Analysis of integration of accumulation systems in Smart Grid

Maksym Oliinyk[1], *Daniel Pál* [2]

[1] *Department of Electric Power Engineering; Faculty of Electrical Engineering and Informatics*
Technical University of Košice
Košice, Slovak Republic

[2] *Department of Electric Power Engineering; Faculty of Electrical Engineering and Informatics*
Technical University of Košice
Košice, Slovak Republic

Maksym.oliinyk@tuke.sk, daniel.pal@tuke.sk

Abstract: *This article focuses on modern energy storage systems. The importance of the further development of modern energy storage systems and above all large quantities of electricity is associated with the widespread introduction of renewable energy sources (RES) in the world in recent decades and exist serious problems in Western countries with providing high-quality continuous and break-even generation of electricity from them. The analysis of the benefits of introducing energy storage systems in a small electrical network. In addition, an analysis is conducted of the possibility of the so-called temporary arbitration of electricity prices, and assess such a possibility by various investment valuation methods of the project.*

Keywords

Smart Grid, Electricity storage systems, renewable energy sources, investment appraisal of projects.

1. Introduction

The main goal of “Smart Grid” technologies (Smart Grid) create the production, transmission of energy safer and more energy efficient. Smart grids combine modern energy capabilities with innovations in digital technology to manage all energy. Thanks to accurate calculations, losses in the electric grid are reduced and uninterrupted supply is ensured. A distinctive feature of the “Smart Grid” is self-diagnosis and self-healing, thanks to which the system can identify emergency sections of the network and automatically rebuild. One of the important elements of smart grids is electricity storage systems. Electricity storage systems (ESS) are developing a class of high-tech devices that open new opportunities for developing the electric power industry. They are sufficient technologies that create all the conditions for smart energy management [1].

Leading countries are pursuing existing results in introducing new technologies. In the USA (California), it is planned to introduce 1325 MW of storage capacity by 2020. In 2016, National Grid (United Kingdom) purchased a 201 MW power supply system. Regarding the accumulated energy in China, up to 2021, it is planned to introduce 46 GW of ESS. In the United States and China, large-scale production of storage devices is being developed, focused on the saturation of the domestic market, and one massive export deliveries. Navigant Research, the global market for energy storage systems, will reach $80 billion by 2025. In the last 10 years, the volume of the global market of ESS has grown almost three times [2].

2. The use of power storage systems and their types

Such a diverse set of functions and applications of ESS is determined by wide possibilities in the accumulation and subsequent issuance of electricity from milliseconds to hours and days; wide range of power, energy intensity and its ratio; high permissible charge and discharge currents; almost instantaneous switching between different modes of operation; high energy efficiency. These qualities open technological possibilities to implement new power system architectures [3]:

1. Power system with many opportunities for managing schedules of electricity generation through install high-capacity electricity storage systems at network nodes. In such an energy system, ESS play the role of systemic regulating power, which makes it possible to optimally use the generating capacity [4].

2. Internet energy (IoEN), in which active consumers, including those owning ESS and own generation and

having the ability to both, manage consumption and provide the accumulated electricity and power of their ESS, realize free energy exchange and other energy transactions and services on decentralized markets. The following features are characteristic of Internet energy [4]:

1) Active consumers are needed flexibly controlled consumption, having a significant share in the energy balance.

2) Flexible load management of generating and network capacities; the possibility of local quality control of electricity on the side of consumers and groups of consumers;

3) Self-balancing of power in small power systems, including the generation and load operation in non-synchronous mode. Here, all generators and consumers are connected to each other through an energy hub - a device controlling and regulating the primary power balance

4) Efficient integration of generation based on renewable energy, increasing the efficiency and share of renewable energy in the energy balance of the power system;

The using of power storage systems connected to grids and participation in energy markets face current uncertainties in the regulatory framework. In particular, there is no concept of a "system of accumulation of electric power", which regulate relations between subjects in the electric power industry; there is no consideration of the features of technological connection of ESS to networks, the order of their participation in the electricity, capacity and related markets. There is an uncertainty in explain expenses for the purchase of electricity and revenues from the sale of stored electricity if the Grid Company, and approximately aggregation of the systems and take part in their units in the electricity and capacity markets, own the ESS. This limits and slows developing the industry [5].

3. Methods for evaluating investment projects

Evaluation of the effectiveness of investments is given in the form of a conclusion based on the analysis of performance indicators. There are several methods for assessing the attractiveness of investment projects, and therefore several key indicators, which are a certain set of indicators. Each method is based on the same principle - because of the project implementation, the company must make a profit, while various indicators provide an opportunity to characterize the investment project from all sides and meet the interests of various groups of people involved in the investment. Two groups of assessment methods are usually used, with the help of which the indicators listed are determined [6].

3.1 Static methods of evaluation.

They are based on the “Typical Method for Determining the Economic Efficiency of Capital Investments”. It has not lost its relevance today, since the methods are simple in execution and at the same time provide an opportunity to get a clear picture of the effectiveness of the investment, especially in the first stage of the evaluation work [7].

1. A payback period of investment (Payback period, PP).
2. The coefficient of investment efficiency (Account rate of return, ARR).

Static methods of investment evaluation do not go without flaws. The main one is that they do not take into account the time factor, and incomparable values are taken for calculations - the amount of investment in the current value and the profit value.

3.2 Dynamic methods

This group of methods is characterized by complexity and the need to take into account many aspects. They are used to test investment projects of great duration, requiring additional investments in the course of their implementation. When using dynamic methods, an important component is a search for discount rates, which allow you to bring income and expenses to values close to real [7].

3.2.1 Net present value (Net present value, NPV).

A positive NPV is a criterion for accepting an investment project. If it is necessary to make a choice from several projects, preference is given to a project with a larger NPV value.

3.2.2 Profitability index (PI).

Under this indicator, is seen the ratio of the current value of the cash inflow to the net present value of the cash outflow, taking into account the initial investment. If, when calculating, the value of PI is greater than one, then the project should be accepted; if less, it is rejected.

3.2.3 The internal rate of return (IRR)

The internal rate of return (IRR), or internal investment rate of return, is the value of the discount rate at which the project's NPV is zero. For example, if a project is financed by a loan from a commercial bank, then IRR shows the upper limit of the level of bank interest rates.

3.2.4 Discount rate

When choosing a discount rate, you need to take into account inflation, the cost of all sources of funds for investment and indicators of risk. The method for calculating risk premiums for various classes of investment/investment projects was presented to scientists J. Honko. These risk premiums are presented in an aggregated form, and the investor needs to choose the purpose of the investment and, the risk change [8].

Forced investment	-
Maintaining a market position	1%
Upgrade of the company's fixed assets	7%
cost savings	10%
Development of new projects	15%
Innovative projects	20%

Tab. 1. Discount rate options [8]

4. Creating a calculation model

To analyze the effect of accumulation systems, a village electric grid model was created. This model includes the elements shown in Table 1. The load is expressed in the annual load schedule Fig 1.

Elements in the model	Number of elements	Installed power, kW
Line	91	-
Loads	58	-
battery	4	48
Photovoltaic	58	191,4
Transformer	2	-

Tab. 2. Elements of the model

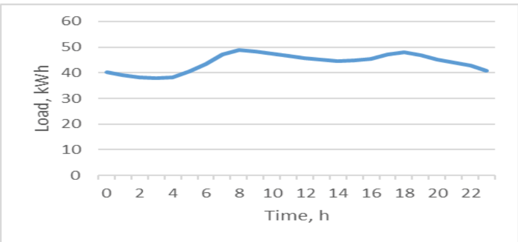

Fig. 1. Annual load schedule

To analyze the investment valuation, prices were taken from one of the leading electricity exchanges in Europe, Nord Pool [9].

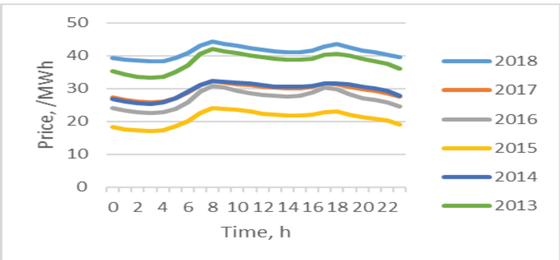

Fig. 2. The annual schedule of electricity prices for the period 2013-2018

5. Analysis of implementing of power storage systems

Because of state support, and a reduction in the cost of solar panels, many experts predict a broader implementation among home consumers. As part of these forecasts, a simple analysis of the power losses in the electrical network of the model under study was carried out. Because of the analysis, dependences of the increase in active and reactive power losses because of the increase in installed power were obtained [10].

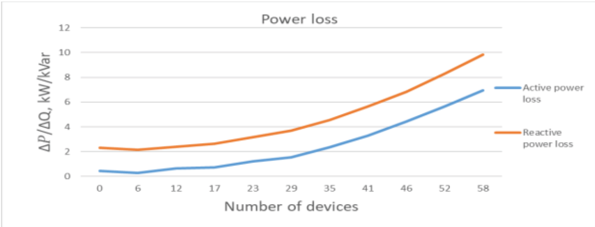

Fig. 3. Power loss versus the number of Photovoltaic

As we see from graph 1, with an increase in the number of solar panels, power losses increase because of the change in the power flow direction. One solution to this problem for power companies is to place energy storage systems. Within this model, the energy storage systems of 48 kW were installed [11].

Mode of Grid	ΔP, kW	ΔQ, kVar
Without elements of a Smart Grid	0,45	2,33
Photovoltaic	6,94	9,85
Battery charging mode	2,61	4,43
Battery recharging mode	0,39	2,18
battery charging mode with Photovoltaic	4,7	7,38

Tab. 3. Power loss in different modes

As we see from Table 2, as a result installing the batteries, it was possible to reduce the power loss during operation of the solar panels by 32.28%, and during the discharge of the battery. However, power losses also increased in a time when the batteries are being charged. The next step in analyzing the benefits of installing energy storage systems is to equalize the daily load curve. For analysis, the day was taken in January and the day in July. Load graphs are presented below in Figure 1 and 2.

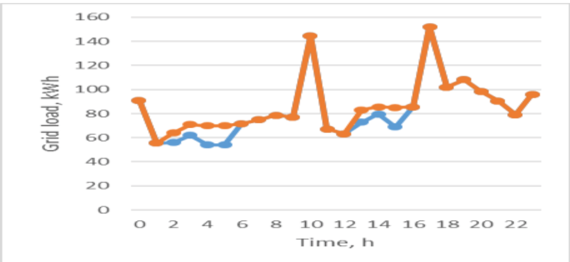

Fig. 4. Daily load chart (January) without using the energy storage system and using the system

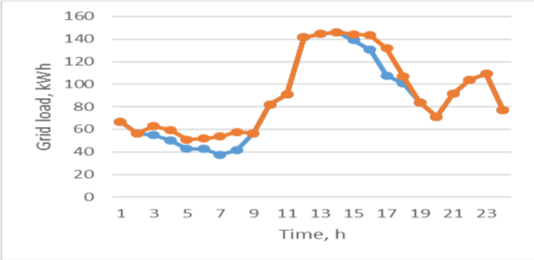

Fig. 5. Daily load chart (July) without using the energy storage system and using the system

As you can see in the picture, the batteries are charged during periods when the load on the network decreases. Thus, the schedule becomes evener. Also not shown on the graph, but at peak times the battery will operate in a discharge mode, which will reduce power loss at the busiest moment, and also reduce the cost of electrical stations. The result may vary depending on the specific day [12].

After Installing the accumulation systems, the power company or consumers will have the opportunity to use price arbitrage. Arbitrage (from Fr. Arbitrage is a fair decision) in the economy - several related transactions aimed at extracting profit from the difference in prices for the same or related assets at the same time in different markets (spatial arbitrage) or on the same volume the same market at different points in time (temporary arbitration, ordinary exchange speculation) [13].

When analyzing prices, it was found that most often the lowest price for electricity is at night and in the afternoon. It is also necessary to take into account that when installing a large number of solar panels, there may be situations when the price of electricity will be much lower than the average price calculated per year. Below are graphs that show the profit from this arbitration analyzed for 5 years. The battery was charged from 2 to 4 and 13-15 and discharged from 8 to 10 and 16 to 18 hours. It is important to note that there may be days when this method will not work. However, on average, over a long period, arbitration remains profitable [14]. The cost of the accumulation system is 10,000 €.

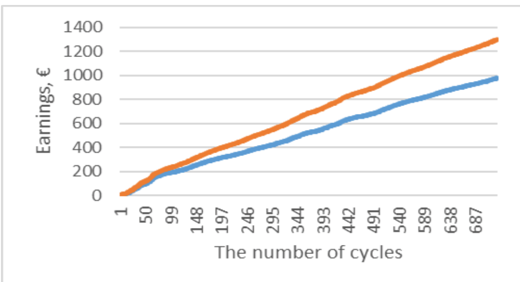

Fig. 6. Profit from the temporary arbitration of electricity prices.

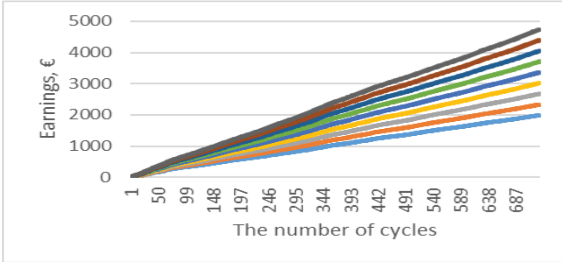

Fig. 7. Profit from the temporary arbitration of electricity prices. Different curves show different possible price reductions because of the development of renewable energy sources.

The graph shows the cases when the price of electricity was about 0 because of the strong production of energy from renewable sources of energy. It can be assumed that these cases will occur more often because of increased efficiency and the number of power plants using renewable energy sources [15].

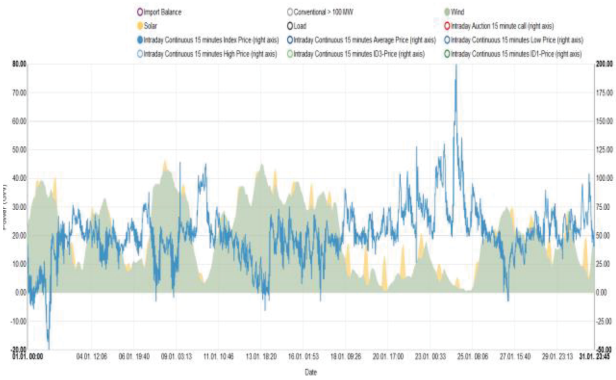

Fig. 8. Price changes in Germany because of high generation in renewable energy sources

It is also worth noting that if a price drops because of strong production on renewable energy sources, the profit from arbitration may increase by a factor of 2-3.

Price changes for photovoltaic		NPV, €	PI	ARR	IRR
1	Normal mode	-8224,8	0,10	0,26	-19%
1	Normal mode+ the power loss	-8224,3	0,10	0,26	-19%
0	Normal mode+PV	-3804,6	0,35	0,88	-2%
	NM+PV+PL	-3804,1	0,35	0,88	-2%
0,2	Normal mode+PV	-4200,6	0,33	0,83	-3%
	NM+PV+PL	-4200	0,33	0,83	-3%
0,4	Normal mode+PV	-4596,5	0,31	0,78	-4%
	NM+PV+PL	-4596	0,31	0,78	-4%
0,6	Normal mode+PV	-4992,4	0,29	0,73	-5%
	NM+PV+PL	-4991,9	0,29	0,73	-5%
0,8	Normal mode+PV	-5388,4	0,27	0,68	-6%
	NM+PV+PL	-5387,9	0,27	0,68	-6%

Tab. 4. The results of the investment assessment methods of the project

It is possible to assess the feasibility of using temporary arbitration of energy storage systems; for this, 4 methods for assessing the investment-attractiveness of the project were chosen. Almost all methods have shown that this investment project is not profitable. Most came in terms of profitability in the situation if in the daily cycle of charging renewable energy sources will produce a large amount of energy, which in theory could reduce the price of electricity to 0€ [16].

6. Conclusion

Now, the widespread use of high-capacity energy storage systems has no economic justification. The following factors prevent widespread use:

1) High cost
2) Inconsistent production of electricity from renewable energy sources
3) The low number of charge/discharge cycles

However, accumulation systems improve network operation parameters, improve power quality, and make the network more flexible to manage. Therefore, perhaps installing accumulation systems makes sense from a technical point of view.

Acknowledgements

This work was supported by the Scientific Grant Agency of the Ministry of Education of Slovak Republic and the Slovak Academy of Sciences by the projects VEGA No. 1/0372/18.

References

[1] M. SHAMSHIRI, C. K. GAN, A C. W. TAN, "A review of recent development in smart grid and micro-grid laboratories", v 2012 *IEEE International Power Engineering and Optimization Conference Melaka*, Malaysia, 2012, s. 367–372.

[2] U. Udalcova and D. Kholkina. EXPERT AND ANALYTICAL REPORT "THE MARKET OF ELECTRICITY ACCUMULATION SYSTEMS IN RUSSIA: DEVELOPMENT POTENTIAL" [Online]. Available: http://www.rusnano.com/upload/images/sitefiles/files/Condenses_system_markets_in_Russia.pdf

[3] NAISH C, MCCUBBIN I, EDBERG O, HARFOOT M. Outlook of Energy Storage Technologies. Brussels: European Parliament, Policy Department, *Economic and Scientific Policy*; 2008.

[4] SAMI BS. An Intelligent Power Management Investigation for Stand-Alone Hybrid System Using Short-Time Energy Storage. *International Journal of Power Electronics and Drive Systems.* 2017 ;8(1):pp. 367.

[5] CHEN H, CONG TN, YANG W, TAN C, LI Y, DING Y. Progress in electrical energy storage system: A critical review. *Progress in Natural Science. 2009*; 19(3): pp. 291-312.

[6] LILJEBLOM E. VAIHEKOSKI M., "Investment Evaluation Methods and Required Rate of Return in Finnish Publicly Listed Companies," p. 16.

[7] HÄRUS, N. C. "Analyzing energy efficiency investments in the process industry - Case Sachtleben Pigments Oy," p. 120.

[8] HONKO, J. & VIRTANEN, K., 1975, The investment process in Finnish industrial enterprises. A study of capital investment planning and control process in the fifth largest Finnish industrial enterprises. Helsinki School of Economics, Series A-16.

[9] Market data "See what Nord Pool can offer you." [Online]. Available: http://www.nordpoolspot.com/.

[10] AL-SALAYMEH A, AL-HAMAMRE Z, SHARAF F, ABDELKADER MR. Technical and economic assessment of the utilization of photovoltaic systems in residential buildings: The case of Jordan. *Energy conversion and management. 2010*; 51(8): pp. 1719-26.

[11] VARKANI AK, DARAEEPOUR A, MONSEF H. A new self-scheduling strategy for integrated operation of wind and pumped-storage power plants in power markets. *Appl Energ* 2011;88:5002-12.

[12] CONNOLLY D, LUND H, FINN P, MATHIESEN BV, LEAHY M. Practical operation strategies for pumped hydroelectric energy storage (PHES) utilizing electricity price arbitrage. *Energ Policy 2011*;39:4189-96.

[13] IBRAHIM H, BEGUENANE R, MERABET A. Technical and financial benefits of electrical energy storage. *IEEE Electrical Power and Energy Conference (EPEC)*, 2012; pp. 86-91

[14] HELLSTRÖM J, LUNDGREN J, YU H. Why do electricity prices jump? Empirical evidence from the Nordic electricity market. Energy Econ 2012;34:1774-81.

[15] Market data, Fraunhofer Institute for Solar Energy Systems ISE [Online]. Available: https://www.energy-charts.de/price.htm

[16] WALAWALKAR R, APT J, MANCINI R. Economics of electric energy storage for energy arbitrage and regulation in New York. *Energ Policy 2007*;35:2558-68.

About Authors

Maksym Oliinyk was born in 1994. In 2018 graduated (MSc) at the Department of Electrical Power Engineering on the Faculty of Electrical Engineering and Informatics at Technical University in Košice. He received a master degree in electric power engineering on subject Smart Grid. At present is a Ph.D. student in the Department of Electrical Power Engineering on the Faculty of Electrical Engineering and Informatics at Technical University in Košice. His scientific research is mainly focused on design and researching SMART GRIDS.

Daniel Pál was born in 1994. In 2018 graduated (MSc) at the Department of Electrical Power Engineering on the Faculty of Electrical Engineering and Informatics at Technical University in Košice. He received a master degree in electric power engineering on subject design for the reconstruction of school spaces lighting. At present is a Ph.D. student in the Department of Electrical Power Engineering on the Faculty of Electrical Engineering and Informatics at Technical University in Košice. His scientific research is mainly focused on research of renewable resources of energy and for the reduction of the power losses in SMART GRIDS.