LAPPEENRANTA
UNIVERSITY OF TECHNOLOGY

Faculty of Technology
LUT ENERGY
ELECTRICAL ENGINEERING

MASTER'S THESIS

Development of power flows around Baltic countries with new grid links

Examiners: Professor, D.Sc. Samuli Honkapuro
Professor, D.Sc. Jarmo Partanen
Instructors: M.Sc. Pekka Vile

Author Nadezhda Belonogova

Abstract

Lappeenranta University of Technology
Faculty of Technology
Electrical Engineering

Nadezhda Belonogova
Development of power flows around Baltic countries with new grid links
Master's thesis
2009
85 pages, 24 figures, 26 tables and 22 equations

Examiners: Professor, D.Sc. Samuli Honkapuro
Professor, D.Sc. Jarmo Partanen
Instructors: M.Sc. Pekka Vile, Fortum Portfolio Management and Trading

In the Thesis main focus is done on power flow development paths around the Baltic States as well as on market-based requirements for creation of the common Baltic electricity market. Current market regulations between the countries are presented; barriers for creating competitive common Baltic power market and for electricity trading with third countries are clarified; solutions are offered and corresponding road map is developed.
Future power development paths around the Baltic States are analysed. For this purpose the 330 kV transmission grid of Estonia, Latvia and Lithuania is modelled in a power flow tool. Power flow calculations are carried out for winter and summer peak and off-peak load periods in 2020 with different combinations of interconnections. While carrying out power balance experiments several power flow patterns in the Baltic States are revealed. Conclusions are made about security of supply, grid congestion and transmission capacity availability for different scenarios.

Keywords: Baltic power market, cross-border trading, implicit auction, ITC-mechanism, BRELL ring, power transit

Acknowledgments

I would like to thank my Thesis supervisor Pekka Vile for countless fruitful discussions and invaluable advice throughout the whole writing process, Jaakko Karas for his practical guidelines, Johan Linnarsson and Timo Piispa for support and inspiration.

I am grateful to professor Samuli Honkapuro for numerous advice and assistance and to professor Jarmo Partanen for his encouragement.

I highly appreciate the personnel of the Strategic Portfolio Development subunit, who made me feel warm and comfortable in Fortum from the very first day.

Special thanks goes to former Master's Thesis students in Fortum and current Fortum employees Liudmila Moiseeva, Elena Gurina and Sergey Ilukhin, who shared their Thesis writing experience with me and provided me with practical hints, which made my writing process efficient from the very beginning.

I am extremely thankful to my family for their understanding and support, for keeping me always going further throughout my studies in Finland.

Espoo 08.05.2007

Nadezhda Belonogova

Table of contents

Abbreviations and symbols

AC	alternating current
BALTSO	Baltic Transmission System Operators
BRELL	Belarus – Russia – Estonia – Latvia – Lithuania
CBT	Cross–border trading
CHP	combined heat and power
DC	direct current
ENTSO	European Network of Transmission System Operators
ERC	Energijos Realizacijos Centras
EU	European Union
HPP	hydro power plant
ITC	inter-TSO compensation
NPP	nuclear power plant
PSP	pumped storage plant
TPP	thermal power plant
TSO	Transmission System Operator
UCTE	Union for the Co-ordination of Transmission of Electricity
WG	working group
P	active power
P_l	active power losses
U	voltage
Q	reactive power
R	resistance
X	inductive reactance
B	capacitive reactance
E	energy

Subindexes

L – losses

Load – load value

Min – minimum value

Max – maximum value

sv – specific value

1 Introduction

The Baltic States have until recently not had any power grid links to other EU countries. In November 2006 the Estlink - 1 interconnection to Finland was taken into use, and further links are now proposed to be built. The Baltic power balance is also changing with the closure of the Ignalina nuclear power plant at the end of 2009. International power trading principles are developing with market coupling between power exchanges optimizing cross-border power flows. These developments will influence the power flows for import, export and transit in the Baltic power market.

It is in the interest of the Baltic countries to create a common power market. The main driver is to enable an efficient integration with Nordic and Polish markets, which will ensure security of supply in the Baltic countries, optimal use of energy sources as well as efficient operation of transmission grid.

The Thesis describes current power market situation, gives technical information about the transmission grid in the Baltics and studies prerequisites, needs and requirements of TSOs (Transmission System Operator) , which will help create all necessary conditions to integrate the Baltic market with the Nordic and Continental (UCTE) markets.

Power flow development is analyzed in this work by using a model of the Baltic transmission grid, which is created in the Thesis. In the model several power balance scenarios are simulated for year 2020 with different combinations of proposed grid links and internal Baltic power generation scenarios. The target is to figure out, how the international grid links will change export, import and transit power of each Baltic country and whether the transmission capacity of the whole grid is enough to transmit estimated power flows of 2020. In the end, new market mechanisms are proposed which contribute to creating the common Baltic power market.

The outline of the Thesis is as follows. The second chapter describes current power balance in the Baltic States, introduces several factors which will have an impact on generation development in the nearest future. Existing interconnections with Finland, Russia and Belarus are shortly described. In the third chapter, current power trading mechanisms within the Baltic Rim area and around it are introduced to the reader; the term market coupling principle is explained. The necessary changes to the power market regulations are listed which will accelerate the creation of a common Baltic electricity market and its integration with the Nordic and Polish markets. In the fourth chapter the reader is introduced to development and verification of the model of the 330 kV transmission grid of the Baltic States. The next chapter makes an overview of proposed new interconnections with Nordic and Polish power networks; several power balance scenarios are carried out for different load periods of 2020. The following chapter is dedicated to the Baltic road map for developing new power trading mechanisms. In the last chapter conclusions of the Thesis are presented.

2 Transitional period in the Baltic countries

Estonia, Latvia and Lithuania are nowadays standing on the border of significant changes in power balance. The consumption of each country is annually growing, whereas several currently available energy sources will either decrease or totally disappear in the coming years. In this chapter the focus is made on description of different factors which will have an impact on the power balance of the countries; several solutions are proposed to avoid power deficit in the coming years.

2.1 Characteristic features of different periods

2.1.1 Overview of the Baltic transmission grid

Due to historical reasons the Baltic countries have been operated in parallel with the Russian and Belarusian networks. Being a former member of the Soviet Union, the Baltic States have networks with strong physical connections and system stability.

Baltic States form the so-called BRELL (Belarus-Russia-Estonia-Latvia-Lithuania) ring with Russian and Belarusian networks (see figure 1). The values for transfer capacities (see table 1) are based on the N-1 criterion, which means that tripping of one element, e.g. a line or a transformer, will not lead to the failure of the rest elements of the ring. The values take into account the limits for temperature as well as static and dynamic stability.

Table 1. Transfer capacity of the BRELL ring interconnections for normal conditions, MW (Arnis Staltmanis 2006)

	Maximum power, MW
Central Russia-St.Petersburg	1800<=>1500
St.Petersburg –Estonia	1000<=>1000
Estonia –Pskov(Russia) - Latvia	1200<=>1500-(0.4Pinpp -300)*
Latvia-Lithuania	Max current, A 1000 <=>1000
Lithuania –Kaliningrad	700 <=>700

Lithuania – Belarus	1400<=>2200
Belarus –Smolensk (Russia)	1300<=>1000

*P_{inpp} – generated power at the Ignalina nuclear power plant

The transfer capacity between neighboring countries depends not only on the maximum power of interconnecting lines, but also on the transfer capacity of the internal grid of the respective country. Due to different loads and transfer capacities of power networks, maximum transmitted powers are different in different directions.

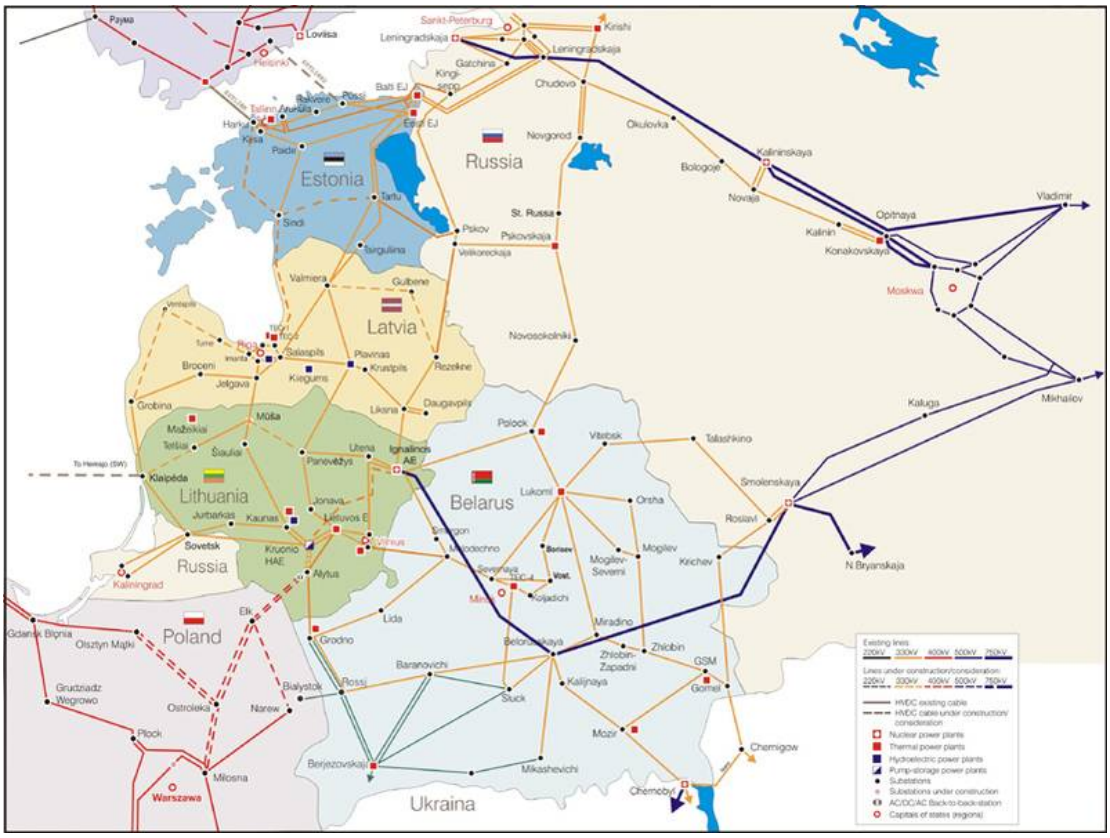

Figure 1. Electrical Ring of the BRELL network 330-750 kV (Arnis Staltmanis 2006)

Estonia has electrical power transmission connections with Russia, Latvia and Finland. From Narva two lines lead to Russia at the voltage level of 330 kV with the total capacity of 1050 MW. From the southern part of Estonia one 330 kV line with the transmission capacity of 500 MW is connected to Russia. In the opposite Russia-Estonia direction the same line has pass-through capacity of 400 MW. In the southern part of Estonia there are also 330 kV lines to Latvia with the capacity of 750 MW.

In 2007 the maximum transmitted power from Narva towards Russia was 565MW, whereas form southern Estonia to Russia it was 204 MW. The technical capacity is much higher than the actually needed one and a lack of capacity has never been experienced so far (see table 2).

Table 2. Usage of cross-border capacities in Lithuania, January 2005(prof. Vidmantas Jankauskas 2006)

Lines	Usage, % (maximum capacity)
Lithuania-Latvia	15
Latvia-Lithuania	37
Lithuania-Belarus	14
Belarus-Lithuania	33
Lithuania-Kaliningrad	82

2.1.2 The impact of the Ignalina NPP decommission in Lithuania

At the times of constructing and commissioning of the Ignalina nuclear power plant (INPP) the safety issues were not crucial. Nowadays the plant does not correspond to the international safety standards which are paid a particular attention in the developed countries. Therefore, one of the requirements of the EU for Lithuania is to close the INPP.

Currently the power plant is covering 70% of electricity demand in Lithuania, i.e. 1300MW with the total average load of 1800MW. Part of the generated energy is exported to Latvia, Belarus and Kaliningrad region.

Lithuania took a firm commitment five years ago to close the nuclear power plant by the end of 2009(FAQ on Ignalina Nuclear Power Plant 2008). However, the country is going to experience power supply problems after the power plant closure until new grid links and power plants will be built. First, the electricity transit from Poland to Lithuania has not been accomplished due to several reasons. Second, Lithuania has not activated other own energy sources to the required extent. As a result, it is being estimated that starting from 2010 there will be electricity deficit equal to the half of the current net consumption of the country (2008).

The electricity price is expected to double for electricity consumers, provided that half of power plants in the country are run by expensive Russian natural gas. However, the government promised financial support which would partly compensate emission allowance costs and increased demand for Russian gas(Staff and wire reports, VILNIUS 2008).

After decommission of the Unit 2, the following power supply alternatives should be considered:

- Russian electricity import of 2.5 TWh based on the signed contract between Lithuanian company Energijos Realizacijos Centras (ERC) and Russia's power supplier Inter RAO. The amount of exported energy will cover almost 25% of electricity demand in the country. It is valid from 2010 till 2020.
- Import from Belarus. ERC also signed a long-term contract with Belenergo in February, 2009.
- Higher generation capacity use of Lithuanian TPP, which however depends on the Russian gas price development. Heavy fuel oil can be used as an altenative fuel, but this is not usually profitable.
- Import from Nord Pool through Estlink going physically partly through Russian networks from Estonia to Latvia and Lithuania in order to avoid congestion of the Baltic grid
- Another solution to the problem is electricity transit from the Ukraine nuclear power plants Khmelnitskaya and Rovenksaya through Belarus. The transmitted power will not only be sufficient for Lithuania, but also for Kaliningrad region and Latvia. However, this might cause

congestions in the Belarus-Lithuania transmission (capacity 1400 MW) during simultaneous imports from Russia and Belarus to Lithuania.

Large-scale import from Latvia and Estonia will most likely cause bottlenecks and overloads of interconnecting lines.

After 2009 Lithuania would become nearly fully dependent on natural gas imports from Russia and so would Latvia during the coming years. Only Estonia will have power plants running on local fuel, i.e. oil shale. They could cover the country's internal consumption and will even be able to export energy but require renovation and upgrading to continue operating.(Niemi, Uus 2003)

2.1.3 Estonian market opening 2013-2015

In the Baltic countries the greatest share of power generation is owned by the state. Eesti Energia, Lietuvos Energija and Latvenergo have a market share of approximately 80%. This can be interpreted as a monopoly power, which does not contribute to socio-economic benefits. Dividing a company into separate units which operate independently in generation, supply, transmission and distribution sectors can increase competition in the Baltic power market.

Another possible way to do that is to increase the size of the market by connecting it to similar markets in neighboring countries. Estilink - 1 already reduces the possibility to exercise monopoly power in Estonia. However, long-term use of the grid link is still reserved for its owners.

Furthermore, to maximize the benefit from trade, perfect competition is required. When this is achieved, the price of the product equals to the marginal cost of production. Pricing at marginal costs secures the social surplus to be at the maximum and the price on the product reflects the cost of the resource. By 2013, the Estonian power market is due to be completely opened and the ownership of Estlink 1 will be transferred to the TSOs.

By interconnecting Baltic and Nordic countries the number of participants, i.e. producers and consumers, is increased as well as optimal use of energy sources is provided.

Open Estonian electricity market will ensure transparency of the market, full access of all market participants (i.e., producers, suppliers, retailers, traders, customers) to the market area, possibility for all customers to switch supplier.
However, there are difficulties of competition introduction into small markets because of low levels of demand and fixed costs of restructuring. Another difficulty to open the market is that there are no common balancing management procedures between TSO and market participants in each of the Baltic countries, which hinder their access to the whole Baltic region. Moreover, oil shale-based energy sector determines security of supply, balancing of foreign trade as well as provides employment for Ida-Viru County. All these conditions give the right to Estonia to postpone the 100% openness of the market and take a transitional period until 2013.

Oil shale-based energy comprises about 90% of electricity production in Estonia. The oil shale combustion causes higher CO_2 -emissions than combustion of other fossil fuels. This leads to a relatively high CO_2 level per capita in Estonia in comparison to other countries and is the reason of lower energy efficiency. Energy consumption per GDP in Estonia is higher than in European developed countries.

Oil shale-based electricity generation might not be competitive under free-market conditions because of high CO_2 emission level. It will possibly not withstand the competitive pressure. Other energy sources will replace it due to their lower environmental emissions and hence environmental costs.

Possible scenarios for covering electricity demand in Estonia:
1. All electricity deficit supply is covered by natural gas-based electricity generation. This option best suits for maximum consumption forecasts.

2. 60% deficit supply is covered by natural gas, the rest is covered by imported electricity. Electricity consumption is smaller than in the first case.
3. 50% - natural gas, 25% - imported electricity, 25% - coal-based electricity generation.
4. Most of the Estonian power is generated by oil-shale. There will be upgradings made at the Eesti power plant which include installing of de-SOx devices. New units can be commissioned. Existing rebuilt 200MW-units, each one at the Balti and Eesti power plants, 4 units of 200MW with de-SOx installations and 2 new units of 300MW at the Eesti power plant will in total provide 1800MW of oil-shale based generation during 2016-2025.

The third scenario in the list is equivalent to oil shale-based electricity generation in terms of environmental impact and hence is least preferable.

According to Fingrid, there must be clear signs of Estonian market opening before Fingrid will decide to invest money in the proposed new Estlink 2. Estonia has not so far fulfilled the obligation to open 35% of the market by the beginning of 2009. However, Estlink 2 is included in the EU financial support proposal and preparations are ongoing for a roadmap for the market development.

In the Nordic market it took 5 years from when it started to open until it began to function fully as an open market. It is obviously not a day long change. Therefore, if Estonia wants Estlink 2 to be commissioned by 2014, the government will have to make decisions already this year. Fingrid has prepared a plan for accelerated construction of Estlink 2 by end-2014(Kekkonen 2009)

2.2 Current interconnections

The following chapter describes the current interconnections of the Baltic States with Finland, Kaliningrad region and possible future transit from Ukraine to Lithuania.

2.2.1 Estlink-1: before and after

Nowadays Estlink 1 is the only interconnection of the Baltics with the European countries. In this chapter the impact of the grid link on the power balance in the countries is presented.

Figure 2 shows that Estlink 1 affected the power balance in each country. The first column of each type of energy, i.e. generation, consumption, export and import, reflects the year 2006 without Estlink-1 interconnection, and the second column – 2007 with the grid link commissioned. Estonia has significantly increased its exported and imported energy. In Latvia the same tendency can be noticed, whereas Lithuania, on the contrary, decreased import and increased export in spite of increase in consumption and decrease in generation.

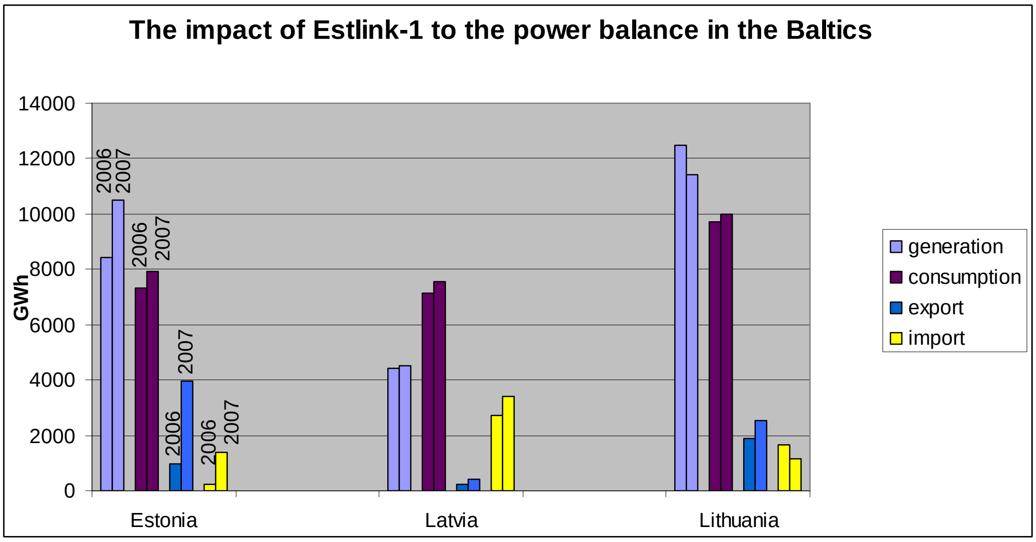

Figure 2. The annual energy balance in the Baltic countries before and after Estlink 1 (BALTSO 2007, BALTSO 2008)

2.2.2 Interconnection with Kaliningrad

Kaliningrad imports electricity from Lithuania through 3 lines of 330kV with overall capacity of 680MW. Before commissioning of the Unit 1 of Kaliningrad CHP in 2006 the electricity import in the region was 93%. Nowadays 30% of electricity deficit in Kaliningrad region is covered by Ignalina NPP, which must be closed according to the requirements of EU by the end of 2009. After decommission of the Ignalina NPP, Lithuania will undoubtedly first think about its own security of supply. Export to Kaliningrad will depend on many factors, among them - the amount of Russian gas and its price.

The second unit of Kalinigrad CHP will be commissioned in 2010, and will satisfy the demand in the region. However, according to forecasts of specialists, due to population increase (approx. 1.2 million by 2010, 2 million by 2020) and increase in consumption per capita, starting from 2012 Kaliningrad region will begin to feel the power deficit which might reach 800MW(ИА REGNUM 2008).

A construction of a nuclear power plant in Kaliningrad is planned to be accomplished by 2015. It will consist of 2 units 1150MW each. 51% of shares will belong to the state. The key target of the power plant is to ensure security of electricity supply in the region.

2.2.3 Perspectives of the electricity transit Ukraine-Belarus-Lithuania

There is an opportunity to transmit power from Ukraine to Lithuania through Belarus. The implementation depends on agreement between Ukraine and Belarus. Two countries have different proposals to each other and have not come to a common agreement yet. Belarus offers to Ukraine to buy 1.5-1 TWh of electricity at €32.89/MWh in hryvnias with a fixed price, setting the tariff for electricity transit to Lithuania to be € 5.3 /MWh.

Meanwhile, Ukraine proposes to export 3TWh of electricity at €34/MWh. The transit tariff is to be €3.8/MWh for Lithuania. (EnergyLand.info 23.01.2009)

2.3 Net consumption and peak loads for 2009-2015

The information about development of net consumption and peak loads in Baltic countries in the following years (see fig. 3 and 4) helps us to estimate needs and requirements of the countries in terms of security of supply and efficient grid operation.

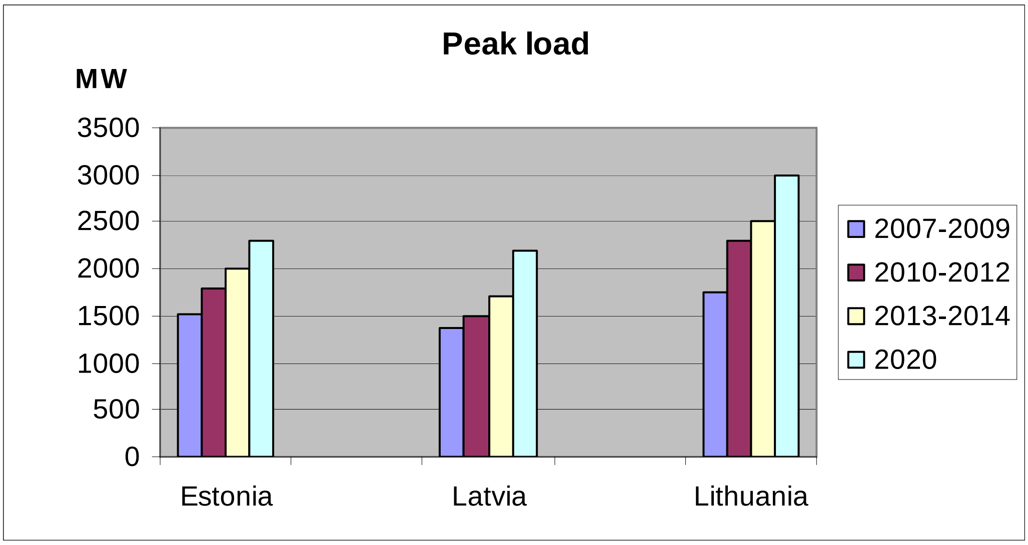

Figure 3 Development of peak load in the Baltic States (EURPROG Networks of Experts 1 April 2008)

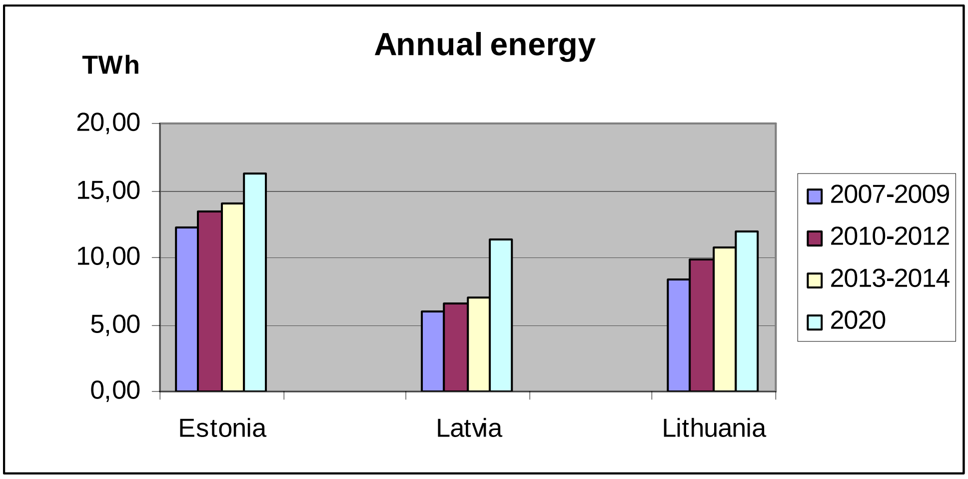

Figure 4 Development of annual energy in the Baltic States (EURPROG Networks of Experts 1 April 2008)

Currently in Estonia the total production capacity is 2385MW, 95% of which is generated by oil-shale. In Latvia 2179MW of generation, hydro power production comprises 70.8% and 28% belong to fossil fuel based energy. Lithuania has 4769 MW of installed capacity, nuclear energy – 25.2%, fossil fuels – 52.8%, 21% of hydro power (BALTSO 2008).

Therefore, we can already now conclude that the countries will experience power deficit in future, having total peak load equal to 7876MW by 2020, with the current available capacity 9333MW, turning into 8000MW after the Ignalina NPP closure. The peak load usually happens during winter times when hydro power availability might be significantly limited. Increasing CO_2 emission allowance prices will limit the economic generation volumes at fossil fuel-fired power plants. Thus, oil shale based energy production will be significantly reduced in Estonia from 2016 on (Andrus Ansip 05.10.2007). Moreover, all Baltic countries do not want to be dependent on Russian gas and electricity. There is no legislation in Russia which requires payment for CO_2 emissions. The three countries are willing to cover their power requirements by own energy sources as well as by importing clean European energy. This claims to say that decisions should be made already today to work out a reliable and self-sufficient supply scenario for the future.

2.4 Conclusions

In this section the current power balance situation as well as future power balance development has been considered. Estonia and Lithuania will lose some energy sources in the coming years. In Latvia the old unit at Riga CHP-2 needs to be replaced. The Baltic countries have only one link to Europe through Estlink 1. Therefore, the power balance change will affect first of all the Nordic countries' power balance and system price if the three countries want to minimize the dependence on Russian gas and electricity. The main conclusion is that the Baltic countries need to create a common regional electricity market before constructing grid links to Nordic countries and Poland. Together they will work as a more efficient and liquid electricity market. Currently the total consumption of the Baltics is comparable to the one in Denmark. As an example given, on 22.04.2009 between 9-10 am, Estonia's, Latvia's and Lithuania's consumption were 1036MW, 941 MW and 1550MW, respectively, which results in 3527MW(OÜ Põhivõrk , Lietuvos Energija AB , AS Augstsprieguma Tīkls). The consumption in Denmark was 4826MW. This comparison is mentioned to show, that the common electricity market of the Baltic countries is large enough to ensure its efficient and competitive functioning as it would be hardly possible for each separate country.

In the next section the current market mechanisms around the Baltics are discussed. The requirements and needs towards integration with UCTE are considered.

3 Development of power trading mechanisms around Baltic States within the period of 2009-2015

Before talking about targets and needs it is necessary first to clarify, why do we need trading between markets. The major reason for that is the difference between supply and demand levels between trading countries. There are different factors that affect electricity supply and demand.

The supply is influenced by differences in technologies, different fixed and variable costs. Production costs vary a lot. They include investment costs, operating and maintenance costs, fuel cost and emissions trading, that are different according to the type of generation.

The electricity demand is influenced by factors driving the electricity price, for instance temperature, fuel price, hydro situation. Different development in economic situation also affects demand level.

The above mentioned factors are different in different market regions and hence determine different prices. When countries are interconnected, they can benefit from those differences by trading power through the interconnection.

3.1 Trading between Finland and Estonia through the Estlink: main targets and needs

Estlink provides higher security of supply for the Baltics. Along with offering a competitive source of energy, it contributes to lower dependence of Baltic countries on Russian electricity.

Nowadays Finland is mainly importing electricity from the Baltics. Its effect on the Nordic electricity market is not significant since it covers only 2.5% of Finnish peak load, whereas it has a noticeable effect on the Baltic electricity market. The transmission capacity of the interconnection is equal to 25% of Estonian peak load.

In case of Swedish-Finnish bottlenecks through Fenno-Skan, Estlink 1 can supply Finland with power, which will prevent the increase of price level for consumers.

In 2007 a Joint Baltic-Nordic project was launched. Its immediate target is to establish a Nord Pool Spot price area for the Estlink cable. The final target is to implement a reference price for the Baltic electricity markets, which is estimated to be carried out 1.5-2 years after settling the area price for the Estlink (Nord Pool Spot AS). In order to reach the target the following prerequisites are required:

1. Remove cross-border tariffs

Cross-border tariffs create a so-called „dead" price range (see fig.5) which is equal to the sum of tariffs from electricity selling to Finland (3.72 euro/MWh) and to Estonia **(**0.66 euro/MWh). Within the range no price bids can be made. As Estonia has joined the ETSO transit compensation system in 2008, the fees have now been reduced. The fees by Fingrid for Estlink in 2009 are the following(Fingrid) :

- Output from grid – 0.68 € / MWh
- Input into grid – 0.30 € / MWh

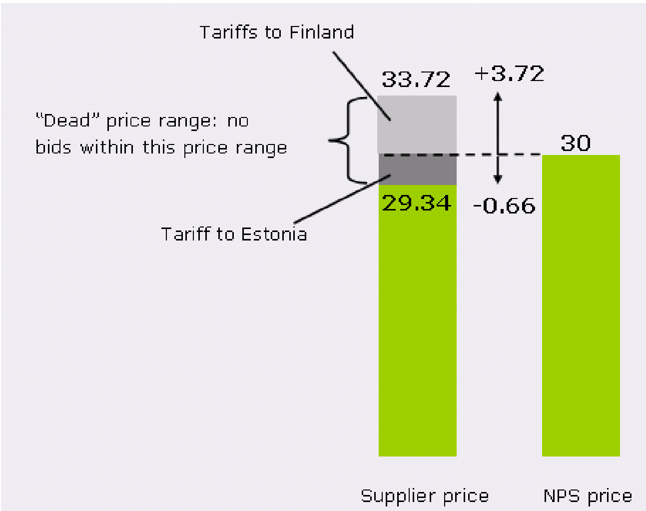

Figure 5. The illustration of the „dead" price range on the Estlink (Karri Mäkelä 2008)

2. Allow subsidized generation to sell in free market without loosing subsidies

If subsidized generators loose subsidies when entering the market, risks of increased power of dominant players appear. This leads to a limited and harmed transparency and liquidity of the price.

3. Remove regulated tariffs for eligible customers.

4. Change current import regulations in Estonia for third countries. This supposes the right for third countries to import to Estonia.

5. When selling electricity to Elspot market in Estonia, the market participants should be allowed to have in their purchase chain imports from third countries.

In the end of 2008 the project was cancelled because some important issues, which were not included in the project tasks, needed to be solved before the area price of the Estlink is finally implemented(Nord Pool Spot AS). The issues are:

- treatment of eligible customers
- import license issues
- removal of cross-border tarrifs
- possibility for Estlink shareholders to offer capacity directly to implicit auction

According to (Nord Pool Spot AS) the area price will not be applied until 1.07.2009 due to the necessity for amendments to the current Estonian legislation regarding eligible customers.

According to the project leader Pasi Kuokkanen, the opening of a new price area could be acomplished by July 2009. However, on March, 19, 2009 he officially stated the closure of the NordPool office in Tallin, thus cancelling all activities towards creating a common Estlink price area. The reason for that is the energy policy in Estonia, which does not contribute to creating a competitive market(4energia 19.03.2009).

Despite the abovementioned fact, the financial support has been already proposed by the European Commission to Estlink -2, which is scheduled to be commissioned already by 2015. (Tere 20.03.2009)

3.2 Trading within the Baltic States

In this chapter the mechanisms of power flows between Estonia, Latvia and Lithuania are clarified, cross-border trading scheme is introduced to the reader; possible future implementation of the ITC-mechanism (inter-TSO compensation) is discussed as well as prerequisites for the wholesale market are listed.

3.2.1 Balancing regulations

Trading in the Baltic countries is based on balancing principles. Currently between Estonia and Latvia, Latvia and Lithuania exist open delivery contracts (Nord Pool Spot AS). It means that two countries made an agreement to supply each other with the amount of power required to establish power balance. Therefore, the "delivery" can be either sales or purchase. Such a contract is opposite to a fixed contract where values of power transmitted between countries are fixed.

Latvia has an open delivery contract with Estonia and Russia. Estonia neither exports nor imports electricity from Russia (New Europe 23 June 2007). Therefore all electricity from Russia to Estonia flows to cover the balance in Latvia as well as further to Kaliningrad region (see fig. 6).

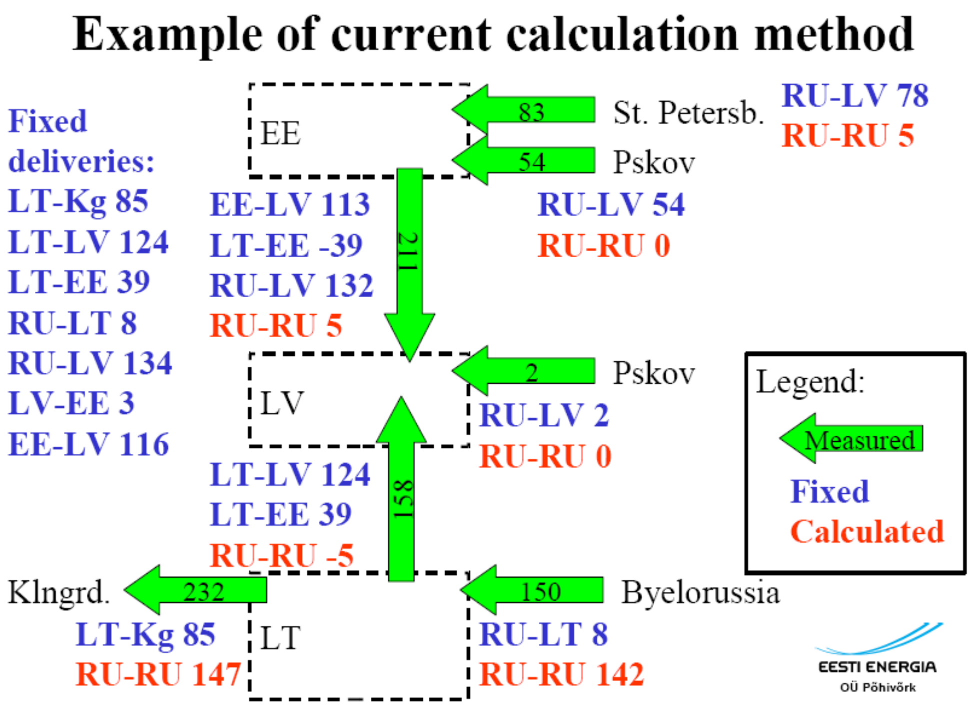

Figure 6. Power flows in the Baltics in 2006 (Nord Pool Spot AS)

There are four interconnecting lines between Lithuania and Latvia. Two of them are so called feed load lines, the other two belong to BRELL ring. This means that two of the lines are not of interconnection type but they are transmitting power to some specific area with large loads. The other two are of in joint use where one cannot specify where the power is exactly going to. Those lines might transmit balancing power and/or transits. Therefore, Lithuania has one fixed and one open delivery contract with Latvia. Lithuania has also an open delivery contract with Russia, according to which it keeps Kaliningrad region in balance.
Russia pays separately to Estonia, Latvia and Lithuania for hosting transit power flows to Kalinigrad.

3.2.2 Ownership of cross-border connections

The cross-border connections between Baltic countries are owned by TSOs of those countries, in which they are located. The power flows on the lines consist of the following components:

- Balancing power between adjacent countries

For example, Estonia is balancing Latvia through the overhead lines Tartu – Valmiera and/or Tsirguliina – Valmiera.

- Transit power flows

Transit power flows from Russia through Estonia, Latvia and/or Lithuania to Kaliningrad region.

- Load feed power, which constantly supplies determined consumption joints in a neighbouring country according to a fixed contract.

Currently the Baltic countries organize the trading operations between each other according to the cross-border trading compensation scheme. The price calculation method is based on three components:

1. Determine how much transit power flowing through a border, based on minimum value of both import and export plus added value of hourly energy over the fixed period of time.

2. Estimate the compensation costs for hosting the cross-border flows, based on horizontal network of the hosting country (see figure 7) and a key factor, which

determines the share of the transit flows in the summary flows (transit + domestic) according to the following equation:

$$K = \frac{transit}{transit + domestic\_load} \qquad (1)$$

3. Determine how much do the perimeter and participating countries have to pay to the compensation fund.

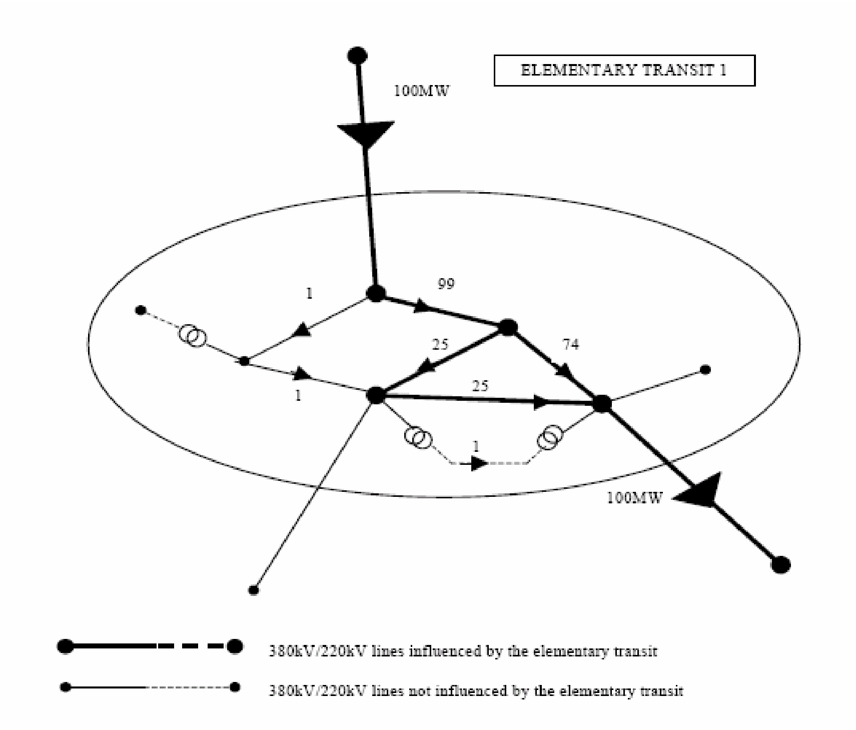

Figure 7. Elementary transit through a horizontal network(ETSO 2005)

3.2.3 EU requirements for cross-border trading

Nowadays the inter-TSO compensation mechanism is implemented in the EU countries. The mechanism should be implemented also in the Baltic States which is one of the requirements for integrating the Baltic market with Nordel and UCTE.

The advantages of the ITC (inter-TSO compensation) mechanism for Baltic States:

- one same principle for all participating entities
- based on actual physical flows
- common software created for all participants
- compensation mechanism contains principles applicable for BRELL countries (Russia and Belarus)

The disadvantages of the ITC mechanism for Baltic States:

- loop flows are not taken into account for transit compensation
- No simulation results since 2005, they should be done by ETSO. Payments for Baltic TSOs might be higher.
- No transit compensation induced to perimeter countries (Russia and Belarus). Additional mechanism is required. (Virbickas 2006)

3.2.4 Prerequisites for the Baltic wholesale market

The prerequisites are the following:

- Physical connections between countries. In the Baltics the interconnecting lines have rather high transfer capacity (see table 1).
- Congestion management principles and procedures at place. They should be determined before the Ignalina NPP decommission due to increased cross-border flows
- Right to conduct import and export activities, which is still not given to all market participants
- Possibility for market participants to use electricity imported or exported. It is not available yet within the three countries.

The main barriers, which could complicate the power trading arrangement with third countries, are:

- Electricity import/export permits system and mandatory auctioning in Lithuania
- Electricity import licensing in Estonia.

The current market situation in the Baltics is described in table 3.

Table 3. Present market trading mechanisms in the Baltic States and requirements for future(Arus 2008)

Country	Present mechanisms	Requirements
Estonia	1. Import license needed; 2. Allowed import produced under EU terms; 3. License issues partially based on data actually unavailable and unrelated to the aim; 4. No procedures of control at place;	Proposition of Nord Pool Spot to change licensing regulation to establish spot market in the Baltics
Latvia	1. No limitations to export/import; 2. Unequal treatment of Latvenergo and other traders in CBT: • Only Latvenergo can trade over Latvian border (instead of TSO- JSC "High Voltage Network" - AS "Augstsprieguma tikls)) • Balancing energy price set by Latvenergo(not TSO) • Enormous spread of balancing energy: • Latvenergo – in balance, other traders - imbalance, but no right to avoid it with the same means	Current regulation should be changed to provide equal access to the network service for all market participants
Lithuania	1. Import/export permit needed to trade, but no clear procedure available; 2. Mandatory auctioning of export/import: 3. TSO has the right to "adjust the price if needed" according to the "weighted average price" methodology. It does not guarantee the price for an importer/exporter	1. Clarify import/export procedures; 2. Issuing permit :actual availability of trading capacity arranged via congestion management procedures – not via "TSO estimation"; 3. Mandatory auctioning removed; 4. Exporter/importer – not subject of transmission fee

In general, licensing is not a serious barrier for the development of the market. Licensing is used as a tool, which allows for the regulator to monitor the processes in the market, to ensure the market stability and to protect the customers. However it will be necessary for regulators to take interim steps to facilitate the entry of prospective participants into the domestic markets and into Common Baltic Electricity Market as well:

- initiate the abolition of the export/import permits and licenses in the Baltic's as soon as possible;
- maximize access to information by posting licensing requirements and other useful information (for instance, application form, licensing requirements in English) on websites. It would be a significant step forward to help applicants learn the requirements of the relevant licensing authority and to simplify and reduce the duration of the licensing procedure.
- propose respective changes to legislative authorities (to Ministries or Governments) addressing the greatest concerns stressed by traders.

Another requirement for the Baltic region is to have a common Energy policy. It supposes the same approach for all three countries in trading with Russia, as well as unified understanding of security of supply in the Baltic States, noting what should be achieved and what should be avoided. Such an approach will help to have cooperation among the Baltic States, regulators, TSOs, and Ministries more productive.

3.3 Trading between Baltic States and European countries: market coupling principle

Market coupling principle ensures utilization of trading capacity on every bottleneck during every hour of operation with power flowing towards the high price. The principle is planned to be implemented on the Estlink-1 interconnection. Thus, it is the first step towards increasing cooperation between two regional markets.

Implicit auction principle supposes combination of market coupling and auction systems. It can be implemented in power trading where at least two power exchanges are involved. It can also be implemented between two bidding areas of one power exchange, when it is called market splitting resulting in different area prices during grid congestions.

In implicit auction principle power flow of an interconnection is found based on market data from the marketplace/s in the connected markets. The capacity between price areas is made available to the spot price mechanism in addition to bid/offers per area, thus the resulting marginal costs per area reflect both the cost of energy in each internal bid area (price area) and the cost of congestion. The price for the capacity is included directly in the price of transmitted energy. The auction is arranged, and the revenue from it belongs, not to TSO (difference from explicit auction) but to MO (market operator). However, the so called congestion rent, resulting from the price difference and the transmitted power during each hour, is usually divided between the TSOs.

The principle is described here because it is planned to be implemented also on the new grid links, i.e. towards Poland and Nordic countries (Ansip, Dombrovskis & Kubilius 27 April 2009).

3.4 Conclusions

Common balancing and reserve market, equal treatment of all market participants, simplified issuing of import/export licenses, same approach towards trading with non EU countries are prerequisites for creating the transparent and competitive common electricity market in the Baltic region. The legislation of the markets should be changed and harmonized on the basis of the market principles of the Nordic Countries.

4 Model development

The power flow software RastrWin is designed for calculation, analysis and optimization of power network regimes. In Russia it is used by System Operator, Federal Grid Company, as well as by several project and research organizations.

In this work RastrWin is used to model 330kV transmission grid of the Baltic countries and calculate several power balance scenarios.

4.1 Assumptions

The model has been created based on the following assumptions:

1. Cross sections of the lines are same, i.e. 300 sq.mm. This enables to use the same specific parameters of resistances and reactances.
2. The lengths of all lines have been estimated by the electronic map.

The following data is given to the input of the software:

1. Joints:

Loads - active and reactive power P,Q

For loads we assume power factor

$$\cos\varphi = \frac{P}{S} = 0.9 \ , \tag{2}$$

where

cos ϕ - power factor,

P - active power,

Q - reactive power

$$Q_{load} = P_{load} \cdot \tan(\arccos\varphi) = P_{load} \cdot 0.484 \tag{3}$$

Generation units – P, U, Qmin, Qmax

The reactive power reserves of all power plants are assumed to be in the range of -999MVAr to +999MVAr in order to keep the busbar voltage constant.

2. Lines : reactances and resistances.

Reactances can be estimated:

$$X_L = \omega * L_{SV} * l_{length} = X_{SV} * l_{length} \quad (4)$$

$$B_L = b_{SV} * l_{length} \quad (5)$$

For 330kV overhead lines the specific parameters(Faibisovich 2006):

Cross-section 300/39

$$X_{SV} = 0.328\Omega / km \quad (6)$$

$$b_{SV} = 3.41 \cdot 10^{-6} S / km \quad (7)$$

Now we calculate resistance of lines

We assume the average winter temperature for the Baltic countries

$$t_{winter,av} = -5^{\circ} C \quad (8)$$

$$r^{(+20)} = 0.048\Omega / km \quad (9)$$

Where $r^{(+20)}$ - resistance of a line with ambient air temperature $t = +20^{\circ} C$

Then specific resistance for 330kV overhead line with cross section 300/39 with 2 wires in phase will be equal to

$$r^{(-5)} = r^{(+20)}\left[1 + 0.004(-5 - 20)\right] = 0.048 \times 0.9 = 0.0432\Omega / km \quad (10)$$

(Faibisovich 2006)

The technical parameters for 330 kV overhead transmission lines of each Baltic country and the corresponding maps are given below.

Table 4 Estimated lengths of lines in Estonia and their technical parameters

		l, km	x, Ω	b, μS	R, Ω
Kiisa	Paide	80	26.24	272.8	3.456
Paide	Sindi	78	25.584	265.98	3.3696
Paide	Eesti	190	62.32	647.9	8.208
Eesti	Pussi	55	18.04	187.55	2.376
Balti	Pussi	70	22.96	238.7	3.024
Tartu	Eesti	150	49.2	511.5	6.48
Tartu	Balti	165	54.12	562.65	7.128
Tartu	Tsirguliina	64	20.992	218.24	2.7648
Tsirguliina	Valmiera	64	20.992	218.24	2.7648

Tartu	Valmiera	200	65.6	682	8.64
Balti	Eesti	15	4.92	51.15	0.648
Eesti	Tsirguliina	200	65.6	682	8.64
Eesti	Kingisepp	40	13.12	136.4	1.728
Kiisa	Harku	29	9.512	98.89	1.2528
Balti	Kiisa	216	77.08	801.35	10.152
Pussi	Rakvere	42	13.776	143.22	1.8144
Kiisa	Rakvere	122	40.016	416.02	5.2704
Harku	Balti	235	77.08	801.35	10.152

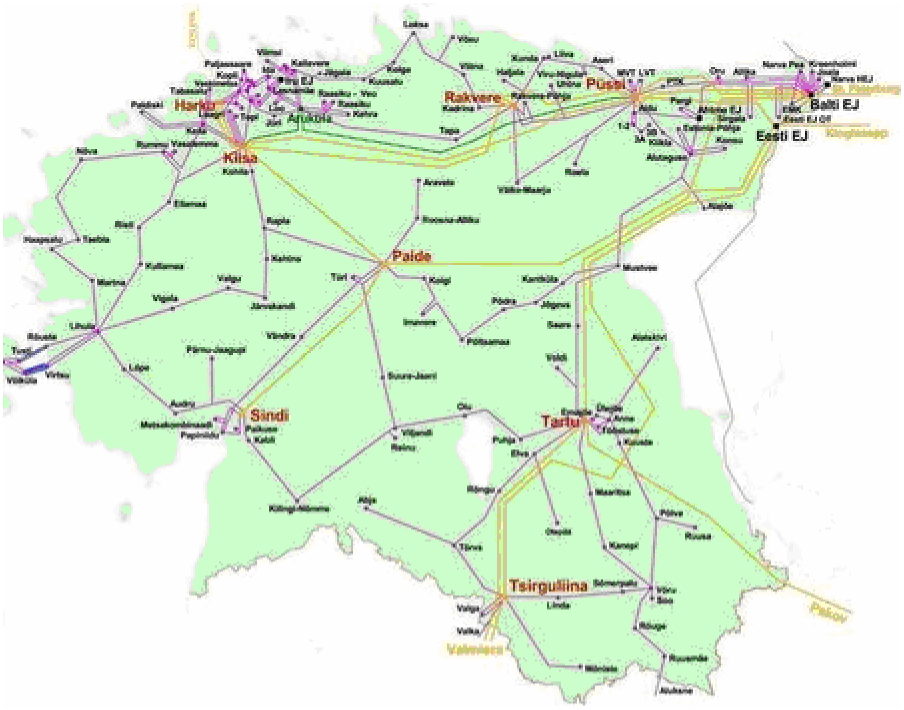

Figure 8. Map of Estonian transmission grid

Table 5 Estimated lengths of lines in Latvia and their technical parameters

		l, km	x, Ω	b, µS	R, Ω
Valmiera	Plavinu	130	42.64	443.3	5.616
Plavinu	Krustpils	45	14.76	153.45	1.944
Krustpils	Liksna	80	26.24	272.8	3.456
Liksna	Rezekne	80	26.24	272.8	3.456
Liksna	Daugavpils	20	6.56	68.2	0.864
Plavinu	Salaspils	70	22.96	238.7	3.024

Salaspils	Valmiera	120	39.36	409.2	5.184
Salaspils	Jelgava	55	18.04	187.55	2.376
Salaspils	Riga	20	6.56	68.2	0.864
Bisuciems	Riga	20	6.56	68.2	0.864
Jelgava	Broceni	65	21.32	221.65	2.808
Broceni	Grobina	90	29.52	306.9	3.888
Jelgava	Bisuciems	20	6.56	68.2	0.864
Bisuciems	Imanta	10	3.28	34.1	0.432
Panevezys	Plavinu	127	41.656	433.07	5.486

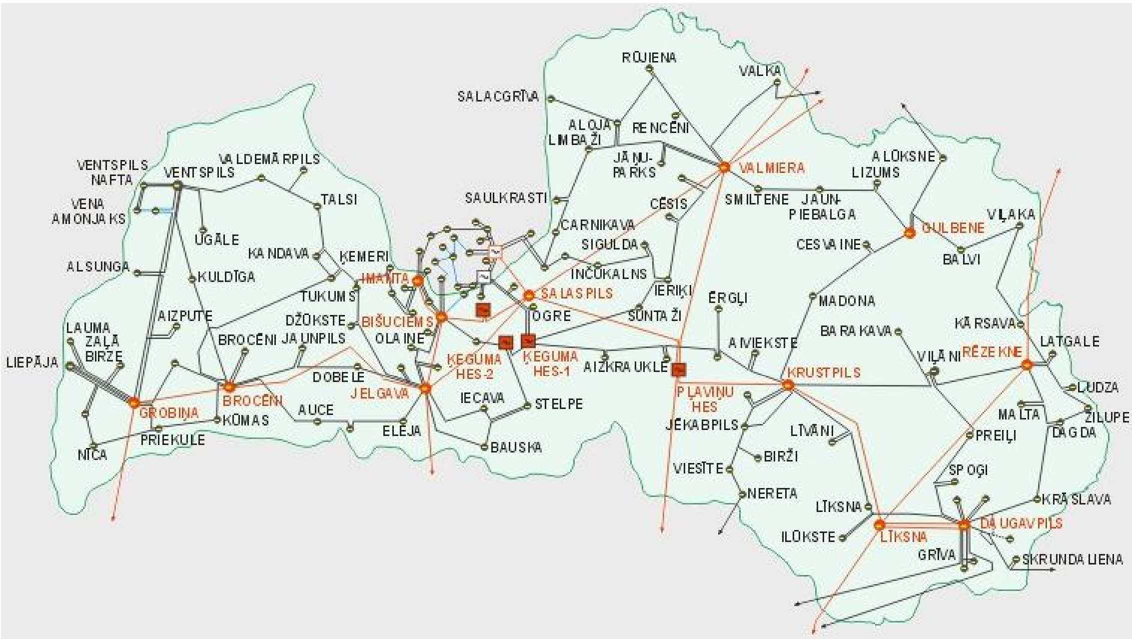

Figure 9. Map of Latvian transmission grid

Table 6 Estimated lengths of lines in Lithuania and their technical parameters

		l, km	x, Ω	b, μS	R, Ω
Grobina	Klaipeda	119	39.03	405.8	5.14
Liksna	Ignalina	60	19.68	204.6	2.59
Ignalina	Utena	17	5.576	57.97	0.7344
Utena	Panevezys	92	30.176	313.72	3.9744
Panevezys	Jonava	80	26.24	272.8	3.456
Utena	Vilnius	96	31.488	327.36	4.1472
Lietuvos	Vilnius	45	14.76	153.45	1.944
Lietuvos	Jonava	53	17.384	180.73	2.2896
Lietuvos	Alytus	80	26.24	272.8	3.456
Lietuvos	Kruonio	65	21.32	221.65	2.808
Kaunas	Kruonio	48	15.744	163.68	2.0736
Kaunas	Jurbarkas	85	27.88	289.85	3.672
Sovetsk	Klaipeda	95	31.16	323.95	4.104
Sovetsk	Jurbarkas	60	19.68	204.6	2.592
Sovetsk	Kruonio	170	55.76	579.7	7.344
Kiisa	Harku	29	9.512	98.89	1.2528
Kaunas	Siauliai	121	39.688	412.61	5.2272
Siauliai	Musa	28	9.18	95.48	1.2
Musa	Telsiai	131	42.968	446.71	5.6592
Musa	Jelgava	60	19.68	205	2.6
Ignalina	Vilnius	110	36.08	375.1	4.752
Musa	Panevezys	100	32.8	341	4.32

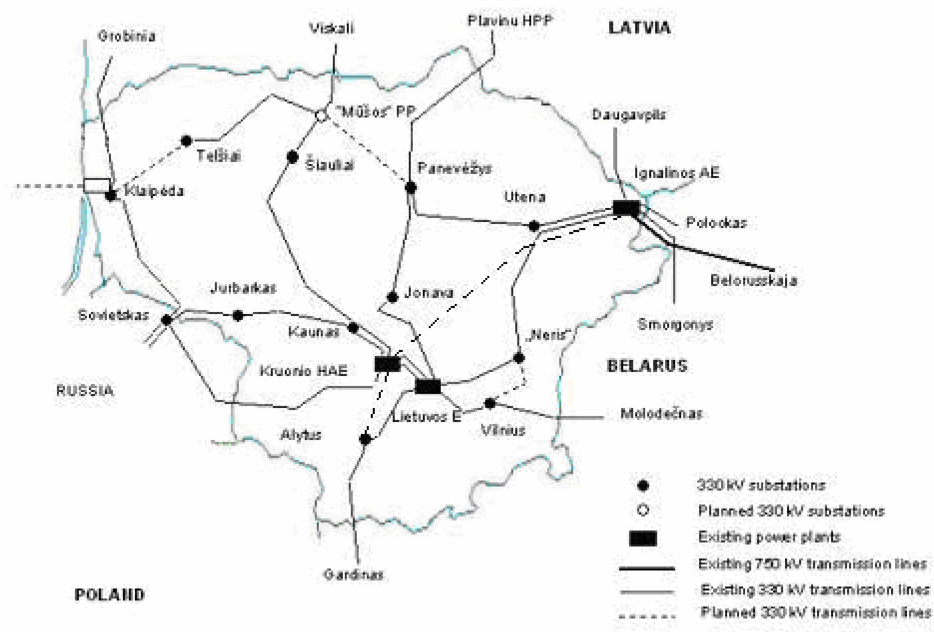

Figure 10. Map of Lithuanian transmission grid

The new interconnections are presented as generation joints with the corresponding capacity in the model.

The software calculates power flows along the lines based on load and generation. The active power losses are determined by the following equation:

$$P_l = \frac{P_{begin}^2 + Q_{begin}^2}{U_{begin}^2} * R_{line} \tag{11}$$

Where Pbegin, Qbegin – active and reactive powers in the beginning of a line

$$P_{end} = P_{begin} - P_l \tag{12}$$

4.2 Verification of the model

The verification method is based on comparison of calculated data with available statistic data. In this work Latvian import and export energy will be calculated for January and compared with the values given in (BALTSO 2008).

We divide the whole January month into four time periods, each one characterized by its specific load value and duration:

- Workday, peak load hours 08:00 – 20:00, P1=0.9 Pmax, duration T1=22workdays*12hours=264h

- Workday, offpeak load hours 20:00 – 08:00, P2=0.7Pmax, duration T2=T1
- Weekend, peak load hours, 08:00 – 20:00, P3=0.8Pmax, duration T3=8weekend days*12hours=96h
- Weekend, offpeak load hours, 20:00 – 08:00, P4=0.65Pmax, T4=T3

As a result, we can calculate the total monthly energy using the following equation:

E=P1*T1+P2*T2+P3*T3+P4*T4 (13)

Next we calculate the maximum power for each month, based on the abovementioned assumptions and provided that the monthly energy is given (BALTSO 2008):

Consumption in January:

$$E_{month} = 0.9P\max{*}\,264 + 0.7P\max{*}\,264 + 0.65 * P\max{*}\,96 + \\ + 0.8P\max{*}\,96 = 562P\max \qquad (14)$$

For Estonia:

$$E_{jan} = 562 * P\max = 800GWh \Rightarrow P\max = \underline{1423MW} \qquad (15)$$

For Latvia:

$$E_{jan} = 562 * P\max = 710GWh \Rightarrow P\max = \underline{1263MW} \qquad (16)$$

For Lithuania:

$$E_{jan} = 562 * P\max = 900GWh \Rightarrow P\max = \underline{1601MW} \qquad (17)$$

The consumption for each substation has been scaled from the forecasts the Baltic Ring Study, made in 1998 for the winter peak of 2010 (Knudsen, Koskinen & :Ellus 1998). The forecasts are presented in the first column of the table 7. The scale factor between total forecasted consumption and the calculated total consumption for each load period is calculated. For example, for peak load hours of workdays the scale factor is:

$$k_{workday\_peak} = \frac{1280}{1544} = 0.829 \qquad (18)$$

In order to calculate the load of each substation in the considered load period, the forecasted load of the respective substation is multiplied by the scale factor as follows:

$$P_{KIISA}^{workday\_peak} = k_{workday\_peak} * P_{KIISA}^{forecasted} = 0.829 * 384 = 318MW$$

The other substations' loads for the considered load periods are calculated the same way.

The average generation in January in each country is found using the available data about generated energy (BALTSO 2008).

Estonia: $P_G = \frac{E_G}{24h * 31days} = \frac{800GWh}{744h} = 1075MW$

Latvia: $P_G = \frac{645GWh}{744h} = 867MW$

Lithuania: $P_G = \frac{1400GWh}{744h} = 1880MW$

Total generation=1075+867+1880=3822MW

It is assumed that generation is constant throughout January. It is distributed between power plants according to the available information about percentage of each type of power plants used to cover demand (BALTSO 2008) .

The results are presented in tables 7 – 9.

Table 7 Consumption and generation in Estonia in different load periods, 2007

Consumption		Workdays		Weekends	
Substation	Forecasted load	Peak 0.9Pmax	Offpeak 0.7Pmax	Peak 0.8Pmax	Offpeak 0.65Pmax
Kiisa	384	318	246	281	229
Paide	150	124	96	110	89
Pussi(110+Arukula)	450	370	288	330	268
Balti	275	227	176	201	164
Sindi	100	82	64	73	60
Tartu	130	107	83	95	77
Tsirguliina	55	45	35	40	33
Total	1544	1280	996	1138	925
Generation					
Eesti		800			
Balti		275			

total		1075			

Table 8 Consumption and generation in Latvia in different load periods, 2007

Consumption		Workdays		Weekends	
Substation	Forecasted load	Peak 0.9Pmax	Offpeak 0.7Pmax	Peak 0.8Pmax	Offpeak 0.65Pmax
Valmiera	108	130	101	115	94
Krustpils	70	84	65	75	61
Daugavpils	167	201	156	178	145
Jelgava	172	207	161	184	149
Broceni	74	89	69	79	64
Grobina	131	157	122	140	114
Bisuciems	16	19	15	17	14
Imanta	58	70	54	62	50
RigaTEC		179	139	159	129
total	796	1136	884	1010	821
Generation					
Riga TEC		300			
Imanta CHP		41			
Riga HPP		100			
Plavinas		426			
total		867			

Table 9 Consumption and generation in Lithuania in different load periods, 2007

Consumption		Workdays		Weekends	
Substation	Forecasted load	Peak 0.9Pmax	Offpeak 0.7Pmax	Peak 0.8Pmax	Offpeak 0.65Pmax
Klaipeda	137	96	75	86	70
Telsiai	110	78	60	69	56
Siauliai	230	162	126	144	117
Panevezys	316	223	173	198	160
Utena	94	66	51	59	48

Jonava	277	195	151	173	141
Neris	278	195	152	174	141
Alytus	205	144	112	128	104
Kruonio	106	75	58	66	54
Kaunas	190	134	104	119	97
Jurbarkas	102	72	56	64	52
Total	2045	1441	1121	1281	1040
Generation					
Ignalina NPP		1343			
Lietuvos E		200			
Kruonio PSP		200			
Klaipeda		10			
Vilnius		50			
Panevezys		35			
Kaunas HPP		50			
Total		1880			

The calculated consumption and generation are put into the model. In every period there is either power deficit or power surplus. We distribute it towards different directions in proportion to the current power flows from the neighboring countries, i.e. Kaliningrad, Belarus, Pskov, Leningrad and Estlink-1. After distributing power deficit or surplus to different directions, we obtain power flows in MWs for each load period.

The next target is to calculate the Latvian import and export energy in January.

The Latvian export power is found by summarizing power flows along interconnecting lines towards Estonia and/or Lithuania.

The Latvian import power is found by summarizing power flows along interconnecting lines from Estonia and/or Lithuania.

The interconnecting lines are:

To Estonia:

- Tartu – Valmiera
- Tsirguliina – Valmiera

To Lithuania:

- Jelgava – Musa
- Grobina – Klaipeda
- Plavinu – Panevezys
- Ignalina - Liksna

The export and import energies are found by multiplying the calculated power by the number of hours of the corresponding period. The results are listed in tables 10 – 13.

Table 10 Export and import powers and energies during peak load hours on weekdays

T1=264h		Export, MW	Import, MW
Tartu	Valmiera	62	
Tsirguliina	Valmiera	75	
Jelgava	Musa	136	
Grobina	Klaipeda		47
Plavinu	Panevezys		55
Ignalina	Liksna		454
Total, MW		273	556
Energy, MWh		72072	146784

Table 11 Export and import powers and energies during offpeak load hours on weekdays

T2=264h		Export, MW	Import, MW
Tartu	Valmiera	145	
Tsirguliina	Valmiera	122	
Jelgava	Musa	132	

Grobina	Klaipeda	23	
Plavinu	Panevezys		68
Ignalina	Liksna		384
Total, MW		422	452
Energy, MWh		111408	119328

Table 12 Export and import powers and energies during peak load hours on weekends

T3=96h		Export, MW	Import, MW
Tartu	Valmiera	129	
Tsirguliina	Valmiera	96	
Jelgava	Musa	134	
Grobina	Klaipeda		9
Plavinu	Panevezys		72
Ignalina	Liksna		434
Total, MW		359	515
Energy, MWh		34464	49440

Table 13 Export and import powers and energies during offpeak load hours on weekends

T4=96h		Export, MW	Import, MW
Tartu	Valmiera	172	
Tsirguliina	Valmiera	152	
Jelgava	Musa	138	
Grobina	Klaipeda	47	
Plavinu	Panevezys		81
Ignalina	Liksna		398
Total, MW		509	479
Energy, MWh		48864	45984

It should be borne in mind, that exported and imported energies of the Baltic countries strongly depend on the power flow values to/from Finland, Russia and Belarus. However, the inaccuracy in calculated values of energies can be avoided if we use the difference between export and import instead of using the single values of each item. In this case, the transit power flows will be eliminated, and the obtained difference can be compared to available data.

To verify the model we will use the following power balance equation:

Production – consumption = export – import (19)

The left part of the equation can be easily obtained from the available data. The right part will be calculated in this section.

Import = 361536MWh

Export=266808MWh

Export - Import = 266808 - 361536 = -94728MWh=-94.73GWh

Production-Consumption =867*31*24-710= -85.76GWh (BALTSO 2008)

The calculating error is 8.97GWh, which is acceptable within the limits of this work.

5 Proposed new interconnections between Baltic States and Nordic countries / Poland and their effects in 2020

The planned electricity interconnectors between the Baltic States and Nordic countries and Poland are nowadays drawn much attention in Europe. The EU commission has made a decision to invest 100 million € in the Estlink-2 interconnection construction and 175 million € in strengthening of the Lithuanian and Swedish transmission grid (Press releases RAPID 28.01.2009)as a preparation step for the interconnection between them. The planned grid links are discussed in this chapter. Technical and market based requirements for their commissioning are listed as well as several power balance scenarios are carried out with different combinations of the links.

5.1 Overview of interconnections

Following interconnections are proposed (BALTSO, Nordel, PSE Operator S.A. 2009):

1. Estonia - Finland – Estonia Estlink-2, 650MW;
2. Lithuania – Poland – Lithuania, 1000MW;
3. Sweden - Lithuania - Sweden, 700MW;
4. Estonia – Sweden (connecting offshore wind power)

The main drivers for constructing the new interconnectors are enhanced competitiveness and security of supply issues. Furthermore, diversification of energy resources will contribute to using less polluting energy prime resources. Renewable resources are prioritized.

The benefit of each interconnection depends on the order of its building.
It has been estimated (BALTSO, Nordel, PSE Operator S.A. 2009), that the interconnections have higher benefit if used in extreme conditions, when the transmission capacity is maximum used.

The first built interconnection usually has a higher benefit compared to the second built one, since it gets the benefits in a certain area before the second built interconnection gets them.

Best solutions are listed below in the order of priority (BALTSO, Nordel, PSE Operator S.A. 2009):

1. Estonia – Finland + Lithuania – Poland
2. Only Sweden – Lithuania
3. Sweden-Lithuania + Lithuania – Poland
4. Build all 3 interconnections

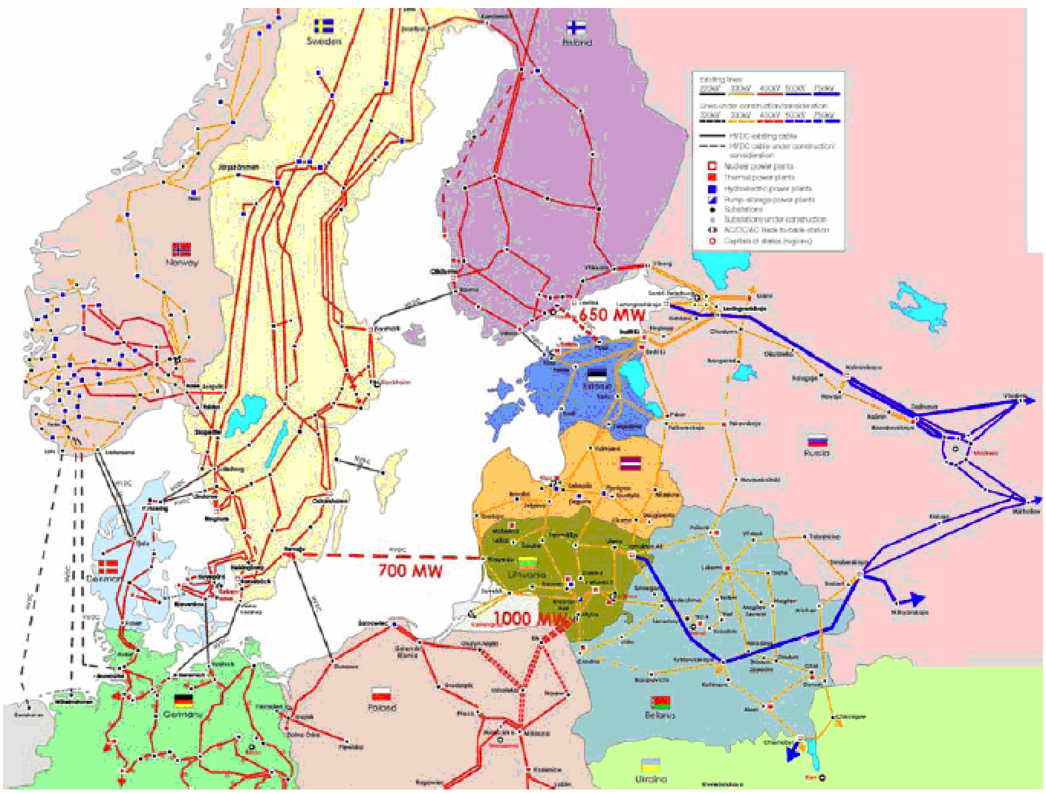

Figure 11 New interconnections from the Baltic market (BALTSO, Nordel, PSE Operator S.A. 2009)

Building both Finland-Estonia and Sweden-Lithuania interconnections is not mentioned here. They function as parallel paths between Nordic and Baltic countries since marginal costs are often the same in Finland and Sweden. During internal Nordic grid congestions or in order to reduce grid losses, the new interconnections could also be used for power transit from northern Sweden and Finland to southern Sweden.

Finland-Estonia link is considered to be more beneficial than Sweden-Lithuania because of its shorter length, and hence lower costs. Besides, less time is required to construct it which will ensure its higher economical benefit.

5.2 Prerequisites for interconnections

In this chapter the necessary changes to electrical networks of the appropriate countries are overviewed, before a new grid link can be commissioned. We concentrate on technical issues, i.e. which reinforcements are required and what are the reasons for that.

5.2.1 Poland – Lithuania

The link is expected to be commissioned by 2015. It will connect the 400kV Elk substation in Poland with the 330kV Alytus substation in Lithuania through a back-to-back DC link in Alytus(Paškevičius 2006).

The whole project is divided into 3 parts:

1. Lithuanian grid reinforcement

It supposes the construction of two 330kV lines. The line connecting Alytus with Kruonis PSP is planned to be carried out from 2010 till 2015. The other line will connect Kruonis with Ignalina. It will provide connection between Poland and Belarusian and Latvian and Russian grids.

These lines will increase transmission capacity of the Lithuanian grid, thus enabling power exchange between two countries. Currently Alytus substation is connected only with the Lithuanian thermal power plant.

2. 400 kV interconnector Elk – Alytus and the Alytus DC station
3. Polish grid reinforcement

5.2.2 Sweden – Latvia vs. Sweden – Lithuania

1. Latvia – Sweden

Latvian transmission grid is weak and requires much reinforcement before any link can be built into the grid. The major plan is to construct a 330kV corridor connecting Grobina – Ventspils – Tume – Riga TEC1/2.

Despite the weak electrical network, Latvia has several justifications for building the link with Sweden:

a. Security of supply. Latvia imports 30 to 50% of electricity annually from Estonia and Lithuania.

b. Ignalina NPP closure and diminishing of oil-shale based energy generation in Estonia will make the export possibilities to Latvia even worse.

c. It is not reasonable to rely on Russian electricity. First, there is only one 330kV interconnecting line. Second, overloads and bottlenecks in Russian western grid will not make it possible to export larger amounts of power to Latvia.

However, as an alternative for Latvia, imports from the Nord Pool through Estlink, with transit through Estonia, could be considered.

2. Lithuania – Sweden

Although Lithuania possesses an advantage over Latvia in terms of better grid conditions, stronger interconnections with Belarus, Russia and Latvia, the neighboring countries are still competing for security of supply on their territory.

However, better grid conditions on the Lithuanian territory obviously demonstrate possibility of sooner construction and therefore exploitation of the Sweden-Lithuanian grid link, which results in higher socio-economic benefits.

In April 2009 the prime ministers of the Baltic countries made a decision to start building the Lithuania – Sweden interconnection as soon as possible. It will be a trilateral energy infrastructure project with Latvian, Lithuanian and Swedish energy companies involved. Implicit auction will be implemented on the interconnection with equal access of all EU-market participants. (Ansip, Dombrovskis & Kubilius 27 April 2009)

5.2.3 Estlink-2

Justifications are security of supply, decrease of dependency of the Baltic States on Russian electricity import, integration with the Nordic market as well as increased reliability of the Estonian power system.

The requirement of the beginning of the link construction is, according to Fingrid, a decision on fully open electricity market in Estonia. Furthermore, a reference price and common market rules should be established in the Baltic power market (4energia 09.10.07).

The power networks of Estonia and Finland do not require any special internal grid reinforcement before the commissioning of Estlink-2. During the past few years strengthening of the grid has been done. Among several major projects, the construction of the Balti – Kiisa 330 kV overhead line, 216 km long, significantly increased the transmission capacity of the network in the central and western parts of the country. Furthermore, replacement of the 125 MVA autotransformers in the 330 kV Tartu substation with the 200 MVA ones has been accomplished (Eesti Energia 2007). This allows larger power flows through the Tartu substation, and thus, is an important step towards constructing the planned Sindi – Tartu connection. The latter will provide stronger connection between eastern and western parts of the transmission grid. This helps to avoid internal grid congestions in case of large power transits through the country.

5.3 Power balance and cross-border flows with different combinations of interconnections in 2020

It is important first to figure out, to what extent is the Baltic transmission grid ready for new power transits from Finland, Sweden and Poland. After necessary changes are added to the model, power flow experiments can be carried out.

5.3.1 Reinforcement of the Baltic transmission grid

Reinforcement of internal grids of each country will be considered for the period up to 2020.

Estonia has relatively strong power networks and can withstand up to 1400MW of export/import (BALTSO 2008). The additional interconnection between Estonia and Latvia is currently being studied by Estonian TSO Põhivõrk together with Latvian TSO Augstsprieguma Tkl*s*. There are three alternative routes, which are being investigated and compared economically for the Harku-Sindi-Riga 330kV corridor.

After 2025 the majority of existing 330kV are planned to be upgraded to a larger cross-section, i.e. 400 sq. mm.

- Latvia

The 330kV overhead line ring Valmiera – Gulbene – Rezekne in the eastern part and Grobina – Ventspils – Imanta in the western part will strengthen the current weak transmission networks. However, these projects are still under study, the date of their construction is not determined yet. The western grid reinforcement will increase reliability of power supply as well as provide reliable connection of new 400 MW Kurzeme TPP, on-shore and off-shore wind parks.

Another alternative of Estonia-Latvia connection includes a DC undersea cable, going from Estonia to Saaremaa islands and from there connected to the Ventspils substation.

- Lithuania

The reinforcement plans are listed in the table 14.

In order to transfer greater power flows from the planned Visaginas nuclear power plant it is necessary to strengthen the northern part of 330kV grid.

The Alytus - Kruonis overhead line will be constructed to enable power exchange between Poland and Lithuania through the new grid link.

The Visaginas NPP – Kruonio PSP line will allow higher power flows from Visaginas NPP to the grid as well as for export, especially if there will be two units of 1635MW.

Table 14 Internal grid reinforcements in Lithuania. Length of lines. (BALTSO 2008)

Substation	l, km	x, Ω	b, µS	R, Ω
Klaipėda – Telšiai	90	29,52	306,9	3,888
Panevėžys – Mūša	80	26,24	272,8	3,456
Kruonis – Alytus	53(dbl)	8,692	361,46	1,1448
Visaginas NPP – Kruonis	200	65,6	682	8,64

The figure 12 shows abovementioned reinforcement plans of the internal grid of the Baltic countries.

Figure 12. Reinforcement of the Baltic transmission grid

5.3.2 Generation and consumption in 2020

In this chapter consumption and generation of the Baltics in 2020 are estimated based on previous data and forecasts of Baltic TSOs.

1. Consumption

The relation between summer and winter peak loads is calculated for:

Estonia

- Winter

In 2007 Pmin/Pmax=442/1525=0.289

In 2006 Pmin/Pmax=424/1553=0.273

Thus, the average coefficient for 2020 is assumed to be Pmin/Pmax =0.28

Pmin=2300*0.28=644MW

- Summer

For summer season relation between maximum and minimum load is calculated:

In July 2006: Pmin/Pmax=424/837=0.5

In July 2007: Pmin/Pmax=442/918=0.48

For summer 2020 the average coefficient Pmin/Pmax=0.5

Pday=Pmax= Pmin/0.5=1288MW

Pnight=Pmin=644MW

Latvia

- Winter

In 2007 Pmin/Pmax=415/1372=0.3

In 2006 Pmin/Pmax=383/1421=0.269

For 2020, Pmin/Pmax =0.285

Pmin=2200*0.285=627MW

- Summer

In July 2006 Pmin/Pmax=383/908=0.422

In June 2006 Pmin/Pmax=415/970=0.427

For summer 2020, Pmin/Pmax=0.425

Pday=Pmax= Pmin/0.425=627/0.425=1475MW

Pnight=Pmin=627MW

Lithuania

- Winter

In 2007 Pmin/Pmax=662/1750=0.378

In 2006 Pmin/Pmax=617/1836=0.336

We assume for 2020 Pmin/Pmax =0.35

Pmin=3000*0.35=1050MW

- Summer

In July 2006 Pmin/Pmax=617/1256=0.49

In July 2007 Pmin/Pmax=662/1308=0.5

For summer 2020 Pmin/Pmax=0.5

Pday=Pmax= Pmin/0.5=2010MW

Pnight=Pmin=1050MW

The results are listed in the table 15.

Table 15 Total consumption in different load intervals in 2020, MW

		Estonia	Latvia	Lithuania
Peak demand Pmax(EURPROG Networks of Experts 1 April 2008)		2300	2200	3000
Winter peak month	Day 0.9Pmax	2070	1980	2700
	Night 0.65Pmax	1495	1430	1950
Summer peak month	Day Pmax	1288	1475	2010
	Night Pmin	644	627	1050

Now we distribute the total consumption of each period between substations. The results are presented in tables 16– 18.

Table 16 Consumption in Estonia, 2020

Substation	Winter day	Winter night	Summer day	Summer night
Kiisa	512	370	318	159
Paide	200	144	124	62
Pussi(110+Arukula)	600	433	373	186
Balti	366	265	228	114
Sindi	133	96	83	41
Tartu	173	125	108	54
Tsirguliina	73	53	46	23
Total	2070	1495	1288	644

Table 17 Consumption in Latvia, 2020

Substation	Winter day	Winter night	Summer day	Summer night
Valmiera	226	163	168	71
Krustpils	146	106	109	46
Daugavpils	350	253	261	111
Jelgava	360	260	268	114
Broceni	155	112	115	49
Grobina	274	198	204	87
Bisuciems	33, 9	24	25	10
Imanta	121	87	90	38
RigaTEC	312	225	232	99
total	1980	1430	1475	627

Table 18 Consumption in Lithuania, 2020

Substation	Winter day	Winter night	Summer day	Summer night
Klaipeda	181	131	135	70
Telsiai	145	105	108	56
Siauliai	304	219	226	118
Panevezys	417	301	311	162
Utena	124	89	92	48
Jonava	365	264	272	142
Neris	367	265	273	142
Alytus	270	195	201	105
Kruonio	140	101	104	54
Kaunas	251	181	187	97
Jurbarkas	134	97	100	52
Total	2700	1950	2010	1050

The generated power from the assumed new commissioned power plants is added to the already existing ones according to the geographical principle:

- Purtse – to Pussi
- Neugrund – to Balti
- Liepaja – to Grobina
- Kurzeme – to Broceni
- Iru to Harku
- Kegums – distributed between Salaspils (Kegums 1) and Plavinu (Kegums 2)

The generation is distributed between the power plants according to merit order of production variable cost (see fig. 13). The priority is the following:

1. Hydro, wind power
2. Nuclear power
3. CHP bio
4. Oil-shale (old units)
5. Coal CHP (Ventspils)
6. Oil shale (new units in Eesti power plant)

7. CHP gas
8. Condensing coal – Kurzeme TPP

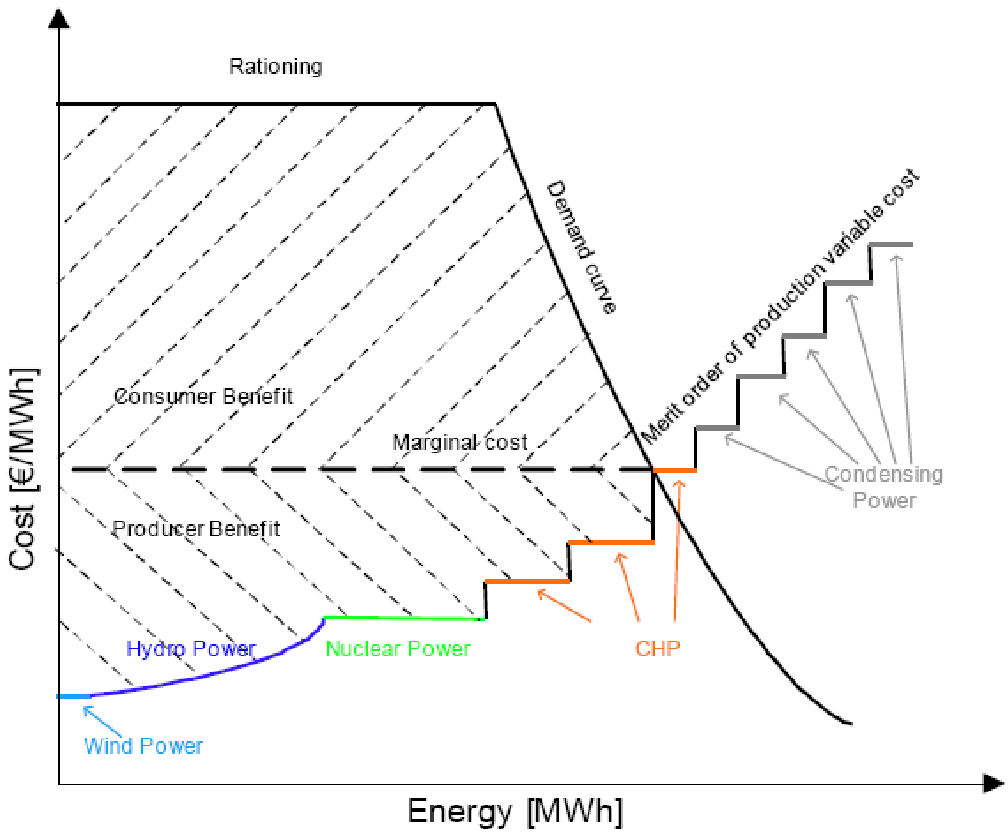

Figure 13. Merit order of production variable cost (BALTSO, Nordel, PSE Operator S.A. 2009)

The price estimation for each period is based on demand and supply forecasts. The higher power demand is, the more expensive power plants are in use and the higher the spot price is. The generation estimations are presented in tables 19 – 22.

Table 19 Generation for each power plant in Estonia, 2020

	Avail. capacity	Current generation/consumption, MW			
		Winter		Summer	
		Day	Night	Day	Night
Balti, Unit 1 + 2	200	21.5+193.5	21.5+193.5	147	147
Eesti	1000	1000	1000	760	760
Ahtme		30	30		
IRU(to Harku)	320	210	210	160	160

Tartu CHP	25	25	25	19	19
Neugrund offshore	200	51	51	51	51
PURTSE (Wind)	128	128	128	128	128
Total generation	1873	1659	1659	1265	1265
Total consumption		2070	1495	1288	644

Table 20 Generation for each power plant in Latvia, 2020

	Avail. capacity	Current generation/consumption, MW			
		Winter		Summer	
		Day	Night	Day	Night
Riga CHP	771	771	627	200	
Imanta CHP	63.9	63.9	16	12.2	12
Plavinu HPP	398	398	199	376	188
Riga HPP	184	184	92	174	87
Daugavpils HPP	45.9	45.9	23	43	21.5
Jelgava CHP	24,9	24.9	0	0	0
Daugavpils CHP	108	108	12	0	0
Broceni PP	104	0	0	0	0
Kurzeme TPP	0	0	0	0	0
Valmiera CHP	10	10	10	7.6	7,6
Ventspils	20	20	20	16	0
Kegums HPP1+2(Salaspils and Plavinu)	121	121	60.5	114	57
Total generation	1830	1810	1060	942.8	373.1
Total consumption		1980	1430	1475	627

Table 21 Generation for each power plant in Lithuania, 2020

	Avail. capacity	Current generation/consumption, MW			
		Winter		Summer	
		Day	Night	Day	Night
Vilnius CHP3, Unit 1 + 2	20+340	20+340	20+340	15+200	15
Kaunas CHP, Unit 1 + 2 + 3	15+160+350	15+160+350	15+24	11+200	11

Lietuvos	1500+400	0	0	0	0
Panevezys CHP	35	35	0	0	0
Kruonis PSP	±900	450	-450	450	-450
Kaunas HPP		33.9	33.9	32	32
Visaginas NPP	1635	1635	1635	1600	1600
Klaipeda CHP	10.8+25	25	25	19	19
total		3064	1643	2527	1227
Total consumption		2700	1950	2010	1050

Table 22 Total generation and consumption in the Baltic countries, 2020

	Winter		Summer	
	Day	Night	Day	Night
Total consumption, MW	6750	4875	4773	2321
Total generation, MW	6681.6	4362	4338	2865
	Balance, import required	Import required	Import required	Export possible

5.3.3 Power balance scenarios

The calculated consumption and generation for different load intervals in 2020 have been used to simulate different power balance scenarios. The first of them is the basic case, when only internal Baltic power balance is considered, without export or import to third countries. This is done to figure out the following issues:

- Security of supply

It can be seen from the figures 14, 15 and 16 that during winter and summer days, as well as winter nights, overall power balance in the Baltic countries is negative and power import, or alternatively gas-fired condensing generation, is required. During summer night (see fig. 17) the Baltic countries have power surplus of 425MW which they are able to export. Sweden is selected as the open delivery supplier for the countries. However, it does not matter where the balancing power comes from. It will be the same, provided that we do not take into account power losses.

In reality, the amount of power surplus or deficit might flow out or into the countries, respectively, through any of the interconnections depending on the price difference between the countries. According to the implicit auction principle, the higher the price difference is the higher is the power flow through the interconnection.

- Congestion

Before making any conclusions about congestion in the grid, it should be first stated what are the maximum powers along the interconnecting lines between Baltic countries.

In table 23 the values for maximum power of single lines are given. In table 24 the values for transfer capacities between countries can be found. Both of those values should be taken into account. The difference between the values, for example if we compare Estonia - Latvia transmission capacity with the sum of the maximum powers through both interconnecting lines between the countries, is due to the fact, that the transmission grid of an importing country cannot accept such high power flows as a single line can.

Table 23. Transfer capacities for interconnecting lines (Joint EURELECTRIC-UCTE WG SYSTINT (with contribution of WG SYSTMED and other experts) 2007)

№	Start	End	Pmax, MW
451	Ignalina	Liksna	860
301	Tartu	Valmiera	550
351	Tsirgulina	Valmiera	730
309	Velikoreckaja	Rezekne	690
457	Jelgava	Telsiai	290
316	Panevezys	Plavinu Hes	570
324	Klaipeda	Grobina	540

Table 24. Transfer capacities (Arnis Staltmanis 2009)

Latvia -Estonia	To Estonia	To Latvia
	750	750
Lithuania – Latvia	To Lithuania	To Latvia

	1300	1500
Estonia – Russia(St.P.)	To Estonia	To Russia
	1000	1000
Estonia – Russia (Pskov)	To Pskov	To Estonia
	300	400

Winter day is the most loaded case. From figure 14 it can be seen that no transmission capacity limits are exceeded between the countries. The balancing joint in this and the other experiments is made in the Klaipeda substation. Thus all power deficit or surplus is shown to be covered by Sweden in all Baltic power balance experiments. However, in reality the balancing power might come from Finland through Estlink 1 or 2, as well as from Poland, depending on electricity prices in the countries.

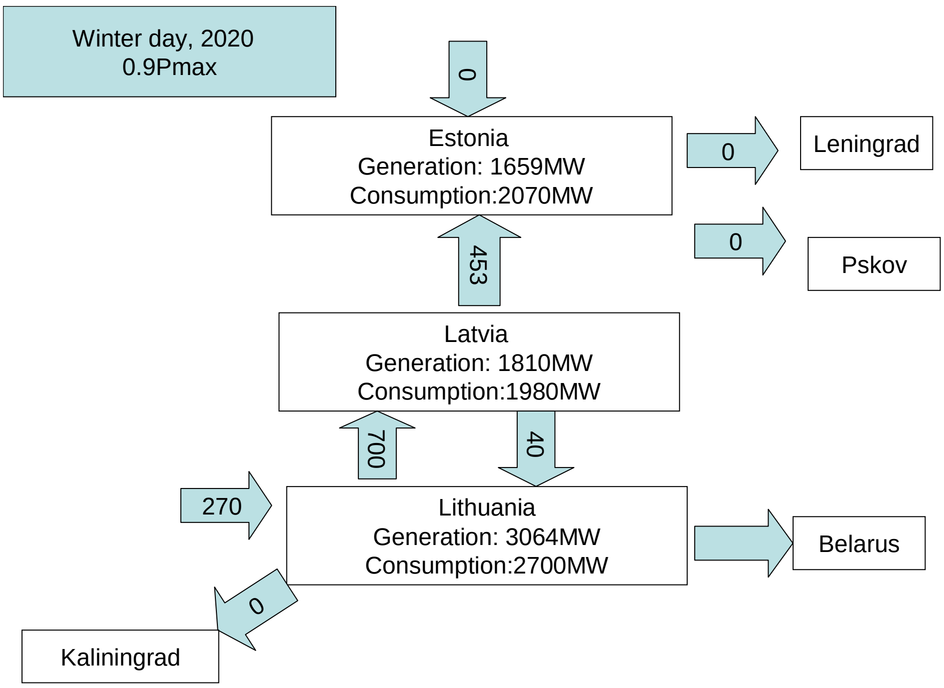

Figure 14. Power exchange between the Baltic countries, winter day, 2020.

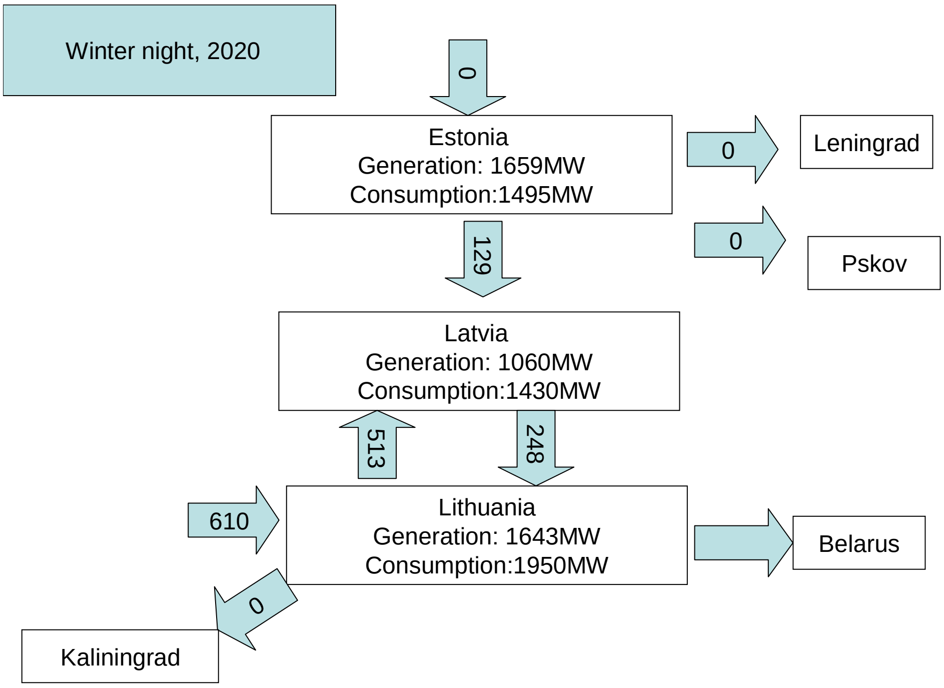

Figure 15. Power exchange between the Baltic countries, winter night, 2020.

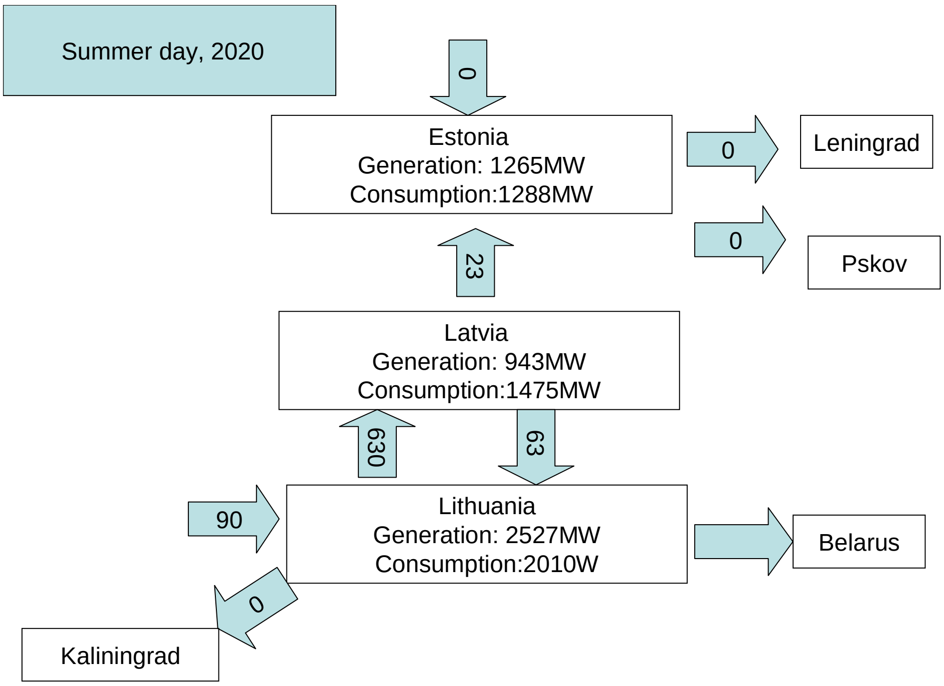

Figure 16. Power exchange between the Baltic countries, summer day, 2020.

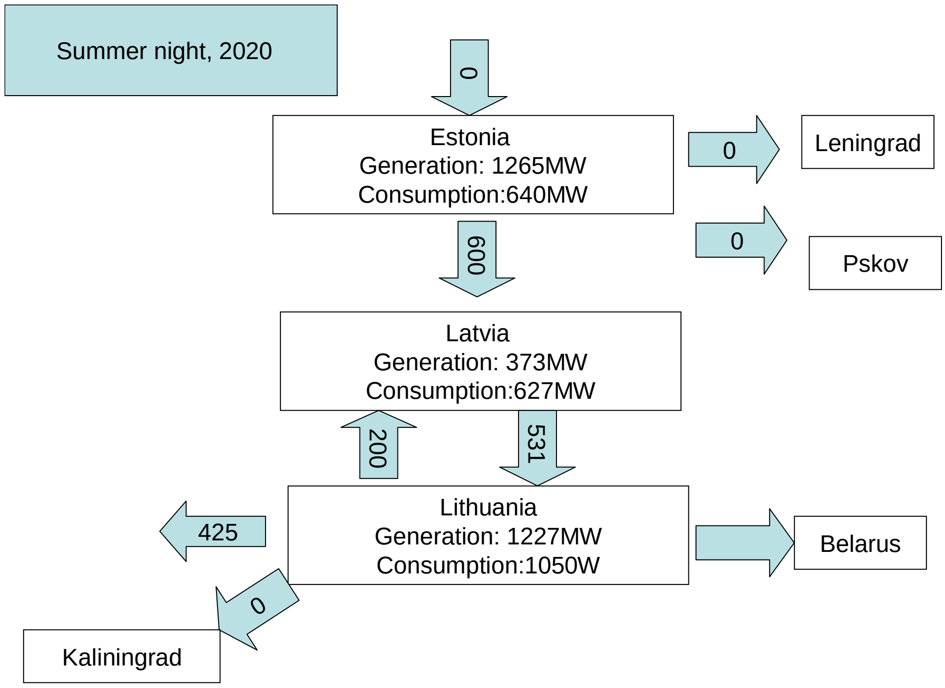

Figure 17. Power exchange between the Baltic countries, summer night, 2020.

It is worth mentioning that the value and direction of power flows in the model are fully based on generation, consumption as well as on angle difference between adjacent joints. The model does not take into account market electricity prices, i.e. market based power flows cannot be reflected in the power flow tool. However, the carried out scenarios can be referred to the National Focus scenario (NF), when the focus is done primarily on the domestic energy sources and the use of interconnections is minimized. It has been calculated for the NF2025 scenario that the marginal cost in Poland will be higher than the one in the Baltic countries. Therefore, power surplus during summer nights will most likely flow through the Lithuania-Poland grid link.

5.3.4 Import from Poland

In this chapter the transit of 1000MW from Poland during summer and winter nights is simulated in the power flow tool. Day time, i.e. peak load hours, is not considered in this scenario because of the negative power balance in the Baltics along with large power flows from south to north, i.e. from Lithuania to Estonia (see fig.14 and 16). The target is to check what the maximum power is that can be transmitted from Poland during night-time, i.e. off-peak hours. The effect on the Baltic and Nordic countries is represented.

Klaipeda is selected again as a balancing joint. The power through the Estlink 1 and Estlink 2 towards Finland is represented as load in the joints Harku and Pussi respectively.

It can be seen from the figure 18, that the interconnections between Finland and Estonia can be fully used during summer nights. No Baltic grid congestion is revealed in this case. There is still enough power to export to Sweden, i.e. 435 MW.

This simulated case might reflect the situation, when marginal cost in Poland is lower than the one in the Baltics. According to the implicit auction principle, power flows from a low price area to a high price area. However, according to the multiregional interconnection study (BALTSO, Nordel, PSE Operator S.A. 2009) the average price in Poland is always higher than the one in the Baltics. This corresponds to the power flow towards Poland. On the other hand, during off-peak times the hourly prices in the Continental thermal power system can be lower than in the Baltic and Nordic markets.

The other reason for importing power from Poland might be that the system price in the Nordic countries is higher than the one in the Baltics, which is the most typical case. The possible case of export from Poland is when the Baltics have the power deficit; meanwhile Poland imports energy from the Ukraine and is in power surplus.

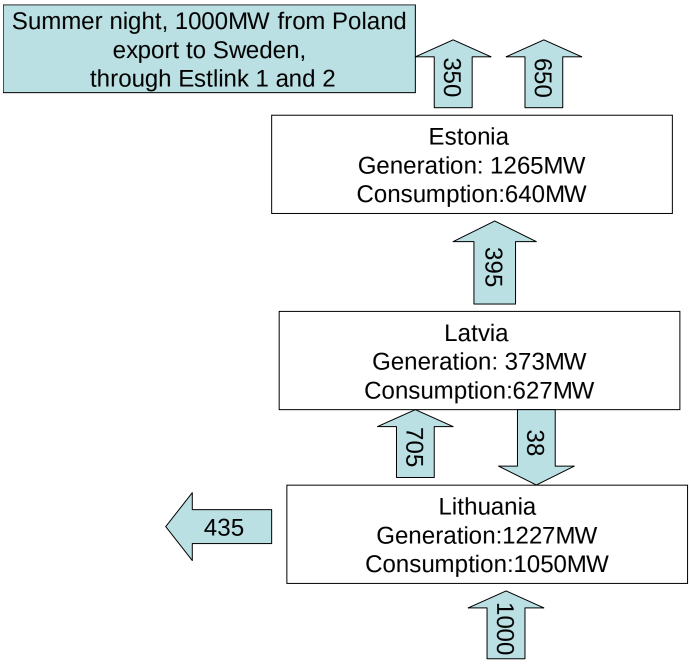

Figure 18. Import from Poland, summer night 2020

However, when the power from Poland is transmitted during winter nights, it will probably only be transmitted to Sweden. No export to Finland is possible because of the negative power balance in the Baltic countries (see fig. 19)

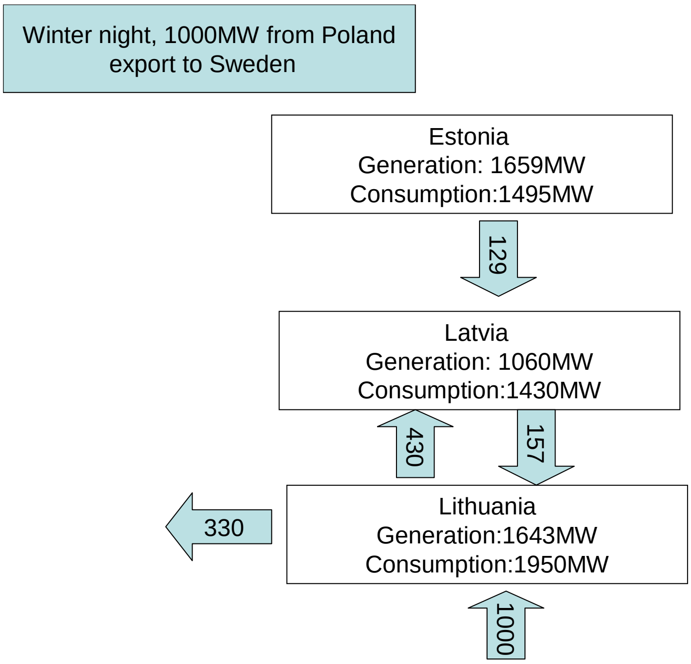

Figure 19. Import from Poland, winter night 2020

5.3.5 Import from Finland

In this chapter two cases are considered, both in the most loaded case, i.e. on a winter day. The main target is to check whether transmission capacity of the Baltic power networks is enough to transfer maximum available power from Finland during peak-load hours. If this is the case, no problems will occur during off-peak load hours.

Import from Finland through both Estlink 1 and 2.

There are three options for power to flow:

- to Sweden
- to Poland
- to both Sweden and Poland

The first way will be most likely chosen if there is grid congestion in Sweden. The power will flow through the Baltics to supply the south regions in Sweden.

The picture 12 represents the power flow tool calculation results. It can be seen, that 1000MW from Finland results in 580MW to Sweden. The rest power covers the power deficit in the Baltics.

Congested line is Visaginas – Utena overhead line, carrying 620MW. Part of generated power could be exported to Poland through the new built line Visaginas – Kruonio.

The given power transmission limits between countries are not exceeded:

Latvia – Estonia – 530MW (max.750MW)

Latvia – Lithuania – 610 MW (max. 1500 MW)

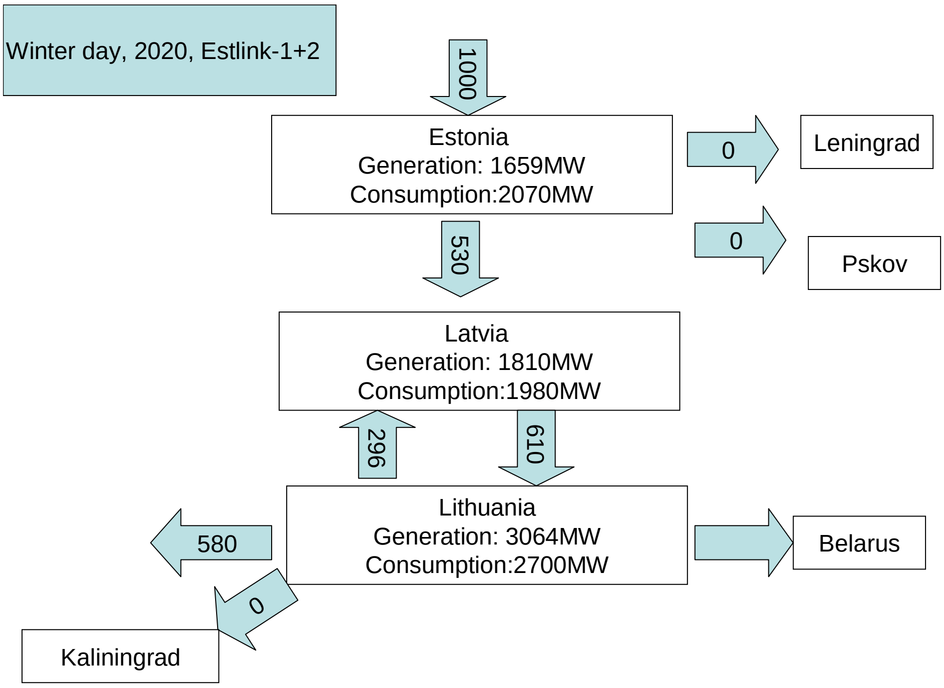

Figure 20. Transit from Finland to Sweden

The next option is export to Poland. According to the studies (BALTSO, Nordel, PSE Operator S.A. 2009) the Lithuanian – Poland grid link is the most congested one in Business as Usual (BAU) scenario for 2025. The scenario supposes already developed day-ahead, forward, intra-day and balancing markets in the Baltic States. Regulated tariffs in the whole Baltic Rim area are abolished and perfect competition is introduced along with support for cogeneration and renewable energy sources. The scenario is considered to be the best estimate for future market developments and is used as a base case scenario in the market based analysis of interconnections organized by TSOs of the involved countries.

The figure 21 shows the power flows.

The line Visaginas – Utena is less loaded in comparison to the previous case, whereas the Visaginas – Kruonio is more loaded due to the concentrated power flow towards Poland.

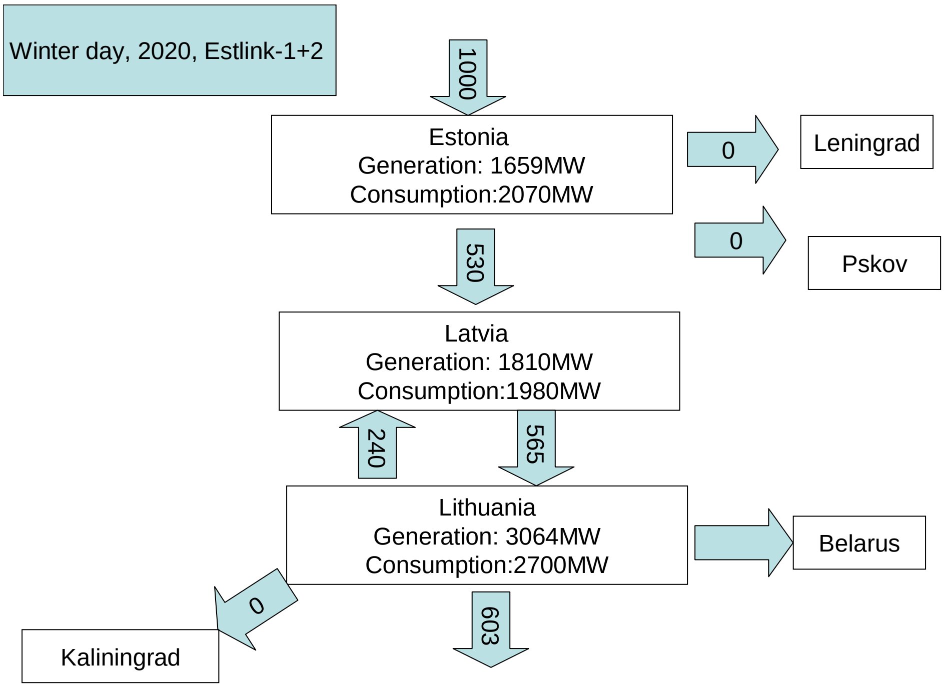

Figure 21. Transit from Finland to Poland

5.3.6 Import from Russia

In this chapter the most loaded case is considered, when both Finland and Russia export 1000MW each on a winter day of 2020. In the simulation the Russian grid is partly taken into account. To be more specific, the substations Kingisepp, Pskov and Velikoreckaya are connected with each other (see table 25). The Russian overhead lines transmit part of imported Russian power and thus relieve the congestion in the Baltic grid.

Table 25. Parameters of Russian grid lines

		L, km	X, Ω	B, S	R, Ω
Tartu	Pskov	175	57,4	596,75	7,56
Eesti	Kingisepp	40	13,12	136,4	1,728
Velikoreckaya	Rezekne	165	54,12	562,65	7,128
Pskov	Velikor	20	6,56	68,2	0,864
Kingisepp	Pskov	195	63,96	664,95	8,424

The calculation results are presented in figure 22.

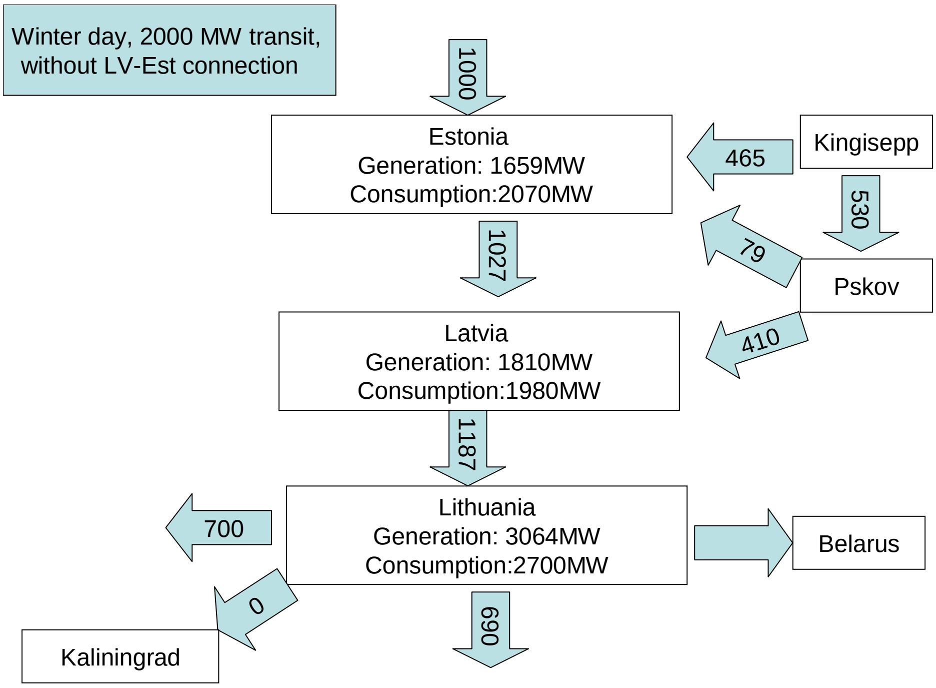

Figure 22. 2000MW transit without LV-EE additional connection

It can be seen, that the power flows between Baltic countries exceed the maximum transfer capacities, stated earlier. Therefore, there is the need for an additional connection between Estonia and Latvia.

In this work a connection from Harku to Ventspils through Saaremaa islands is modeled. The total impedance of the line can be found using the following equation:

$$Z_{total} = Z_{undersea} + Z_{overhead} \tag{20}$$

For overhead lines we assume the same specific parameters as previously.

For a submarine AC cable 330kV with cross-section equal to 550 sq. mm. specific parameters have the following values (Faibisovich 2006):

$r_o = 0{,}032\,\Omega / km$; (20)

$x_o = 0{,}075\,\Omega / km$; (21)

$b_o = 150\ \mu S/km$; (22)

There might be two options to implement the undersea cable: either AC or DC. A DC cable does not generate any reactive power unlike an AC cable, which has a large capacitive reactance. A DC cable requires the installation of two converter stations which are rather expensive.

The reactive power in the AC cable heats it which results in high power losses. The choice of the cable should be made after proper techno-economic calculations. In this work, we model the DC cable.

Lsubmarine= 75km (Ventspils - Sääre) +10km (Virtsu – Kuivastu) =85km

$R_{submarine} = 85 \cdot 0.032 = 2.72\Omega$

The total resistance of the interconnection is:

$$Z_{total} = Z_{OH} + Z_{submarine} = (4.49 + 0.99 + 4.58) + 2.72 + j(34.11 + 7.5 + 34.76) =$$
$$= (12.78 + j76.37)\Omega$$

$b_{OH} = 354.64 + 78.43 + 361.46 = 794.53 mkS$

The technical parameters of the interconnection are presented in table 26.

Table 26.Technical parameters for the EE-LV interconnection for overhead lines

		L, km	X, Ω	B, μS	R, Ω
Overhead transmission lines					
Harku	Lihula	104	34.112	354.64	4.4928
Lihula	Virtsu	23	7.544	78.43	0.9936
Orissaare	Sääre	106	34.768	361.46	4.5792
Submarine cable					
Ventspils Virtsu	Sääre Kuivastu	85	0	0	2.72

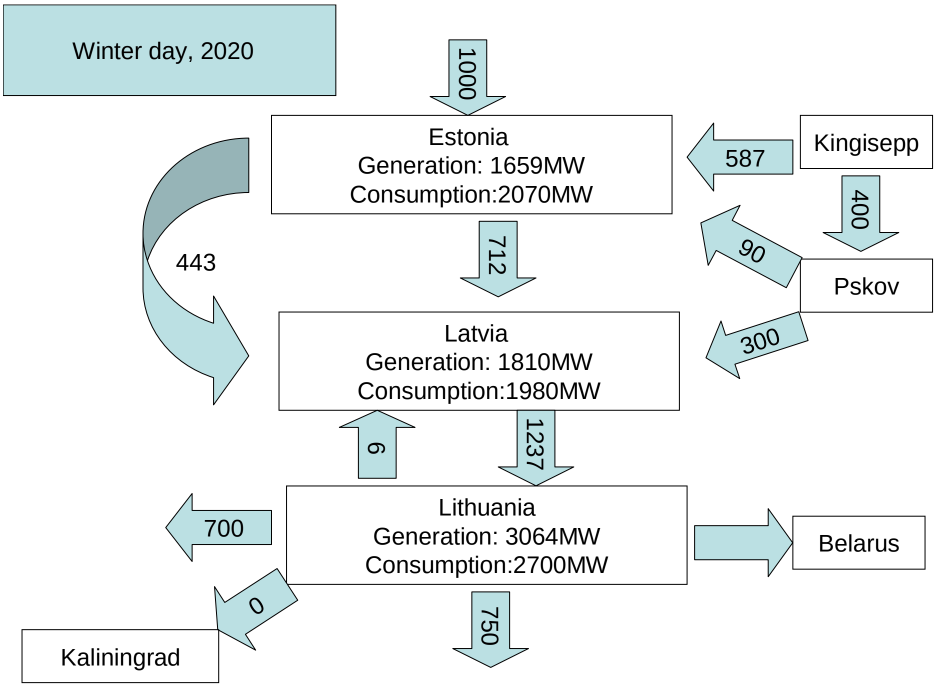

Figure 23. 2000MW transit through the Baltics

Main congestion is concentrated around Riga (see fig.24). The reason is that Salaspils and Bisuciems have small consumption, whereas Riga CHP and HPP produce almost half of generated power in the country. This results in highly loaded overhead lines, up to 780 MWs.

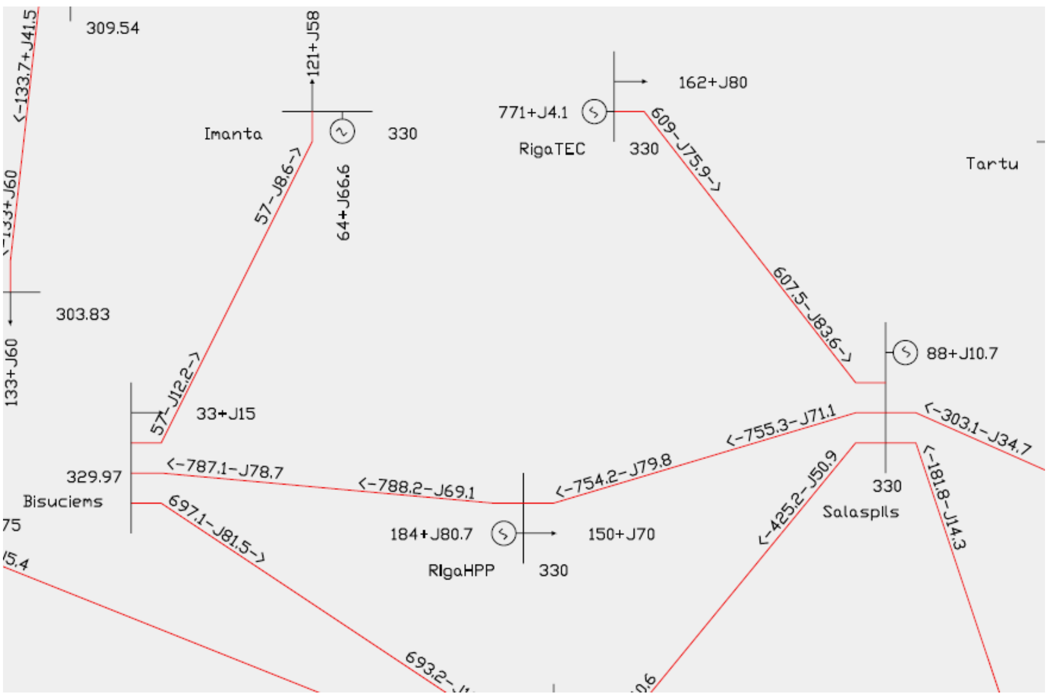

Figure 24. Congestion around Riga region

The additional overhead line from Harku to Riga could relieve the congestion.

5.4 Patterns in Baltic States

1. The calculation results of all power balance scenarios showed up that the direction of power flow along Jelgava – Musa –Telsiai and Ignalina – Liksna is always the same, i.e. to Lithuania and Latvia respectively. This results in the fact, that Jelgava – Musa – Telsiai and Ignalina – Liksna are load feed lines. Daugavpils in Latvia is supplied by power generated from the Ignalina NPP (Visaginas NPP in 2020 scenario), whereas Telsiai in Lithuania is supplied by power transmitted from Latvia. Direction of power along the lines is always same no matter if it is peak or offpeak hours. Therefore, Panevezys – Plavinu and Grobina – Klaipeda overhead transmission lines belong to the BRELL ring. The power flow along them varies according to the current power balance in the countries.

2. The power flows from Klaipeda towards Grobina during peak load and off peak load hours in winter, 2007, as well as during peak load hours in summer.
The opposite direction is observed always during summer nights, i.e. off peak load hours, in 2007 and in 2020.

3. The power goes from Plavinu HPP (Latvia) towards Panevezys (Lithuania) in all scenarios of 2020. Latvia and Estonia are balancing Lithuania.
The opposite direction is observed in 2007. Latvia was an importing country.

4. The power direction along Latvia – Estonia interconnecting lines depends on the current power balance in the neighbouring countries as well as on transits, which are determined by power flow direction and value on the grid links.

5. New lines:
1. Telsiai -> Klaipeda

Power tends to flow always from Telsiai towards Klaipeda. It relieves the interconnecting line Grobina – Klaipeda, thus supplying Klaipeda also through the other interconnecting line Jelgava – Musa

2. Panevezys -> Musa

Power tends to flow always from Panevezys towards Musa. It also relieves the interconnecting line Jelgava - Musa and supplies Telsiai with the country's own power reserves.

3. Kruonio – Visaginas NPP

Power flows always towards Kruonio.

4. Alytus – Kruonio

Power flows always towards Kruonio except summer night, i.e. off peak load hours.

5.5 Conclusions

The model does not take into account electricity market principles and regulations. The power flows are fully based on generation and consumption and result into most economical power flows. Power does not recognize the limits of each country and flows freely, always choosing the less resistive line. It results in minimum power losses. Therefore, we may roughly assume that the model reflects the Business As Usual scenario.

In 2015 the marginal costs in the Baltics are assumed to be higher than in Sweden, Finland and Poland. This ensures the power flowing towards the Baltics. In 2025 the price relations between the countries change to the opposite resulting in the opposite power flows along the interconnections. In other words, Baltic countries experience a transitional period from power deficit to power surplus between 2015 and 2025 according to the BAU scenario. If the power balance will be observed in the middle of the considered time period, i.e. 2020, the calculation results in this section correspond with it. Hence, there is a linear time dependence in power balance development of the Baltic countries.

6 New power trading principles in the Baltic Rim area

In this chapter the Baltic power market road map is described from basic requirements for an open electricity market till creating a common Baltic market which is characterized by liquidity, transparency and fully competitiveness. Nord Pool Spot market core elements and mechanisms are proposed as a basement for the future Baltic market.

6.1 Needs and benefits of the new power market mechanisms

6.1.1 Market opening requirements

Market opening requirements should be completed during the first quarter of 2010 in order to start the Baltic market integration (WG EMI Sub Group 2009). This supposes the following activities:

1. Regulated tariffs removed for eligible customers in each of the Baltic countries.
2. License permits and border tariffs have to be removed to avoid cross border restrictions of power and enable optimal, most economical and efficient use of energy sources. This will also contribute to creation of common balancing and regulating Baltic market.
3. Subsidized generators should freely enter the market without loosing subsidies. This provides better competition conditions on the market, when all generators have free access to the market and are treated equally.

Renewables such as wind, biomass and solar have high total production costs, therefore, in order to be profitable on the market they must settle high prices on the market. Most customers will not be able to afford it as a market price for their total electricity demand. Energy subsidies are a financial support, which covers partly the production costs and therefore keeps the price for producers above market levels. Support can also come as feed-in tariff or certificates from the customers.(Fingrid Oyj 2009).

Without support it might happen so that subsidized generators will loose subsidies when entering the competitive market.

4. Core activities of TSOs will be separated from import/export activities.

In Lithuania a Compliance Programme came into effect on July, 1, 2007, which objective is to ensure the independence of TSO (Lietuvos Energija) from its activity of electricity production on the market. This ensures undiscriminating treatment of all market participants, providing them an equal access to the transmission grid and use of the transmission system.

The objective of the Compliance Program is to represent Lietuvos Energija AB in two independent parties:

- As TSO
- As a market participant (trader, producer, supplier etc), which has equal rights on the market place along with other market parties.

The main function of Lietuvos Energija AB in its role of Transmission System Operator is to ensure efficient and reliable operation of the Lithuanian power system

5. Congestion management method is established between the Baltic States. There is no congestion between Baltic countries currently. The transmission capacity of interconnecting lines comprises about 70% of peak load of the Baltic countries. A congestion management tool is however required for future to establish a common price in the Baltic States as well as to ensure efficient use of transmission capacity of interconnecting lines and avoid bottlenecks with future generation development scenarios.

6. The Baltic States and Finland must have a common ITC treatment of the perimeter countries.

7. Price area Estlink should be established by Nord Pool Spot.

8. Establishment of Lithuanian day-ahead power exchange (Spot Market) according to Nord Pool Spot model.

After fulfilling all abovementioned requirements next step will be fine tuning of market functioning.

6.1.2 Fine tuning of the developing Baltic market

1. Latvia and Estonia follow Lithuania in creating day-ahead market, based on Nord Pool trading platform.
2. Intra-day market (Elbas market in NordPool) is introduced step-wise
3. Congestion management, i.e. implicit auction between Baltic countries, managed by Nord Pool Spot

The congestion rent on one area connection for a specific hour between bidding area A and B with planned flow in direction from area A to area B is found like this:

(PB - PA) * FA->B

PA = Area price area A
PB = Area price area B
FA->B = Flow going from area A to area B
Congestion rent is allocated to TSOs as transmission grid owners.

4. Common balancing power and reserves market
5. Harmonized imbalance settlement and imbalance pricing development of financial markets (OTC) – forwards, futures, call and put options to hedge against future price fluctuations.

6.1.3 Final stage of integration

The following activities are included in the final stage:

1. Retail market is fully opened.
2. Common power exchange for the Baltic, Nordic countries. This is the requirement for implicit auction implementation, unlike in explicit auction, where two power exchanges participate in trading.
3. Financial market should become available
4. Network tariff harmonization for generators.
5. Common position and trading principles of the Baltic States and Finland towards non EEA third countries, i.e. Russia, Ukraine, Belarus.

7 Conclusion

The model of 330kV transmission grid of Estonia, Latvia and Lithuania was developed to study the impact of the new proposed interconnections on the power balance of the Baltic States. The sufficiency of transmission capacity of the power networks has been checked in the following most loaded cases:

- Import of 1000MW from Finland through Estlink 1 and 2.
- Import of 1000MW from Finland and 1000MW from Russia

The congestion around the Riga region was revealed in the second case. This can be explained by high generation in the city and low consumption in the suburbs. It was proposed to build an additional overhead line from Sindi in Estonia to Riga, which could partly relieve the congestion.

The possibility to import electricity from Poland to Sweden and Finland was checked during off-peak load hours in the Baltics. The results showed that 1000MW can be transmitted from Poland through the countries towards Finland during summer off-peak hours and only towards Sweden during winter off-peak hours.

In all simulated scenarios several overhead lines have been revealed, along which power flows in the same direction. Thus, it has been figured out, that two overhead lines, namely Ignalina NPP – Liksna and Jelgava – Musa – Telsiai belong to the load feed lines, power along them has the constant direction in all scenarios. The lines Panevezys – Plavinu HPP and Klaipeda – Grobina belong to the BRELL ring, operating as balancing power lines, since the direction changes according to the power balances in the countries.

The Baltic road map was developed. The main steps are:

1. Regulated tariffs are removed and free access to CBT between Baltic is provided to all Baltic power market participants.
2. Spot market established first in Lithuania, later in Estonia and Latvia.
3. Elbas market gradually starts to operate in the Baltics
4. Balance settlement mechanism is established in all three countries

5. Financial market starts functioning, enabling futures, forwards, call and put options for all market participants.

The above mentioned items show that the common Baltic market will be based on the Nord Pool Spot market principles.

8 References

4energia 19.03.2009, "Nord Pool shelves plan to expand into Estonia" Available from: http://www.4energia.ee/index.php/lang/eng/article/990.

4energia 09.10.07, "Estlink 2 cable to be built be Estonian Energy, Fingrid" *Available from:* http://www.4energia.ee/index.php/lang/eng/article/524.

Andrus Ansip 05.10.2007, *Ansip: we have to make strategic choices in Estonian energy policy*.

Ansip, A., Dombrovskis, V. & Kubilius, A. 27 April 2009, *Joint declaration of the prime ministers' council of the Baltic council of ministers*, Vilnius.

Arnis Staltmanis 2009, "Impact of wind generation development of the Baltic transmission grid" .

Arnis Staltmanis 2006, *Congestion management and capacity allocation methods used in the Baltic region*.

Arus, I. 2008, *Baltic balancing market. Baltic Balancing Market Harmonisation WG meeting.* Eesti Energia.

AS Augstsprieguma Tīkls . Available from: www.latvenergo.lv [2009, 04/22] .

BALTSO 2008, *Annual report 2007.*

BALTSO 2007, *Annual report 2006.*

BALTSO, Nordel, PSE Operator S.A. 2009, *Market based analysis of interconnections between Nordic, Baltic and Poland areas in 2025*.

Eesti Energia 2007, *Estonian transmission system. 110 - 330 kV electrical power network. Annual report 2006/2007*.

EnergyLand.info 23.01.2009, [Online]. Available from: http://www.energyland.info/news-show-18368.

ETSO 2005, *ETSO proposal for the 2006 CBT mechanism*.

EURPROG Networks of Experts 1 April 2008, *Statistics and prospects for the European electricity sector (1980 - 2000, 2004, 2005, 2010-2030)*, Union of the Electricity industry EURELECTRIC, Bruxelles.

Faibisovich, D. 2006, *Справочник по проектированию электрических сетей*.

FAQ on Ignalina Nuclear Power Plant 2008.Available from: http://www.ambvilnius.um.dk/NR/rdonlyres/96C4B895-429B-4FB8-87F8-063BDAB0BFB4/0/IgnalinaFAQ.pdf.

Fingrid.Available from: http://www.fingrid.fi/portal/in_english/services/cross-border_services/estonian_connection/ [2009, 04/24] .

Fingrid Oyj 2009, *Opinions about feed-in tariffs?*, Fingrid Oyj, Helsinki.

Joint EURELECTRIC-UCTE WG SYSTINT (with contribution of WG SYSTMED and other experts) 2007, *European, CIS and Mediterranean Interconnection: State of Play 2006*.

Karri Mäkelä 2008, *Overview of the NPS Baltic project*.

Kekkonen, J. 2009, *Sähkomarkkinapäivä 21.4.2009*, Fingrid.

Knudsen, H., Koskinen, M. & :Ellus, L.O. 1998, *Power System Analysis Report*, Baltic Ring Study, Working Group 2.

Lietuvos Energija AB . Available from: http://www.lpc.lt/en/ [2009, 04/22] .

New Europe 23 June 2007, "Estonia wants EU to impose duty on Russian electricity", no. 735. Available from: http://www.neurope.eu/view_news.php?id=75368.

Niemi, P. & Uus, M. 2003, *Retrofitting Oil Shale-Fired Power Plants in Narva, Estonia with advanced CFB Technology*, Power-Gen Europe.

Nord Pool Spot AS *No.27/2007 Joint Baltic-Nordic project launched*.

Nord Pool Spot AS *No.55/2008 Introduction of implicit auction via the Estlink cable by 1 July 2009 at the earliest*.

OÜ Põhivõrk . Available from: http://www.pohivork.ee/.

Paškevičius, V. 2006, "Lithuanian power system and integration into European Union electricity market", Lietuvos Energija AB, Vilnius, Lithuania.

Press releases RAPID 28.01.2009, The commission proposes € 5 billion new investment in energy and Internet broadband infrastructure in 2009-2010, in support of the EU recovery plan .Brussels. Available from: http://europa.eu/rapid/pressReleasesAction.do?reference=IP/09/142&format=HTML&aged=0&language=EN&guiLanguage=en.

prof. Vidmantas Jankauskas 2006, *Electricity market in the Baltic countries*.

Staff and wire reports, VILNIUS 2008, "Lithuania looks for electricity after Ignalina", *The Baltic Times,* October 23-29, 2008.

Tere, J. 20.03.2009, *Brussells supports establishing a power cable between Estonia and Finland*, Baltic States news & analyics, Tallinn.

Virbickas, D. 2006, *Inter TSOs compensation mechanism - current state in Baltic States*, Lietuvos Energija AB.

WG EMI Sub Group 2009, *Road Map to creating common Baltic Electricity market*, Helsinki.

ИА REGNUM 2008, "**Эксперты: Поставлять электроэнергию из Литвы в Калининградскую область после закрытия Игналинской АЭС**

будет проблематично", [Online], 15.03.2009.Available from: http://www.regnum.ru/news/978505.html.

Appendix

Table of joints in the software RastrWin

Узлы

	O	S	Тип	Номер	Название	U_ном	_сх	Район	P_н	Q_н	P_г	Q_г	V_зд	Q_min	Q_max	U_
1			Нагр	1	Kiisa	330			270	130						
2			Нагр	2	Paide	330			144	70						
3			Нагр	3	Sindi	330			96	45						
4			Ген	4	Tartu	330			125	60	25	89	330	-999	999	
5			Нагр	5	Tsirguliina	330			53	20						
6			Ген	6	Balti	330			265	120	265	24.2	330	-999	999	
7			Ген	7	Eesti	330					1000	-56.2	330	-999	999	
8			Ген	8	Pussi	330			433	200	128	132.6	330	-999	999	
9			Ген	11	Valmiera	330			163	80	10	161.8	330	-999	999	
10			Нагр	12	Pskov	330										
11			База	13	Rakvere	330										
12			Ген	14	Harku	330			100	50	210	135	330	-999	999	
13			Нагр	15	Rezekne	330										
14			Нагр	16	Krustpils	330			106	50						
15			Ген	17	Plavinu	330					215.5	20.8	330	-999	999	
16			Ген	18	Salaspils	330					44	81.4	330	-99	99	
17			Нагр	19	Jelgava	330			260	100						
18			Ген	20	RigaHPP	330			100	50	92	161.2	330	-999	999	
19			Ген	21	Imanta	330			87	40	16	111.1	330	-999	999	
20			Нагр	22	Broceni	330			112	50						
21			Нагр	23	Grobina	330			198	90						
22			Нагр	24	Liksna	330										
23			Ген	25	Daugavpils	330			253	120	35	108.1	330	-999	999	
24			Ген	26	Ignalina NPP	330					1635	-9.7	330	-999	999	

Table of lines in the software RastrWin

Ветви

	O	S	Тип	N_нач	N_кон	Название	R	X	B	Кт/r	P_нач	Q_нач	Na
2			ЛЭП	2	3	Paide - Sindi	3.37	25.58	-256		-96	-21	
3			ЛЭП	2	7	Paide - Eesti	8.2	52.8	-544		176	41	
4			ЛЭП	7	8	Eesti - Pussi	2.37	18.04	-188		70	1	
5			ЛЭП	8	13	Pussi - Rakvere	1.82	13.77	-143		-169	20	
6			ЛЭП	1	14	Kiisa - Harku	1.25	9.5	-99		167	127	
7			ЛЭП	6	7	Balti - Eesti	0.65	4.92	-51.1		367	-49	
8			ЛЭП	4	6	Tartu - Balti	7.13	54.12	-562.6		429	-75	
9			Выкл	4	12	Tartu - Pskov							
10			ЛЭП	4	11	Tartu - Valmiera	6.35	48.22	-501		-329	46	
11			ЛЭП	5	7	Tsirguliina - Eesti	8.64	65.6	-682		502	-99	
12			ЛЭП	13	1	Rakvere - Kiisa	5.27	40	-416		-168	8	
13			ЛЭП	6	14	Balti - Harku	10.15	77	-801		-58	50	
14			ЛЭП	5	11	Tsirguliina - Valmiera	1.98	15	-157		-449	119	
15			ЛЭП	11	17	Valmiera - Plavinu	5.62	42.6	-443		-263	45	
16			ЛЭП	11	18	Valmiera - Salaspils	5.18	40	-409		-351	45	
17			ЛЭП	17	16	Plavinu - Krustpils	1.94	14.7	-153		-85	-5	
18			ЛЭП	18	17	Salaspils - Plavinu	3	23	-239		122	-4	
19			ЛЭП	16	24	Krustpils - Liksna	3.45	26.24	-273		21	30	
20			ЛЭП	24	15	Liksna - Rezekne	3.45	26.24	-273		-0	30	
21			Выкл	15	50	Rezekne - Velikoreck					0	-0	
22			ЛЭП	24	25	Liksna - Daugavpils	0.43	3.28	-136.4		-218	2	
23			ЛЭП	24	26	Liksna - Ignalina NPP	2.59	19.68	-204.6		239	-31	
24			ЛЭП	26	27	Ignalina NPP - Utena	0.73	5.58	-58		-497	-65	
25			ЛЭП	26	31	Ignalina NPP - Neris	4.55	36	-375		-453	-7	