POTENTIAL FOR ENERGY STORAGE IN LATVIAN AND LITHUANIAN PRICE AREA IN THE NORD POOL SPOT

Karlis Baltputnis, Antans Sauhats, Olegs Linkevics

Riga Technical University, Institute of Power Engineering, Azenes iela 12/1, Riga, LV-1048, Latvia

Abstract

This paper considers the potential for energy storage in Latvia and Lithuania with a particular focus on electrical energy storage benefiting from price arbitrage. A model to optimize the operation of a generic price-taker storage plant participating in a liberalized market has been created and applied to Kruonis pumped storage plant in Lithuania. The ability of a compressed air energy storage plant to benefit from price spread depending on its size and efficiency has been analyzed as well.

The paper is structured as follows: the first section gives a brief overview of the peculiarities of electricity market in Latvia and Lithuania, including a description of currently utilized energy storage options and an overview of compressed air technology; the next chapter describes the mathematical model; the third chapter summarizes the results from the case studies, followed by the conclusions.

1. Introduction

1.1. Latvian and Lithuanian price area

Most of the electrical energy produced in Latvia and Lithuania is traded in the Nord Pool power market. The latter joined the exchange in 2012, whereas the former – in 2013. Nord Pool Spot is the largest electrical energy market in Europe bringing together the producers, traders and consumers of the Nordic and Baltic countries.

In order to account for congestion in the transmission network the market is separated into several bidding areas, each country being its own area. Norway and Sweden is an exception to this, however, as due to their low population density and large geographic scope congestion can happen within the country are thereby they are each divided further into multiple bidding areas.

While most of the areas in the Nord Pool Spot are rather well integrated and high price differences caused by insufficient transmission capacities are rather the exception than the norm, the situation in the Latvian and Lithuanian power systems has proven to be different. For example, in 2015 the Elspot (day-ahead) prices were the same in Latvia and its Northern neighbor, Estonia, for only 33.95% of the hours, signaling seriously lacking transmission capacity between both countries. Latvia and Lithuania, on the other hand, are sufficiently interconnected – Elspot prices were the same for 99.17% of the hours. [1] In essence, we can conclude that the Latvian/Lithuanian area is somewhat isolated from the rest of the Nord Pool.

Furthermore, the limited access to Scandinavian markets results in the electricity price constantly being higher in Latvia and Lithuania than in the other bidding areas as can be seen in Fig. 1. Another factor causing high prices is the lack of cheap generation sources. Both countries are net importers of electrical energy, especially since the closure of Ignalina nuclear power plant in 2009. Latvia does occasionally have power to export, but only during the spring flood season.

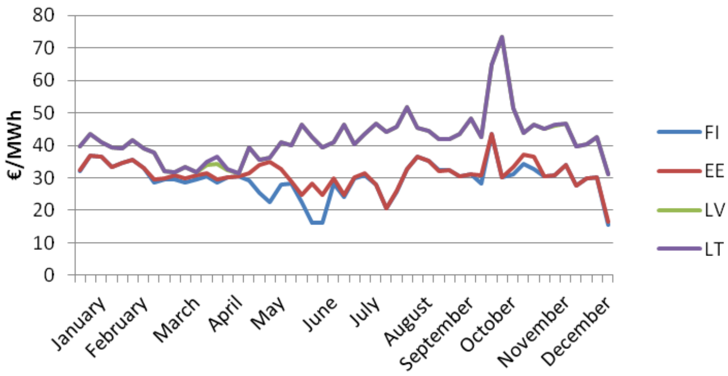


Fig. 1. Weekly average Elspot price in select bidding areas

1.2. Renewable energy integration

The above mentioned reasons illustrate the potential necessity for developing electrical energy storage options in the region. While the limited interconnectivity problem might be at least partially mitigated as further inclusion of the Baltic power systems into the European grid is realized (e.g. two new links were launched at the end of 2015 connecting to Poland and Sweden; synchronization with the grid of Continental Europe is planned at some point in the future as well), these developments are likely to only increase the value of storage options, especially since the European Union is moving towards decarbonising its economy and significantly increasing the share of renewable sources in its energy balance.

This, however, introduces new issues for power system operators and market participants as a significant portion of the renewable energy sources are intermittent in nature, e.g. wind, solar and to some extent also run-of-the-river hydropower. Even though the current penetration of wind and solar energy into the Latvian and Lithuanian region is rather small (1.98% of total electricity production in 2014 in the former and 17.49% in the latter), the trend is for the installed capacity to increase rapidly. For example, within just 10 years the sum rated power of wind turbines in the region grew from nothing to 348 MW [2], [3], though there is still a lot of untapped potential. The European Commission projects in its EU Energy, Transport and GHG Emissions Trends to 2050 even further increases of wind energy penetration in Latvia and Lithuania. For example, they predict the total installed wind turbine capacity in the region to reach 932 MW by 2030. [4]

1.3. Currently available large-scale energy storage options

Pumped storage hydroelectric power (PSHP) plants are the oldest and most widely used electrical energy storage technology. More than 99% of the storage capacity in the world can be attributed to PSHP plants [5]. Their high popularity can be explained by the maturity and relative simplicity of the technology – in accumulation mode water is pumped from the lower to the upper reservoir, whereas in generation mode it is released and discharged through turbines. The most important requirement for pumped storage is the availability of locations where sufficiently high elevation between the upper and lower reservoirs can be achieved. PSHP plants can be built as standalone facilities (pure pumping) or some pumping capacity can be installed in conventional reservoir hydroelectric plants.

Currently the only pure pumping plant in the Nord Pool is located in Lithuania – the Kruonis PSHP. It has four reversible pump/turbine units and their total installed capacity constitutes 900 MW in both, pumping and generation mode. When the upper reservoir has been filled, the Kruonis PSHP can discharge at rated power for about 12 hours.

In Latvia, on the other hand, there is significant conventional reservoir hydroelectric power capacity. The scheme of three hydroelectric power plants (HPP) on the Daugava River (total capacity above 1500 MW) comprises approximately 30 to 50% of the total annual electrical energy production in the country, but the exact amount differs each year depending on its wetness. It should be noted that one of the cascaded plants (Plavinas HPP) is the second largest in the European Union by installed capacity.

While not a storage option in the most traditional sense, reservoir HPPs without pumping capacity can still provide similar services t0 conventional storage plants by increasing or decreasing their production, as when generation is halted, water is accumulated in the reservoirs. Granted, there are several constraints that limit the flexibility of reservoir HPP operation, namely, the risk of overflowing when inflow is large and, conversely, limited production capabilities when inflow is low.

There are no other large or medium scale electrical energy storage facilities in either Latvia or Lithuania. However, there are some notable options of storing energy in different mediums, particularly, underground gas storage (UGS). Currently there is one active UGS site in Latvia – Incukalns UGS which stores natural gas imported from Russia. Thanks to unique geological formations – porous sandstone layers – there exist several other sites in Latvia where underground storage might prove to be technologically feasible. This is potentially interesting not only in terms of natural gas storage, but also in developing power to gas conversion to prevent intermittent renewable generation curtailment or investing in compressed air energy storage (CAES).

1.4. Compressed air energy storage

The operation of a CAES plant has certain similarities to a conventional gas turbine based power plant, the difference being that CAES decouples the compression and expansion cycles of a gas turbine into separate processes that occur at different time [6]. Cheap electricity is used to compress ambient air. It is then cooled via intercoolers and stored in underground caverns. In the generation phase the compressed air is preheated and mixed with natural gas, burned in combustion chamber and expanded through a multistage turbine-generator. This setup allows a CAES plant to generate three times more electricity than a simple cycle natural gas power plant using the same amount of fuel. Currently there are only two large-scale CAES plants in the world – Huntorf, Germany (290 MW) and McIntosh, USA (110 MW). [7]

The necessity to burn fuel in the generation phase is the most obvious deficiency in the conventional CAES technology, as this fuel is most often natural gas. There are, however, plans to solve this issue by introducing advanced adiabatic compressed air energy storage (AA-CAES) which strives to eliminate the need for a combustor. This is achieved by storing the heat from the compression and using it during the expansion process. The main technical challenges in AA-CAES development are designing cost-effective thermal energy storage and high-pressure compressors capable of handling increased compression temperatures. [7] Nevertheless, if the need for fossil fuel combustion is eliminated AA-CAES can be viewed as a near closed loop storage and thus the modeling of its operation becomes similar to other storage technologies, especially, pumped storage.

2. Methodology

2.1. Storage optimization in scientific literature

One of the most important input parameters when estimating the feasibility of a storage plant is its ability to provide positive cash flow when operating in electricity market. In this study we assume that the owners of storage plants strive to increase their profit and thereby try to optimize their operation. There are several approaches in scientific literature to solving the task of storage plant scheduling optimization.

For instance, the authors of [8] deal with the problem of devising optimal bidding strategy for a multi-unit pumped storage plant. They propose a solution employing evolutionary tristate particle swarm optimization. The same authors have also proposed a multi-looping sequential optimization approach using mixed integer programming [9].

The participation of battery energy storage in day-ahead electricity market is studied in [10]. The task is divided in two subtasks where the first finds optimum bidding/offering schedule using stochastic mixed integer linear programming while the second simulates market clearing procedures.

Another model similarly employing stochastic mixed integer linear programming is proposed in [11]. The electricity market price is forecasted using ARMA and ARIMA time series models.

[12] introduces biogas plants as energy storage options that are capable to provide demand-based renewable energy. The authors found that if utilizing a market-based optimization model a biogas power plant is capable of achieving more profit when operating on direct marketing (optimization based on price signals) as opposed to relaying on feed-in tariffs (optimization to maintain high efficiency).

2.2. Mathematical model

Generally, the optimization task of a closed loop price-taker electrical energy storage plant operating on price arbitrage can be described as a profit maximization task by objective function (1) and constraints (3-5).

$$PF = \sum_{m=1}^{M} \sum_{t=1}^{T} P_t \cdot c_{m,t} \rightarrow \max, \tag{1}$$

for

$$\begin{cases} P_t = -f(\Delta L_t) / \eta_{\mathrm{acc}}, & if \quad \Delta L_t > 0 \\ P_t = -f(\Delta L_t) \cdot \eta_{\mathrm{gen}}, & if \quad \Delta L_t \le 0 \end{cases}, \tag{2}$$

where

PF - profit (in a simplified case - difference between revenue from sold and expenditure from purchased electricity);

P_t – electrical energy to be sold (purchased if the variable is negative) at hour t;

$c_{m,t}$ – electrical energy market price at hour t and prediction m;

η_{acc} – charging efficiency;

η_{gen} – discharging efficiency;

ΔL_t – change in the amount of stored energy during hour t;

$f(\Delta L_t)$ – a function characterizing the relationship between produced or consumed power versus changes in the storage medium (e.g. water level for PSHP);

M – number of realizations;

T – length of the optimization horizon in hours;

subject to

$$\sum_{t=1}^{T} \Delta L_t = L_T - L_0, \tag{3}$$

$$-\sum_{t=1}^{S} \Delta L_t \le L_0 - \underline{L}, \tag{4}$$

$$\sum_{t=1}^{S} \Delta L_t \le \overline{L} - L_0, \tag{5}$$

where

L_0 – initial storage level (e.g. upper reservoir water level for pumped storage);

L_T – storage level at the end of the optimization horizon;

$\underline{L}$, $\overline{L}$ – lower and upper bounds on storage level, respectively;

$S \in T$ – variable to enforce storage capacity bounds.

The constraint defined in (3) ensures that the model reaches certain previously set level of its storage medium at the end of the optimization horizon. Constraints (4) and (5) ensure that at no point in the horizon the bounds on the storage level are violated.

The model is realized in MatLab scripting environment and the optimization problem is solved using Global Optimization Toolbox, particularly, pattern search algorithm. [13]

3. Results and Discussion

3.1. Case study: pumped hydro scheduling

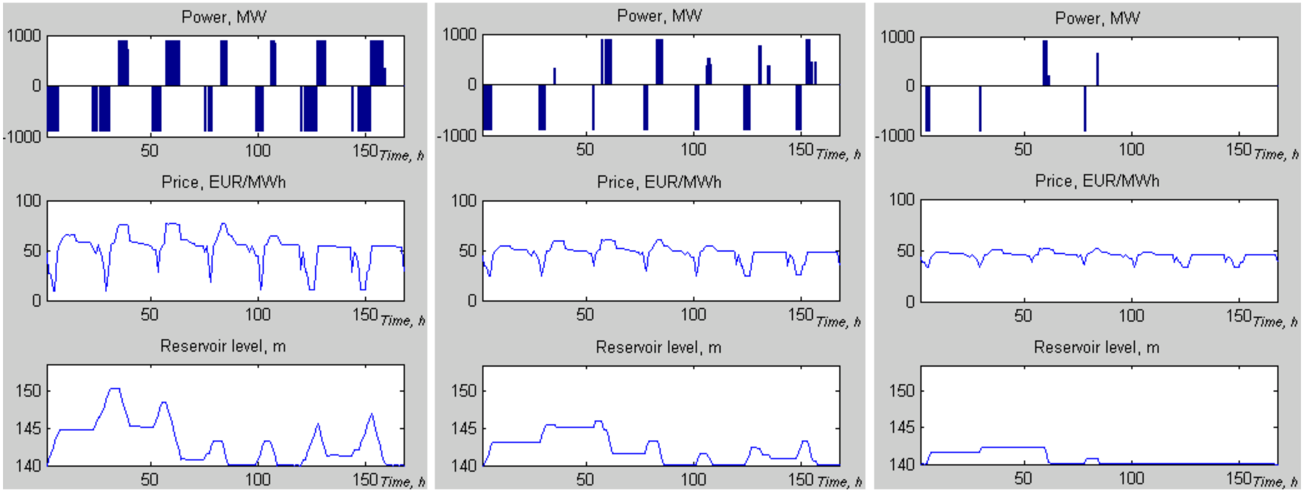
The model described in the previous section is applied to Kruonis PSHP in Lithuania (Table 1). Several assumptions have been made: the storage plant aims to operate on price arbitrage, price is exogenous and the duration of charging/discharging cycles is only constrained by upper reservoir capacity. Operating costs are assumed to be 1 €/MWh.

Table 1. Technical parameters of Kruonis PSHP

	Pumps	**Turbines**
Capacity	900 MW	900 MW
Efficiency	0.8	0.9
Discharge (one unit)	226 m^3/s	189 m^3/s
Life storage	41 million m^3	
Maximum water level	153.5 m	
Minimum water level	140 m	

The price profile for one week (Nord Pool Spot statistics in the Latvian/Lithuanian price areas from August 10 to 16, 2015) is used to carry out the optimization of Kruonis PSHP scheduling. During this week the ratio between minimum and maximum price was 0.117. It proved to be sufficient for feasible operation resulting in 696 119 € profit (Fig. 2).

In order to assess the effect price spread can have on PSHP scheduling we repeated the optimization procedure using price curves that have been smoothened to achieve 0.4 and 0.65 ratio between minimum and maximum prices. Decreasing the price spread significantly reduced the number of hours of PSHP operation. For instance, in the last case the plant would only work for 7 hours in the 168 hour period.



Min. price	**Max. price**	**Price ratio**
9.06 €/MWh	77.14 €/MWh	**0.117**
Consumption	**Production**	
34.2 GWh	25.3 GWh	
Expenditure	**Revenue**	**Profit**
988 281 €	1 684 400 €	**696 119 €**

Min. price	**Max. price**	**Price ratio**
24.39 €/MWh	60.96 €/MWh	**0.4**
Consumption	**Production**	
16.2 GWh	11.69 GWh	
Expenditure	**Revenue**	**Profit**
461 710 €	654 900 €	**193 190 €**

Min. price	**Max. price**	**Price ratio**
33.43 €/MWh	51.41 €/MWh	**0.65**
Consumption	**Production**	
3.6 GWh	2.66 GWh	
Expenditure	**Revenue**	**Profit**
122 620 €	136 610 €	**13 990 €**

Fig. 2. Optimized Kruonis PSHP operation considering different price scenarios

The results obtained performing Kruonis PSHP scheduling optimization show that price profiles in the Latvian and Lithuanian price areas in the Nord Pool Spot can have sufficient spread to motivate active storage plant operation. The model developed during this study should be expanded to include additional value streams a storage plant can access, for instance, providing reserves and various grid services.

3.2. Case study: compressed air storage sizing

As described in section 1.3 there are geographical sites in Latvia where compressed air storage might be technologically feasible. In order to estimate the potential economic performance of an AA-CAES plant we apply the same model, but vary input parameters like efficiency and storage capacity. We assume nominal power of 200 MW. The results are summarized in Table 2.

Table 2. Profit obtained by a generic AA-CAES plant in a 168 hour time span

		Discharge duration		
		4 h	8 h	12 h
Full cycle efficiency	0.65	106 550 €	111 790 €	111 790 €
	0.70	123 080 €	134 170 €	134 730 €
	0.75	141 270 €	157 090 €	159 870 €

If the efficiency is lower (0.65), increasing the storage capacity has little effect on the schedule and by extension – on the profit. Doubling the storage capacity from 4 to 8 hours only increased profit by 4.918%. Further increases in the storage size had no impact as already in the 8 hour discharge duration scenario the storage site did not reach full capacity within the week.

In case the full cycle efficiency is higher the benefit from increasing storage size also becomes more evident. If we increase the capacity from 4 to 8 hours then profit increases by 9.010% for a 0.70 round trip plant and by 11.198% for a 0.75 efficiency plant. Again, however, further increases had little effect, i.e. 0.417% and 1.770%.

4. Conclusion

While electrical energy storage options already established in the Latvian and Lithuanian region, particularly, Kruonis PSHP, can effectively exploit the price spread currently observable in the corresponding Nord Pool Spot price area, the construction of new large-scale projects is hindered by high capital costs, specific location requirements and currently fairly low share of intermittent renewable generation sources. The deployment of wind generation, however, is projected to increase steadily, amplifying volatility in the electricity markets. This factor in combination with better access to Nordic power systems signifies renewed interest in the development of electrical energy storage in the region.

Advanced adiabatic compressed air energy storage is particularly interesting in the Latvian case, as among all the unconventional storage technologies AA-CAES has the best efficiency and its technological and economic parameters are similar to PSHP plants. The presence of several locations in Latvia suited for underground gas storage opens the possibility of utilizing these sites for CAES, but further research in this direction is necessary to quantify the storage potential this technology might bring to the Latvian and Lithuanian power systems.

Acknowledgment

The work presented in this paper has been co-financed by the National Research Program LATENERGI (2014-2017).

The development of this paper has been co-financed by the project nr.256/2012 'Power System Risks Management'.

References

[1] "Day-ahead Price Statistics." [Online]. Available: http://nordpoolspot.com.

[2] "Energy Statistics in Latvia." [Online]. Available: http://csb.gov.lv.

[3] "Energy Statistics in Lithuania." [Online]. Available: http://stat.gov.lt.

[4] A. De Vita, N. Tasios, D. Papadopolous, P. Siskos, E. Apostolaki, M. Zampara, L. Paroussos, K. Fragiadakis, N. Kouvaritakis, and P. Capros, *EU Energy, Transport and GHG Emissions Trends to 2050 - Reference Scenario 2013*. 2014.

[5] V. W. Loose, "Quantifying the Value of Hydropower in the Electric Grid: Role of Hydropower in Existing Markets," no. January, 2011.

[6] X. Luo, J. Wang, M. Dooner, J. Clarke, and C. Krupke, "Overview of Current Development in Compressed Air Energy Storage Technology," *Energy Procedia*, vol. 62, pp. 603–611, 2014.

[7] H. Ibrahim, K. Belmokhtar, and M. Ghandour, "Investigation of Usage of Compressed Air Energy Storage for Power Generation System Improving - Application in a Microgrid Integrating Wind Energy," *Energy Procedia*, vol. 73, pp. 305–316, Jun. 2015.

[8] P. Kanakasabapathy and K. Shanti Swarup, "Optimal bidding strategy for multi-unit pumped storage plant in pool-based electricity market using evolutionary tristate PSO," in *2008 IEEE International Conference on Sustainable Energy Technologies*, 2008, no. December, pp. 95–100.

[9] P. Kanakasabapathy and K. Shanti Swarup, "Pumped storage bidding and its impacts in combined pool-bilateral market," in *2009 International Conference on Power Systems*, 2009, pp. 1–6.

[10] H. Pandzic and I. Kuzle, "Energy storage operation in the day-ahead electricity market," in *2015 12th International Conference on the European Energy Market (EEM)*, 2015, no. 13, pp. 1–6.

[11] A. A. Sanchez de la Nieta, T. A. M. Tavares, R. F. M. Martins, J. C. O. Matias, J. P. S. Catalao, and J. Contreras, "Optimal generic energy storage system offering in day-ahead electricity markets," in *2015 IEEE Eindhoven PowerTech*, 2015, pp. 1–6.

[12] D. Gohsen and H.-J. Allelein, "Development of a Market-based Optimisation Model for a Demand-based and Storable Electricity Production from Biogas," *Energy Procedia*, vol. 73, pp. 79–86, Jun. 2015.

[13] "Global Optimization Toolbox." [Online]. Available: http://mathworks.com.