption side is expressed only in terms of needs, i.e. y. the main driving force of the model is the demand for heat and electricity. It selects generating technologies that meet the demand at the lowest cost and meet all the system's constraints, such as environmental requirements, technological and bandwidth constraints. [23]

The energy system in the Balmorel model is divided into regions. A region can be anyone, from an individual city or district to a state. Regions can exchange electricity with each other based on market forces: energy will only be transmitted when the price of electricity in the transmitting region is lower than in the receiving region. Naturally, heat cannot be exchanged between regions. Both inter-regional and intra-regional transmission losses are estimated. [23]

Each region has its own needs, resources, and generators. An electricity balance must be ensured for each region. However, unlike in the heat sector, the transmission of electricity between different regions is allowed. Therefore, the electricity balance equation for each region can be expressed as:

$$\sum_{i \in I_r} P_{i,t} = \sum_{r \in R} \left((1 - L_{loss}) * P_{trans} \right) = P_{r,t}^{load} + \sum_{i \in I_{elecsto}} P_{i,t}^{stoload}$$

On the left side of the equation represents the sum of generator power ($P_{i,t}$) of the (r) region and the power of flow capacity(P_{trans}) between neighboring regions while taking transmission losses (L_{loss}) into account. The right side of the equation represents instantaneous electricity demand in region r ($P_{r,t}^{load}$) as well as consumption of accumulating equipment ($P_{i,t}^{stoload}$).

The model describes the power transmission system in terms of linear losses, linear operating costs, and capacity power. An electrical or electrical group describes both technical and economic parameters: fuel type, power, efficiency, pollution (NOx and CH4), fixed and variable production costs, annual production costs, investment costs, primary fuel prices and their variation. Power plants can use several types of fuel and work in cogeneration mode. The modeling also takes into account the electrical start-up time and costs, as well as the minimum production capacity. Planned or typical nuclear power plant shutdowns are taken into account. [23]

Balmorel uses a linear optimization method. The goal of optimization, taking into account all constraints, is to find a solution at the lowest cost - such a distribution of the production structure among the whole region that would achieve the greatest socio-economic benefits, i. e. the total costs of electricity and heat production are minimized. [23]

4. MODELLING RESULTS AND ANALYSIS

4. 1. Model’s input data correction.

Balmorel model outputs a significant amount of information that can be applied for various studies.

In this case the focus will be on electricity market impact only. The results will be analytically overviewed and compared with some of the theoretical expectations.

Model’s base case scenario has preset values which were altered slightly to bring the model closer to real-time data of Lithuania. The following data were input in the modelling:

- The countries simulated:
  - LITHUANIA
- The geographical extension simulated is subdivided as follows:
  - Country LITHUANIA is subdivided into regions and areas as follows:
    - Region LT_R is subdivided into areas as follows:

LT_R_Urban	LT_R_Rural

- The years to be simulated, i.e. those in SET Y are:

2023	2024

- The seasons in SET S and their duration:

Name:	S20
Days:	365.0

- The time segments in SET T and their duration (if a season had 24 hours' duration):

Name:	T001	T002	T003	T004	T005
Hours:	4.8	4.8	4.8	4.8	4.8

- The length of the time segments (S,T) has a duration that is equal to the product of the durations of the element in S and the element in T. For the first time segment of the year, for instance, this is equal to 1752.0 hours. The complete table of the lengths (hours per year) of the time segments (S,T):

T001	1752.0
T002	1752.0
T003	1752.0
T004	1752.0
T005	1752.0

- If each season were of duration 24 hours, then the length in hour T in a season would be as follows. (Usefull in relation to short term storages that are assumed to be working on a daily basis, although cyclical within each season, which need not be of 24 hours' duration.)

T001	4.8
T002	4.8
T003	4.8
T004	4.8
T005	4.8

- Electricity demand (GWh), first and last years in simulation period:

	2023	2024
LT_R	11192	10957

- Loss in electricity distribution:

  - percentage of electricity entering the distribution network

  - percentage of consumption

  - quantity (relative to nominal demand) in first year (2023)

  - cost

	%	%	MWh	EUR90/MWh
LT_R	12.00	13.64	1526182	8.86

To see the change in price the data of the model was also corrected. The price that was put into data was of 2024-05-07 day ahead market which was around 98 Eur/MW.

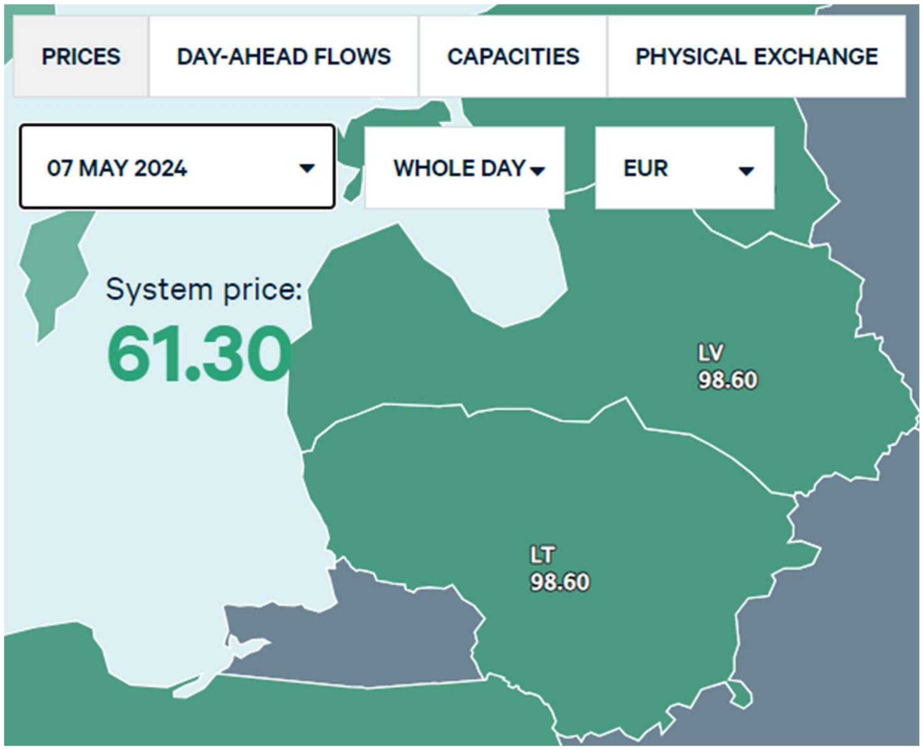

Figure 9. 2024-05-07 day ahead prices.[28]

Considering that every household has their own agreements and might be getting different tariffs for electricity it will be more accurate to use the price for electricity before taxes apply. Since the transmission line that is being modelled is connecting Lithuanian-Latvian region and the prices most of the times do not differ that much between Lithuania and Latvia, the following data was put into the model.

4.2. Impact on electricity prices in the region

Firstly, considering that the price of transmission line itself will set the investor back by approximately 120-150 million euros. This price is based on the publicly available estimations and analytical point of view that this line would be an important asset to the regional grid for both Lithuania and Latvia so the materials used should be of a high quality. The whole project would need to be well thought out so that concludes into that price of this new transmission line. This is, of course, while not considering the upcoming prices of the loss compensation, reactive power, generated by a long-distance line which would require to activate additional reactive power compensation capabilities that will increase the cost if the line Is not loaded enough.

Balmorel model uses a lot of input information for its calculations. For example, demand of both electricity and heat, distribution of different regions and cost of transmission between countries or regions.

In this paper it was already stated that one of the most important factors that impact the electricity market is the capacity. Since the line that is being modelled here will have a capacity of 300 MVA, as it was described in 1.5. section, the data will be corrected accordingly to see the change in price.

Initial transmission capacity between regions data:

Region	EE_R	FI_R	LV_R	LT_R	PL_R	RU_W	RU_K	SE_N	SE_M	SE_S
2000.LV_R	1300	0	0	1200	0	0	700	0	0	0
2000.LT_R	0	0	1200	0	0	1000	0	0	0	0

By adding the capacity value of the transmission line that is being modelled in this paper, the following table is what was used in the Balmorel modelling:

Region	EE_R	FI_R	LV_R	LT_R	PL_R	RU_W	RU_K	SE_N	SE_M	SE_S
2000.LV_R	1300	0	0	1500	0	0	700	0	0	0
2000.LT_R	0	0	1500	0	0	1000	0	0	0	0

Data of Denmark, Germany and Norway were hidden since neither Lithuania nor Latvia have any connections with these countries and their regions. Data seen by the Poland's and Sweden's regions are zeros since there is no synchronous connection between those countries and the countries that are being studied in this model yet. Also since Baltic region does not sell or buy any electricity from third world countries, the export and import to those countries we set to zero.

The output data of change in prices:

	S2.T0
LV_R	-28.0000
LT_R	-24.1400

Table 1. Modelling results of change in price of electricity. Unit: Money/MWh.

Concluded modelling results state that considering the increase in capacity in both Lithuania and Latvia regios by 300 MW, the prices would decrease by 28 Eur/MWh in Latvia and 24,14 Eur/MWh in Lithuania. This number is only produced from the data that was presented for the model and it should be treated that way. Precise and accurate prognosis require detailed confidential information so in this paper only the model's data will be analyzed.

The results are very possible, especially considering that Baltic region has stopped participating in any economical exchange of electricity with third countries, so the increase of capacity between regions has much more impact than before.

Another analytical point of view that should be considered is that since Litgrid took Lithuania down the path of innovative electricity future, the renewable energy can be implemented in the systems more easily and with bigger capacities. Just as it is foreseen and planned in the strategy of energy independence Lithuania from being an importer of electricity will become the exporter. One of the main innovative implementations is that transmission grid allows to connect more than 100% of renewable energy of line capacity. Of course each resource‘s capacity on its own cannot exceed this capacity. This is something that can be seen in the RES map provided by Litgrid:

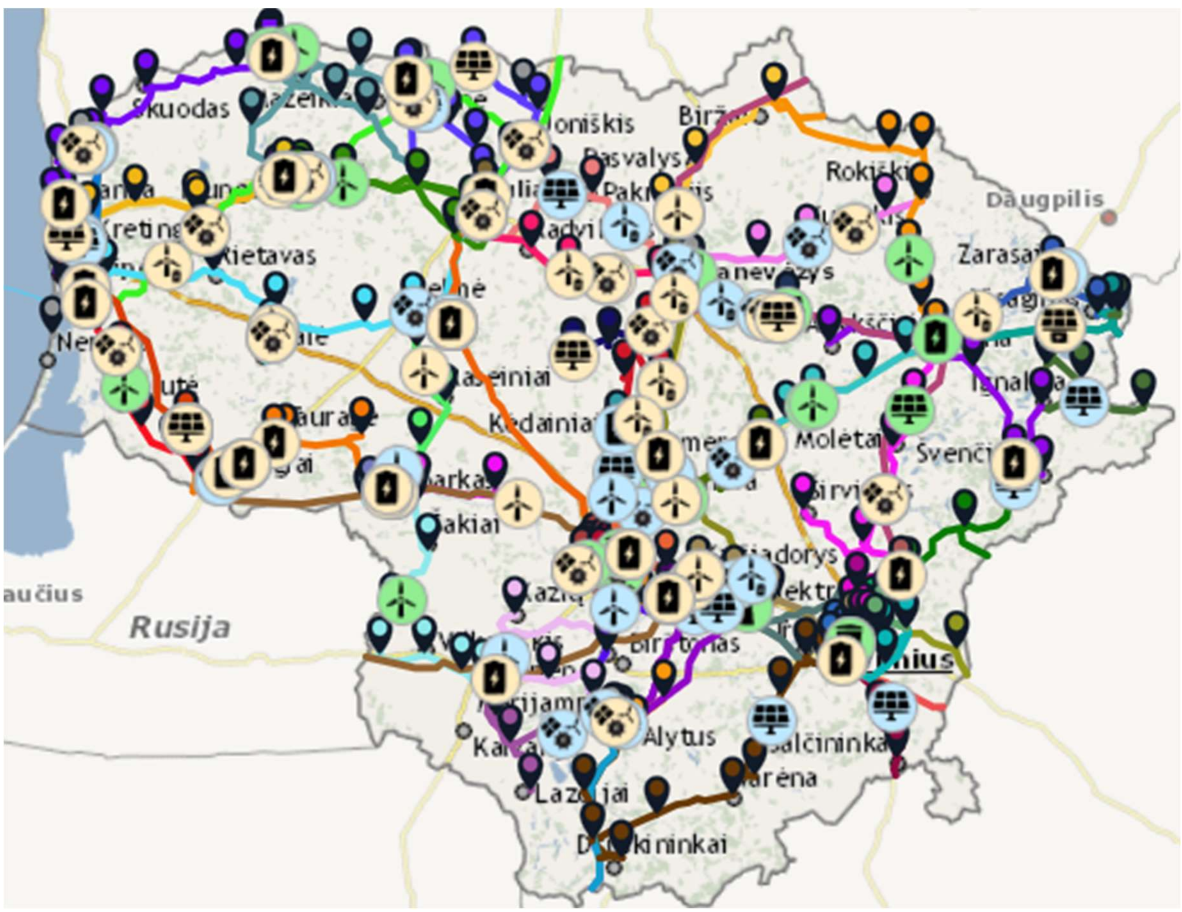

Figure 10. RES allocation map. [29]

This map represents RES allocation in the 110 kV and 330 kV grid. When selected, a certain line information is presented:

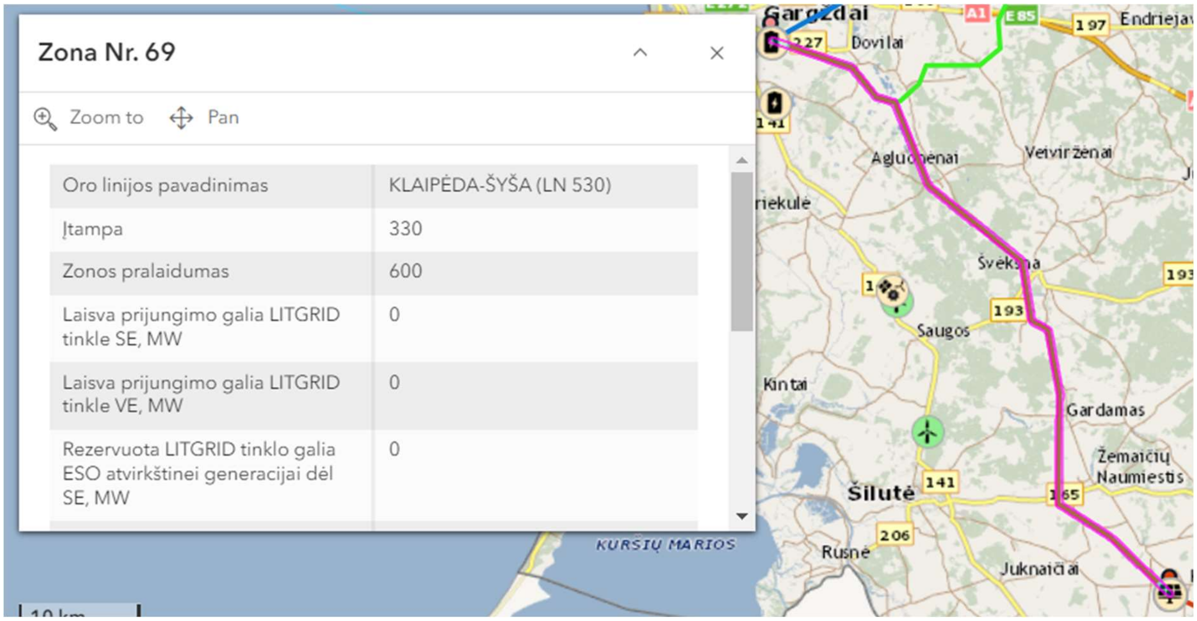

Figure 11. Line's name, voltage and capacity.[29]

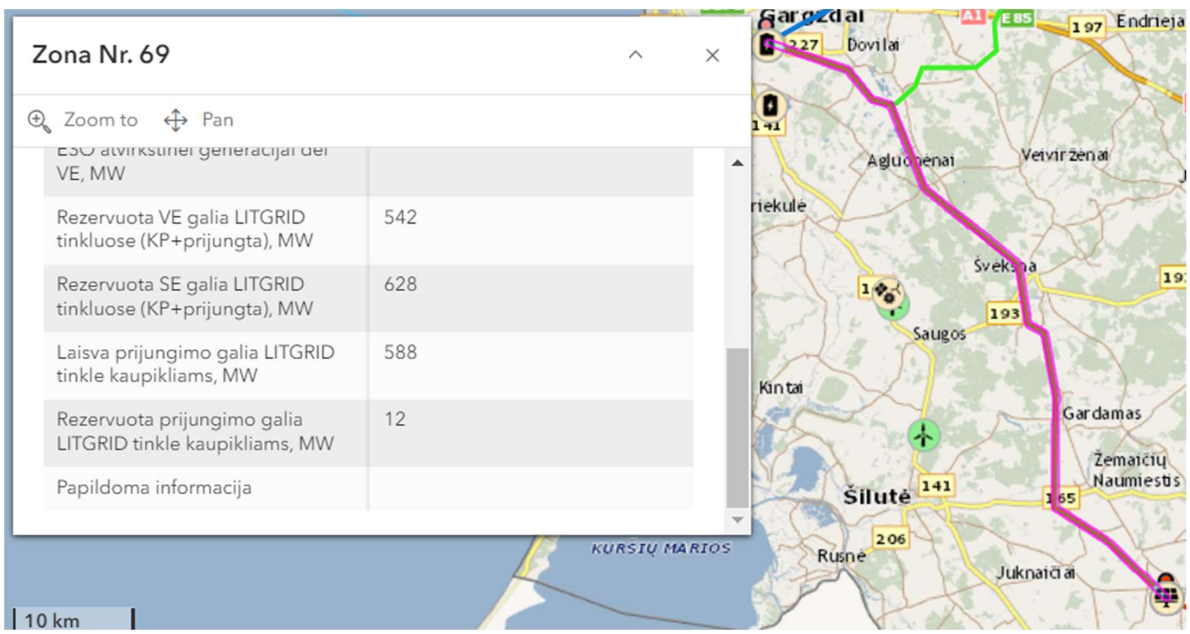

Figure 12. Line's reserved capacity for wind, solar powerplants and capacity for energy storage units.

From this map it is possible to analytically determine that it is possible to connect the amount of line's capacity of each solar, wind and energy storage power plants. This brings the possibility of using the potential of the modelled transmission line even more. Implementing more renewables would mean using less gas-powered power plants which leads to a decrease in prices of electricity since the price of gas is high. Prices that were modelled would be even lower for both Lithuania and Latvia since it could contribute to each countries demand.

4.3. Impact on stability electrical grid

Considering the impact that the transmission line itself can have on the grid's stability, line's reactance calculated in 1.5. section should be mentioned.

Line's length is a big factor, since line this long will generate a lot of reactive power, especially when not loaded. It should be remembered that Lithuanian's side of the line will be in Darbėnai substation which will have a big offshore wind power plant connected to it so it is highly unlikely that the line would be unloaded. That leaves only the reactance of loaded line which will need to be controlled since it would drastically increase voltage in both ends of the line. This can be reduced and controlled using the wind farm that will be connect to Darbėnai substation during windy days or using the synchronous condenser that will be connected in the grid relatively close to the transmission line that is being modelled. There might be other ways and technologies to control reactive power but if there are any that's confidential information of the TSOs. From theoretical point of view those technologies could mainly be shunt reactors.

CONCLUSIONS

1. The transmission line that is modelled in this paper would increase capacity between Lithuanian and Latvian regions by 300 MW and reduce electricity prices by 24,14 Eur/MWh and 28,00 Eur/MWh respectively as well as risks of overloading tie lines. Modelling results were compared with theoretical point of view to conclude that results are realistic.

2. Data used for the modelling was altered to ensure that parameters like 11192 MWh of 2023 demand, 1200 MW of cross-border capacity between Lithuania and Latvia and average electricity prices of 98,6 Eur/MWh would be close to current state of the Lithuanian power system. To model the new transmission lines impact on the market for Lithuania, Balmorel model was used since it has the data of surrounding regions implemented in it.

3. Construction of new transmission lines is necessary to keep up with the development of the electrical grid. 330 kV line that has 300 MW of nominal capacity will allow connection of 300 MW of wind power plants, 300 MW of solar power plants and 300 MW of energy storage units. This is especially relevant for Lithuania because of its rapid renewable energy sources development and synchronization with Continental European synchronous area.

4. Transmission line development requires to ensure that every aspect of impact on the environment and electrical grid is foreseen.Nedir

5. Since the Baltic region stopped commercial exchange of electricity with the rest of IPS/UPS system regions it became more crucial to construct more internal lines to ensure stability of the Baltic region.

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APPENDIXES

Appendix 1. Lithuanian 330-110 kV electricity transmission grid. Source: AB Litgrid, 2022, https://www.litgrid.eu/uploads/files/dir189/dir9/6_0.php