BIO Web of Conferences **63**, 02006 (2023) https://doi.org/10.1051/bioconf/20236302006
ASE-2023

Economical Efficiency of Energy Storage for the Traction Energy System

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Abstract. The paper provides results of the study dedicated to estimation of the energy storage economical efficiency in the traction energy system of electric railways. The energy storage offered will allow obtaining the line of technological and technical advantages: increasing the degree of recuperation use, which will lead to reduction of consumed traction energy, obtained from the external power system; minimizing risks, in the part of failures in energy supply of the infrastructure complex facilities; increasing economical efficiency indicators; optimizing costs in traction energy supply; equipping energy supply facilities with efficient technical means and technological systems. Statement of need of the products designed is provided. The definition of economic effect from using the developed products on the railway network of JSC "Russian Railways" and the compensation period, and the project risk analysis have been given.

1 Introduction

The energy storage market is one of the most promising high tech global markets, demonstrating exponential growth rates. McKinsey Global Institute included this technology type into Top 12 the most important for global economy development. According to Bloomberg New Energy Finance forecast, for the period from 2016–2030, the volume of investment into electric energy storage systems will exceed 100 bln USD. [1].

The traction energy system of electric railway is one of the most promising fields for developing energy storages. Railway transport uses electric energy as the major energy carrier. For the time being, one of railway transport priority tasks is increasing the crossing and carrying capacity. But an issue of decreasing electric energy specific consumptions rises together with this task. Energy consumption increases together with traffic volume growth. The task of traffic volume growth is solved due to train weight increase. The higher is the weight of separate trains, the higher are peak loads on the traction energy system, and the higher are traction network losses. If we check time graphs of consumed power, the average parameter value grows in proportion to the train service volume growth, and maximal load power values, in proportion to the highest train weight. This increases nonuniformity of both consumed and recuperated power.

The energy storage, consisting of a battery unit, a transformer, and a control system, by using the preprogrammed operation algorithm, should provide redundant energy acceptance and supply it to network when consumers create the increased load. The energy storage under

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consideration will allow obtaining the line of technological and technical advantages: increase the degree of redundant energy use (e.g., that recuperated by electric rolling stock, or obtained within is own generation [2]), that will cause the decrease in consumption of electric energy, obtained from the external energy supply system; decrease risks, in particular, failures in energy supply of the infrastructure complex facilities; increase the energy efficiency indicators; optimize energy supply costs.

2 Materials and Methods

The study was carried out for the purposes of implementation of the "Energy Strategy of Russian Railways Holding Throughout 2030", in the part of full and reliable transport process energy provision, minimizing risks in crisis situations in railway transport energy supply. The goal of the study conducted was estimating the energy storage economical efficiency in the traction energy system of electric railways.

Calculations were carried out by means of simulation with the use of KORTES software package developed by JSC "All-Russian Research Institute of Railway Transport". Calculations were performed for the actual two-track section under the condition of trains passage at the set speed, with total number of trains in both directions equaling 64. Maximal train weight is 7,100 tons in both directions. The train circulation plan meets the average day amounts of movement in the selected section. Full simulation time is 24 hours; with per-minute breakdown, 1 hour.

As KORTES software package does not provide for energy storage operation simulation, it was simulated by a traction substation with an inverter and adjustment of parameters, corresponding to the storage operation.

3 Results and Discussion

For the purpose of increasing the efficiency of recuperation energy use, it is suggested to install energy storages. In this case, no power increase of traction substantions and the entire energy supply system will be required. Due to the fact that the maximum value power consumption has the sporadic and short-term nature, there is a possibility to store energy in time intervals with no energy consumers (during the train running intervals) with the purpose of subsequent energy supply of a heavy-tonnage train, passing the low voltage section. The storages will be accepting energy of recuperating electric locomotives in the absence of load, and give it to the traction network when the load increases.

In the field of issues of using energy storages in railway transport, studies were carried out by such researchers as Pupynin V.N., Shevliugin M.V., Nezevak V.L., Zarutskaya T.A., and the others. The offered solutions were developed and repeatedly published at the level of ideas and general schematic solutions, but there were only singular cases of their practical implementation exactly for traction energy systems. Options of energy storage installations on traction substantions, on sectioning points and on electric stocks have been considered. The main schematic solutions were determined, and the efficiency of using energy storages on different railway sections, including subway, was estimated [3-6].

The required values of the energy storage capacity and power in charge/discharge modes were estimated in the studies conducted. However, in practical implementation of the projects, creating and energy storage with capacity around 100-300 kW·h and power of 3-5 MW is complicated.

There are available technical solutions and practical implementation of using the energy storages in general energy supply systems (pump-storage plants) and for separate small-capacity load (uninterruptible power supply units). Experiments for using energy storages on the electric stock have been carried out [7, 8]. For the purpose of implementing the pilot project of using the energy storage for the traction energy system, variants of the energy storages with power up to 1MW have been considered. The energy storage application efficiency on their power dependence has been analyzed.

Today, on the polygon of tracks, electrified at permanent voltage of 3.3 kV, the share of traction substantions with inverters, able to accept recuperated energy and return it to the three-phase external energy supply system, is less than 1%. Recuperated energy is accepted only by the other electric locomotives. But at this, an electric locomotive in traction (load) mode is not always found near. At remote load on the recuperating electric locomotive, voltage should be increased, that may cause flashing over on the engine collector, moving to the generator mode. If voltage increase and current transfer to the traction network do not provide the required force for braking, or there is a high probability of damaging the engine collector, generated energy is sent to brake resistors. Therefore, the share of energy that could be used for traction by other electric stock, transforms into heat energy and dissipates in the environment.

The calculation section has the alternative profile with long inclines both in even and odd directions (Fig. 1). Maximal inclines make up to 10‰. Durations of such inclines are 5-7 km each, giving a possibility to recuperate energy on these sections. The section is fed by five traction substantions TS1–TS5. Power supply diagrams: parallel and nodal.

The most advantageous areas for placing recuperated electric energy receivers: traction substantions TS2 and TS3; sectioning points SP1, SP2 and SP3 [9].

Following the results of simulation of the all-day train schedule on the calculation section:

- losses in traction network are 9.6%;
- minimal voltage on the collector bow is 2,308 V (section TS3–TS4), 2,320 V (section TS2–TS3).

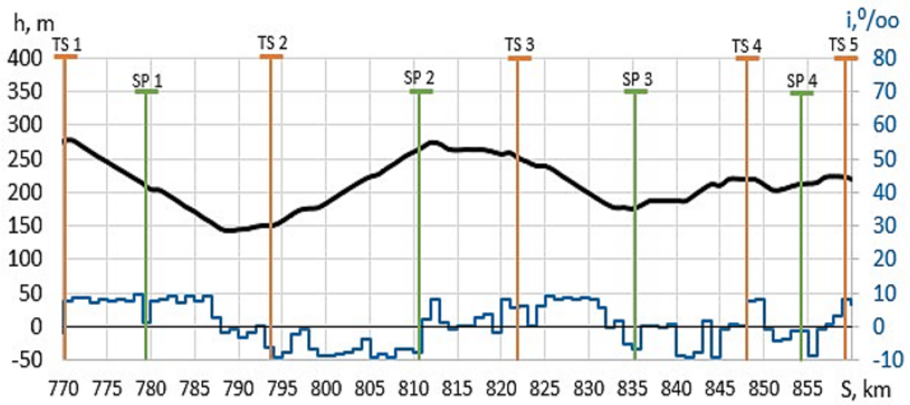

Fig. 1. Grading of the section track with identification of height (h), inclines (i), sites of traction substantions (TSs) and sectioning points (SPs).

Placement of the energy storages separately on sectioning points gives almost the same effect: electric energy consumption decrease by 4-4.5%. At this, capacity of the non-controlled energy storage up to 3 MW·h is required, with charge/discharge power of 3.5/11 MW.

Energy storage operation mode control allows decreasing requirements to capacity and power without the loss of recuperation energy efficiency. The operation principle is based on accepting recuperation energy at the level of its redundancy. That is, the part that cannot be consumed by rolling stock in the traction mode, due to the present train situation. Energy return to the traction network is performed not in peak load periods, but at any passage of the

 https://doi.org/10.1051/bioconf/20236302006

train in the traction mode of the energy storage operation zone. Therefore, the energy storage will be always ready to accept energy. This mode disadvantage will be the fact that the energy storage will fail to provide the additional supply of maximal load, and provide the considerable voltage level raise in the traction network.

With the purpose of the pilot project implementation, calculation of the controlled energy storage with the power of 1 MW has been conducted. According to the data obtained, capacity of 0.32 MW·h will be sufficient for such power. As was stated above, the effect of increasing the minimal voltage level is small, equaling 50-70 V in load mode (Fig. 2). But the recuperation energy use efficiency gives a possibility of electric energy consumption decrease, similar to energy storages, by 4.27% (Fig. 3, 4).

The positive result is achieved due to the fact that the energy storage is ready to accept only the part of recuperated energy power, however, sufficient to bring the electric locomotive to the recuperation mode at remote load.

The technical and economy effect, reduced brought to actual annual electric energy consumption by traction substations, that were simulated in the study, will be 3790 ths. kW·h or 17 mln RUB (at the rate of 4.47 RUB per kW·h).

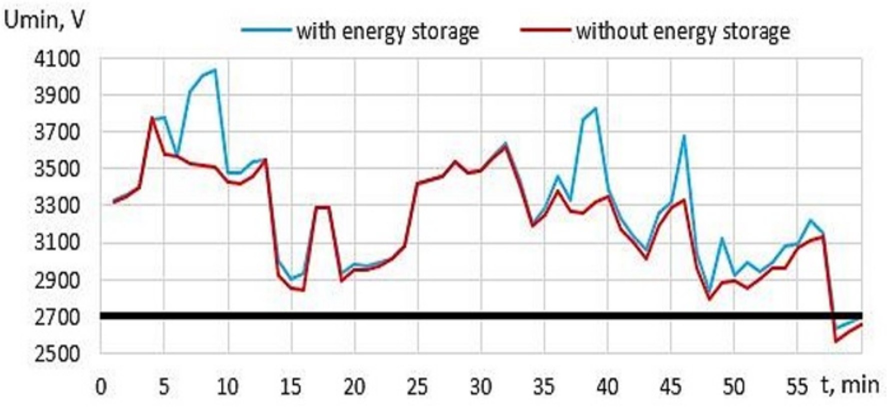

Fig. 2. Minimal voltage level in the contact network (1 h simulation).

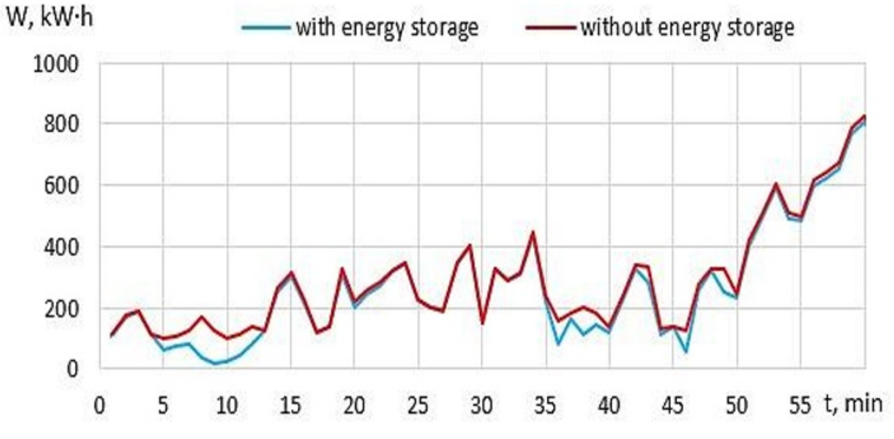

Fig. 3. Electric energy consumption by train traction, kW·h.

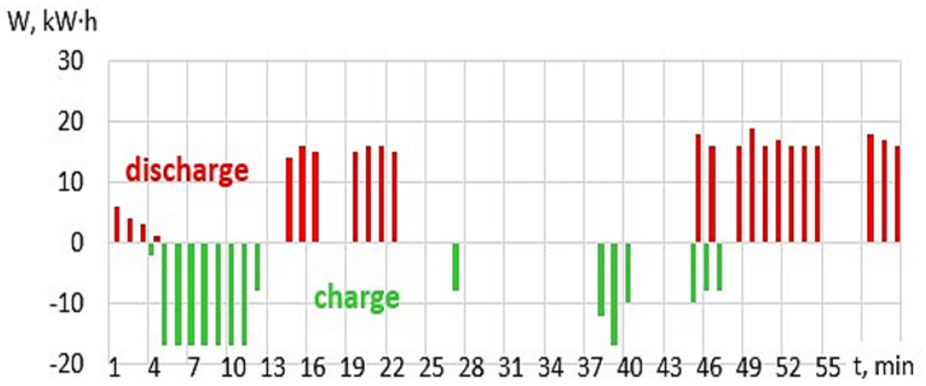

Fig. 4. Volume of energy, received and returned to the traction network of the energy storages, kW·h.

In the process of implementing the project of the energy storage implementation on the railway polygon, and operation activity, external and internal factors, able to affect its efficiency, i.e., project risks, may be shown. [10].

In quantitative terms, the risks may be expressed through the change of the project numerical indicators: net present value, internal rate of return, and payback period.

For estimation of possible factors, able to affect the achievement of the planned project efficiency parameters, the risks, the most inherent to this project implementation conditions within the period of taking measures, were determined:

- change of price environment on branch markets of the material supplier and the contractor, that will produce the traction energy storage, that may cause the growth of investment value compared to the planned level;
- non-fulfillment or breach of obligations from the contractor's side in the part of work volume and/or work completion time, and work completion quality, that may cause rescheduling of the project operation activity.

The main factors should include the risk of non-conformity of the actual train sheet to the approved List of Train Running Intervals under the conditions of block system and energy supply devices (Table 1).

Table 1. Possible risk damage estimation.

Risk	Risk event probability	Assessment of risk event consequences
Non-conformity of the actual train sheet to the approved List of Train Running Intervals under the conditions of block system and energy supply devices	Average	Traction energy storage operation efficiency decrease. Consequences are significant
Exceeding the planned investment volume	Average	Consequences are insignificant
Increase of project implementation terms	Low	Consequences are insignificant

4 Conclusion

Preliminary calculations, carried out for one railroad section, demonstrated that using the energy storage with the power of 1 MW and capacity of 320 kW·h, at the existing movement parameters, will allow decreasing electric energy consumption by train traction by

3.8 mln kW·h per year or 17 mln RUB (electric energy rate is 4.47 RUB per kW·h).

Approximate value of the energy storage with the parameters specified may reach 90 mln RUB. Therefore, the simple pay-back period for the project implementation will be 6 years. The exact project implementation cot can be obtained only after the design documentation completion.

Using energy storages with the relatively low power (around 1 MW) in the traction energy system allows solving the task of increasing the use of recuperation potential on the section and makes the project cost effective. Installation of the energy storages with power values of around 10MW will also solve the task of increasing the section crossing capacity. But, as its cost will grow in proportion to power, the decision on its use will compete with the construction of a new traction substantion.

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