Usage of electric energy storages to increase controllability and reliability of the Belarusian energy system

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Abstract. The paper provides an efficiency assessment of lithium-ion energy storage unit installation, including flattening the consumers daily load curve, reducing electricity losses and regulating voltage at the ESS installation point.

Introduction

The basic Energy System construction paradigm is a simultaneous and synchronous electricity production and consumption. Thus allowing to maintain one of the most important operating parameters – the frequency of the alternating current.

A daily load curve of both the entire Belarusian Energy System and its individual energy centers is characterized by a significant unevenness between the distinguished daytime peaks and the nighttime power dips. The unevenness coefficient of the daily load curve is 0.65-0.7.

When the second power unit of the Belarusian NPP is put into commercial operation in 2023, the capacity of the two units operating based on the daily load curves of the Belarusian Energy System will be about 40% of the maximum load of the Energy System. To comply with the self-balance operation condition, it is necessary to reduce the number of the powerful cycling power units of the condensing power plants (CPP) in hot reserve.

ESS connection to the electric energy system will make it possible to separate in time the processes of electricity generation and consumption (considering high efficiency of the ESS), which will lead to the load curve flattening of an individual power unit and the Energy System as a whole. This problem being solved, the ESS can become one of the key elements of the Smart electric power industry.

Potential areas of the ESS implementation in the Energy System also include: voltage and frequency regulation, hot reserve of the Energy System, emergency power supply to prevent system failures (when sectioning off the Energy System) and to recover the system after an accident, the electricity consumer emergency power supply. A special value of the ESS is its ability to simultaneously perform the above mentioned functions [1].

It should be noted that the renewable energy sources (RES) in the Republic of Belarus are not significantly distributed (the share of the power plants with RES in the installed capacity of the Belarusian Energy System is about 3%). However, the ESS usage is a key solution for the effective integration of a renewable energy source into the Energy System.

1 Analysis of ESS usage experience in the world

In the world, the Energy storage systems have been used for quite a long time. For example, galvanic cells were invented in the 1800s, and the first pumped storage projects were introduced in the early 1900s.

A relevant objective of using ESS in the Belarusian Energy System, minding a significant installed capacity of the Belarusian NPP, is to flatten the uneven daily load curves. ESS can be used to supply consumers with electricity during those periods of the day when the energy consumption exceeds its production at an economically efficient generating equipment (NPPs, large power units of TPPs), and for the accumulation of electricity during the periods when its production at those sources exceeds the consumption (resulting in the need to stop the operation of the generating equipment). Moreover, ESSs reduce the necessity to increase or decrease the load of the generating equipment in case of an emergency in the Energy System.

ESS energy intensity, their maximum output power during the discharge period, the duration of the discharge, and the efficiency of the storage unit shall be considered to determine the ESS efficiency.

The well-known energy storage technologies can be divided according to the type of stored energy into:

- mechanical (pumped storages, flywheels),
- electrochemical (accumulator batteries, flow batteries),
- chemical (fuel cells),

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- electrical (capacitors, supercapacitors, superconducting magnetic accumulators),
- thermal (use of molten salts and hot water).

Depending on the technology, the duration of the energy storage can vary from less than 10 hours (e.g. some of the batteries) till the seasonal storage (weeks, months and years) (e.g. pumped storage systems).

Fig. 1 schematically presents the information about the power level and the ESS discharge time (duration) of various technologies [2].

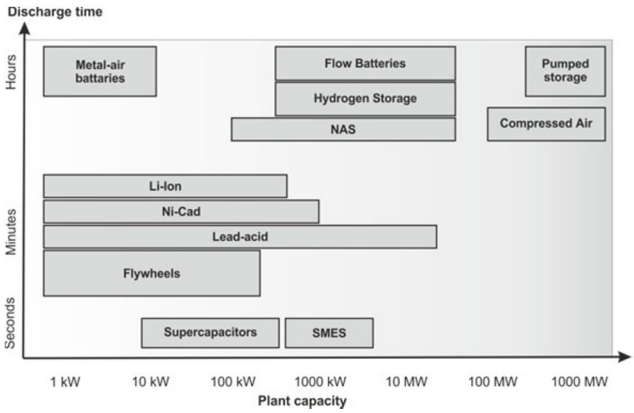

Fig. 1. Power levels and time (duration) of discharge of the various ESSs

The key technical characteristics of the main energy storage technologies are given in [2].

2 ESS technologies possible to use in the Belarusian Energy System

At present, the ESS technology level and the industrial designs maturity in the CIS countries enable us to draw the conclusions on the applicability of only several of the ESS described above in the Belarusian Energy System.

As it was mentioned above, the commissioning of the Belarusian NPP has prioritized the issue of covering the peak load and the dip in the daily load curve of the Belarusian Energy System, since NPP units usually operate in the base-load operation condition. A traditional means to solve this problem is to construct a **pumped-storage station (PSS)** together with a nuclear power plant. The pumped-storage station is both a highly controllable source of peak power and a regulating consumer. It is effectively used:

- to cover the peak part of the graph;
- for multiple short-term system load pick-ups;
- to optimally increase the night load of the TPP in terms of technical reliability;
- as a frequency maintaining quick-operating reserve and a short-term emergency reserve;
- as a network reactive power balance regulator.

In Belarus, due to the terrain peculiarities and the necessity to flood large land areas, the unit capacity of a pumped-storage station is limited to 400-570 MW. Therefore, to provide a reliable power backup of two power units of the Belarusian NPP, each having capacity of 1200 MW, the construction of several such stations is required. In addition, this infrastructure solution requires significant capital investments and a long implementation time, which is economically inadvisable at present.

At the same time, the world experience of using ESS in the energy sector demonstrates a significant interest in the use of **lithium-ion accumulator batteries (AB)**, since they have better characteristics compared to other AB technologies. The number of lithium-ion batteries used in power generation and in other spheres grows due to their long service period, high cell voltage, good low temperature performance, sufficient charge retention, and required depth of charge.

The project "Usage concepts of the energy storage systems based on lithium-ion batteries in the Belarusian Energy System", which provides for the integrated implementation and the use of ESS at the generating facilities of the State Production Association "Belenergo", in the electrical networks, and at the electric power facilities of the industrial enterprises, and at transport, was developed in 2022.

According to this document, technically available potential of the ESS installation in industrial consumers distribution electrical networks in the Belarusian Energy System ranges approximately 500 MWh and 100 MW.

3 Usage of ESS in the distribution networks up to 110 kV of the Belarusian Energy System

In 2022, RUE Belenergosetprojekt carried out an R&D work to assess feasibility and justify technical effectiveness of installing lithium-ion energy storage systems in order to flatten the daily load curve, reduce electricity losses and regulate voltage at the ESS installation point.

A number of substations, at which the transformers load was about 50% during the standard operation, were selected as "typical" 110/10 kV substations (SS). It should be stated that in the Belarusian Energy System the percentage of the substations with such a significant transformers load is less than 5%. They are basically located either in the capital city, or in the large regional cities, and in the large industrial centers of the Republic of Belarus. However, in accordance with the policy to increase electricity consumption for heating and hot water supply pursued in the Republic of Belarus, the contracted capacity increase of both domestic and industrial consumers is expected in the coming years. This will entail the need to solve the problem indicated below.

With the increase of the electrical load at those substations the efficiency of ESS was tested in two alternative options:

- the reconstruction with an increase in transformer capacity;
- the installation of ESS for flattening the daily load peaks and keeping the existing transformers in operation avoiding their overloading.

The initial data were:

- the reported measured values of the Electricity Commercial Metering Automated System (half-hour load measuring) on the transformers windings of the substation during four typical days (winter/summer, working day/day off);
- the electric load in accordance with the active technical specifications issued for the power supply of the consumers by a given substation;
- the schematic diagrams of the substation and of the supplying network.

Substation Korzyuki of RUE Minskenergo was chosen as a "typical" 110/10 kV substation with a dominating residential type of the load.

A theoretical substation was modeled as a "typical" one with a dominating industrial type of the load.

Two 110/10 kV transformers with the capacity of 16 MVA each are installed at the 110 kV Korzyuki substation. Fig. 2 displays a simulated daily load curve of a winter weekday of this substation, considering the load increase, which allows for the use of ESS, provided having the equal discharge/charge areas of the battery. The permissible maximum load is 28% higher than the power limit of the substation, in this case, the required operating capacity of the battery should be about 38.0 thousand kWh, and the rated power should be 6.5 MW.

The horizontal line on the graph shows the overload power limit of the substation (40% –1232 A), considering the withdrawal of one of the transformers in the case of the maintenance or the emergency shutdown.

Comparative cost calculation for 110/10 kV Korzyuki substation modernization options (transformer replacement or ESS installation) shows that the capital investment in 10 kV ESS installation 12 times exceeds the cost of the transformer replacement.

110/10 kV substations with dominating industrial type of the load and a continuous operation of the enterprise (oil refining, metallurgy, heavy engineering, etc.) were not considered in this work, since they have a daily load curve without distinguished peaks and dips in electricity consumption, during which the accumulator could be charged/discharged. The installation of ESS at such substations in order to reduce the peak load is inadvisable. This does not exclude the installation of ESS for the reasons of ensuring the reliability of power supply for the most critical units of the production process of this type of an enterprise.

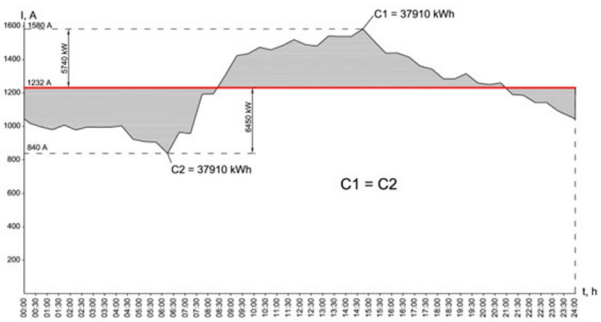

Fig. 2. Daily load curve (load current, A) of the 110/10 kV Korzyuki substation on a winter weekday, considering the equality of the discharge/charge areas of the ESS.

A 110/10 kV substation of the wood-processing industry with two transformers of 16 MVA capacity each was considered as a substation with a dominating industrial type of the load. Fig. 3 shows a load curve for such a substation, having equal battery discharge/charge areas, which allows for the usage of ESS.

The permissible maximum load exceeds the power limit of the substation by 62%, the required operating capacity of the battery is about 79.0 thousand kWh at a rated power of 11.5 MW.

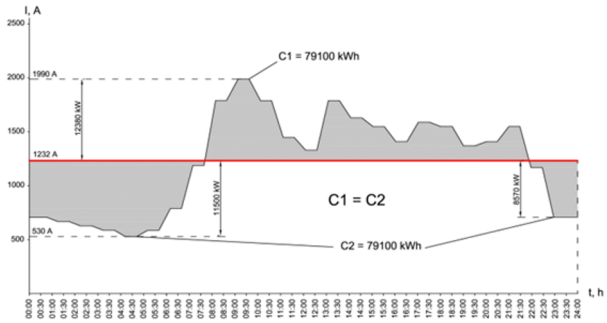

Fig. 3. Daily load curve (load current, A) of 110/10 kV substation of the wood-processing industry on a winter weekday, considering the equality of the discharge/charge areas of the ESS

Comparative cost calculation for the wood-processing industry 110/10 kV substation modernization options (transformer replacement or ESS installation) shows that the capital investment in 10 kV ESS installation 26 times exceeds the cost of the transformers replacement.

A series of calculations performed for the substations with two typical load curves showed that in order to achieve complete flattening of the load curves, it would be necessary to install an ESS of significant power and capacity – 12 MW and 80 thousand kWh (Fig. 4).

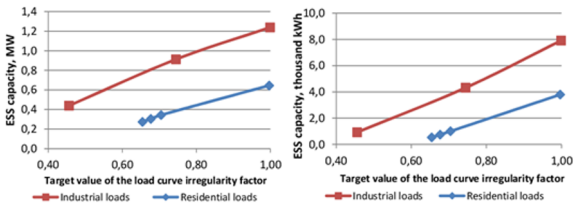

Fig. 4. Dependence of the required power and capacity of the ESS on the target coefficient of unevenness of the load curve.

4 Electricity losses in the network with an installed ESS

To assess the impact of ESS on the electricity losses, the changes in the electricity losses of the Minsk electrical network of 10 kV and above within a given period were calculated for the following options:

Option 1 - the ESS and a lower power transformer (16 MVA) were used;

Option 2 - a higher power transformer (25 MVA) was used.

The calculations were performed using the RASTRWIN program.

Additional annual electricity losses in the network of 10 kV and above were defined by the formula:

$$\Delta W = \Delta P \cdot \tau, \quad (1)$$

where ΔP – additional electricity losses in the network of 10 kV and above caused by increased load (without ESS);

τ – time of maximum losses, determined by the formula:

$$\tau = (0{,}124 + \frac{T_{MAX}}{10000})^2 \cdot 8760, \quad (2)$$

where T_{MAX} – time of the maximum load being used is taken equal to 5000 hours.

Electricity losses in the transformers are determined by the formula:

$$\Delta W_T = \Delta P_{NL} \cdot 8760 + (\frac{S_{MAX}}{S_R})^2 \cdot \Delta P_{SC} \cdot \tau, \quad (3)$$

where ΔP_{NL} – no-load operation losses of the transformer;

ΔP_{SC} – short circuit losses of the transformer;

S_{MAX} – the highest value of the total power flowing through the transformer;

S_R – rated power of the transformer.

Electricity loss in 10 kV ESS is determined based on the overall efficiency of the lithium-ion energy storage device that equals about 85%, according to the manufacturer's data.

The analysis of the calculation results proved that, when the ESS was used, the electricity loss in the ESS, the increase in the losses under the load in the lower power transformers, according to the option 1, were not compensated by the decrease in no-load operation losses of the lower power transformers according to the option 2. Therefore, in general, the electricity loss with the installed ESS is greater than without it. And, consequently, it should be considered in the feasibility studies.

5 Usage of ESS for voltage regulation

It was calculated in what way a 6.5 MW ESS affects the voltage level in the 10 kV network of the 110 kV Korzyuki substation. 10 kV ESS inverters are selected considering the possibility to generate the required reactive power in order to regulate the voltage in the 10 kV network. The power of the inverters should be about 7.2 MVA, if a load power factor equals 0.9. According to the ESS passport data, the power factor control range is from 0.1 to 1 p.u., provided that the inverter is not loaded with active power. Thus, a 7.2 MVA inverter can control reactive power in the range from -6.5 MVar to +6.5 MVar.

A change by 6.5 MVar in the reactive power on the 10 kV buses of 110 kV substation Korzyuki, causes a voltage level change by 0.6 kV in the 10 kV network. By means of the full range of regulation, a 7.2 MVA inverter is capable of regulating the voltage within the range of 1.2 kV (about 12%).

The 10 kV ESS are mainly used to prevent overloading of 110 kV substation transformers when one of the two 110/10 kV transformers is disconnected in the situations of the significant loads at the substation in winter. While both of the two transformers are in operation during the previously mentioned period or considering the operation of the summer loads, the active power of the ESS will not be used to its full potential. This circumstance makes it possible to use those systems as a means of voltage regulation (generation/consumption of reactive power) in a 10 kV network when consumption/generation of active power is below the nominal value of the installation.

The reactive power generation/consumption technical feasibility can be determined only after the required level of the inverter load by the active power for a specified substation load operation mode has been calculated. It should also be mentioned that for the voltage regulation on the 10 kV side, 110/10 kV transformers are equipped with on-load control devices, in this regard, the use of the ESS for 10 kV voltage regulation is not of the primary importance.

According to the preliminary estimates, the cost of an ESS being below 200 US dollars / kWh can be an economic feasibility criterion of the ESS wide usage in the 10-110 kV distribution networks of the Belarusian Energy System, in this regard the following factors should be considered:

- the service life and the degradation of ESS,
- the payback period of ESS, as an energy saving means, not exceeding 10 years.

It should be noted that when specifying the efficiency of the ESS usage in 10 kV distribution electrical network of an industrial enterprise, it is essential [3]:

- to determine specific requirements for the reliable work of the basic equipment of the enterprise;
- to clarify the cost-beneficial analysis based on the additional conditions of the contractual relations with the power-supplying organization (paying for the contracted capacity, taking part in the frequency regulation demand management, etc.);
- to clarify the cost indicators and the maintenance costs of the devices to be installed.

Conclusion

1. Usage of ESS at a 110/10 kV substation allows for compensating daily load unevenness, compensating daytime peak loads and increasing nighttime minimum loads (load dips), and avoiding the replacement of 110/10 kV transformers with higher power transformers.

2. ESS can be used to regulate the voltage in the 10 kV substation network, however, due to the use of 110/10 kV transformers with on-load tap-changers, this task is not of the primary importance.

3. The ESS installation cost significantly exceeds the facility reconstruction cost, which makes it indefinite and disputable to conclude the advisability of ESS widespread use in 10 kV distribution electrical networks.

References

1. Bushuev V.V., Novikov N.L. Infrastructure storage units in the electric power industry. Energy Policy, 2020, No. 10, p. 74-89.
2. Review of Energy Storage System for Microgrid. G.V. Brahmendra Kumar and K. Palanisamy, 2021.
3. Ilyushin P.V., Shavlovsky S.V. Payback mechanisms for investments in electric energy storage systems when used to reduce peak loads and power costs // Relay protection and automation, 2021, no. 3, p. 14-22.