Electric power accumulators in system of supplying railways with traction energy by direct current

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Abstract. The article describes core criteria, which define efficient application of energy accumulators in railway traction power supply system. Installation points for energy accumulators in electric power system of train electric drivers, where application is most effective, are identified. These points are railway sub-stations, electric traction network and traction power system. The main types of energy accumulators, which essentially can be used on railway transport in traction power system – traction sub-stations and traction network, electric motive power, are examined. They can be used on railway transport and. The quality factors of work for traction energy power and electric motive power are presented, improvement of which can be performed using energy accumulators. International experience of energy accumulators application for railway transport is presented. Russian developments and implementation of energy accumulators from domestic manufacturers are examined, both in the traction power system and in the electric rolling stock. The polygons for the most efficient use of energy storage in the traction power supplying system are identified.

1 Introduction

Railway transport is not only a consumer of country energy system's products, but, at the same time, is a technological link in a chain of production, transporting and consumption of energy. Traction power supply system of railway transport is one of the most heavy consumers of electric power. Along with that, traction power supply system has the most uneven energy consumption schedule. Over a period of few minutes or even several seconds, consumed power of one traction power sub-station feeder vary from 0 till 10 MWt. Such load fluctuations influence complete electric equipment badly. Because of this traction sub-stations of the underground experience significant load fluctuations caused by summing up of feeder loads. At peak loads generated by start-up currents which are superimposed in the feeders, the voltage on bus bars of traction sub-station and in traction power system on intermediate stations that are located between the two closest traction sub-stations reduces. It feels especially strong in the end of console sectors. This slows down trains launching processes and leads to additional electric power losses in traction power supply system. For

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these reasons traction sib-stations power equipment has extensive available capability, which is necessary for load factoring.

The main part of the energy expenditures of electrified railways is the cost of traction of trains. Due to that, it is necessary to implement energy saving technologies, and exactly in traction power supply system [1]. One of the most efficient methods of energy saving is local buffering on various phases of energy delivery to the user. This means implementation energy accumulator into transport electric system, which can lower capital investments for basic traction equipment and save electric power that is applied for train traction [5,6].

Kinetic energy of moving trains is equal to the sum of the products of squares of their velocities per mass at the moment of the onset of deceleration. It is currently not predominantly recovered into the network, but is converted into electric energy, which in the process of braking is released as heat in the braking rheostats of an electric car or locomotive.

2 Materials and methods

It is possible to avoid the described disadvantages by fitting traction network with energy accumulators that would take overflown energy recuperation during breaking with following returning of it into traction power supply system at trains start and acceleration. In this case, on the one hand, energy for train traction is saved, on the other hand, the load on the traction sub-station decreases. To take braking energy recuperation, power accumulators can be located at traction sub-station in the middle of feeder zones, on a bracket arm and on the rolling stock. From view point of power interchange, the use of on-board power accumulators and rolling stock to take braking power is the perfect decision. However, weight-size parameters of present accumulative systems make difficult to accumulate energy on the rolling stock. That is why now it is useful to use stationary versions.

With the aim to assess possible potential of brake power recuperation, we addressed to research in the Moscow underground. Here On during 2 hours the current measurements and stresses on traction chains of rolling stocks were carried out (Fig.1 demonstrates a fragment of measuring during 30 minutes). In this case rolling stock did not use modes of regeneration braking.

3 Results

Analyses of experimental tests showed, that 25% of traction energy can be returned back into chain (provided the presence of receiving device) through the use of regenerative braking modes.

It is necessary to pay special attention to increase of energy losses in traction power supplying system from uneven schedule of power consumption. Local buffering of energy can solve the persistent problem of inconsistency of the desired modes of operation of the energy source and the consumer. It allows dividing required energy values into produced and consumed energy. Granularity of energy consumption in traction power supplying system is determined by its unique terms of work. The first factor that influences energy granularity is uneven train schedule. The second factor is special irregular mode of energy consumption by each unit of traction power supplying system or locomotive. To solve this complex of questions is possible with help of energy accumulators. With the aid of static analyzer there were performed field measurements and fixation of current and pressure on present traction sub-station "Fili" of the Moscow railway. Measurements were made continuously with a sample spacing of one millisecond for 11 days. On the Fig. 2 there is a fragment of current oscillograph trace and pressure of traction feeder #3 on traction sub-station "Fili" in time function at field measurements during 5 days with sa step in 1 ms.

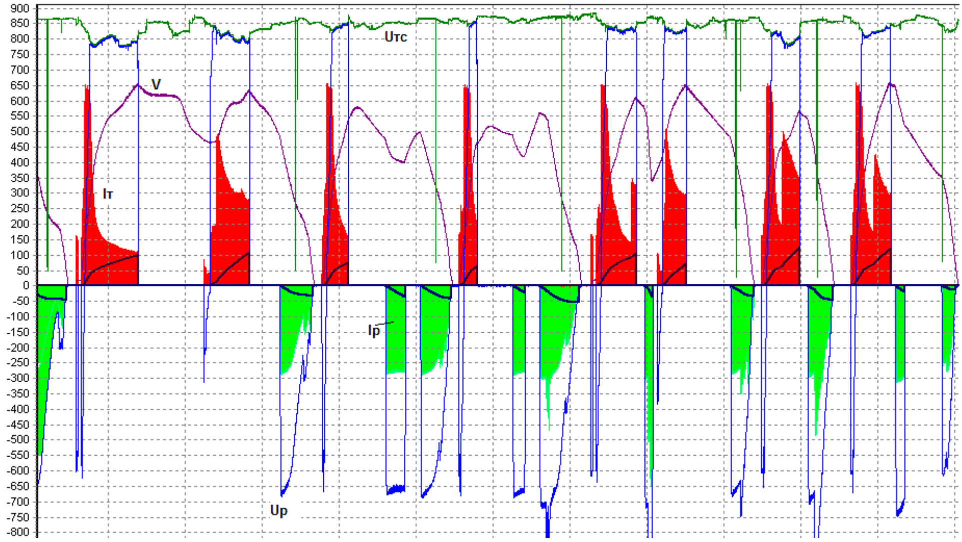

Fig. 1. Results of rolling stock performance measurement on Tagansko-Krasnopresnenskaya line of Moscow underground .

The above mentioned oscillograms clearly illustrate the impulse nature of the feeders' work of the traction sub-station. In this case traction current surges reach the value of 2300A, and at the average current about 100A (line at the bottom of the graph). Negative emissions of current have no relation to recuperation and are evidence of energy flows through the bus bars of traction sub-stations to the neighboring zones. In case of recuperation the current of traction sub-station could have more uneven character.

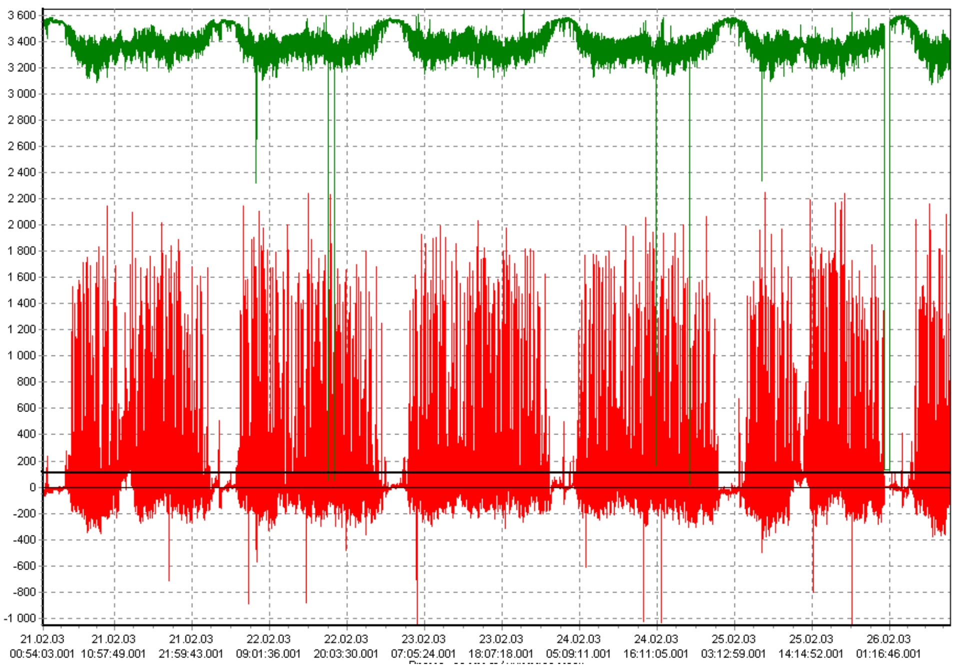

Fig. 2. Current of the feeder #3 and pressure of traction sub-station "Fili" of Moscow railway in time function during 5 days.

The main technical and economic damage in the traction power supply system arising from the non-uniformity of the traction load, are: an increase in the installed capacity of the traction sub-system; acceleration of equipment aging; serious increase of energy loses in traction network and in primary electric supply system; difficulties and sometimes the impossibility of use of recuperation and others. For complete or partial decrease of these the basic factors that influence uneven energy consumption were identified. That is: the effect of the train schedule and the mode of operation thereof; effect of regenerative braking; effect of uneven traction energy consumption of electric devices from traction power supply system; impact of traction energy consumption unevenness on loses in external system and tractive energy saving.

In examining of stationary power accumulators, it is worth to divide two types – controlled and uncontrolled accumulator. Energy accumulating devices of an uncontrolled type are those whose accumulating element is connected to traction sub-station tiers, and the modes of charge or discharge of power accumulators are determined by the conditions of the circulating energy in the traction network and the voltage therein. Energy storage are belong to the type of power accumulators which accumulating element is connected to traction sub-station tiers due to converting unit, that sets the operating modes of the drive in accordance with the selected algorithm [7]. The choice of type and functionality of power accumulator is determined by the specific conditions of their operation.

4 Discussion

Worth to note that implementation of power accumulators and railway electric system, especially actively conducted all over the world. Here are some of them: Batteries Kawasaki Gigacell 750 V Municipal metro service Osaka (nickel-metal hydride battery); CAPAPOST companies Meiden railway Seibu (battery supercondenser); B-CHOP company Hitachi (lithium-ion battery) municipal transport Kobe; E3Solution company Toyo Electric (lithium-ion battery) municipal transport Kagoshima; GS Yuasa Company Toyo Electric (lithium-ion battery) West Japanese railway.; SITRAS SES company Siemens for small metro service, г. Cologne (battery supercondenser).

Let's turn to Russian experience of putting into operation power accumulators at traction power supply system on railways with direct current and metro services.

One of the first was the introduction of power accumulator of uncontrolled type at the Test loop of railway with direct current in Sherbinka (VNIIZHT). On traction sub-station «Sherbinka» was made and tasted on tires 3,3 kV breadboard setup from two parallel-connected branches of twelve consecutively connected supercondensers (C = 1,55 Ф, $U_н$ = 300 V) produced in Russia (picture 3). However, their summary energy intensity by mass-size indicators can not be used as a store of energy for the re-operation of test subjects on the Test loop of electric trains, due to the lack of energy intensity. Now it is applied at commutation test of speed switches to provide the required di/dt. Besides such installation can be used for voltage and current filtering on 3.3 kV buses of traction sub-stations.

Fig. 3. Aupercondenser battery.

As early as in 2006, the first experiments of the autonomous course of the electric vehicles of the metro on the energy of the onboard energy accumulators, consisting of 14 supercapacitors (Fig. 4) [2,3,4], were conducted. Then it was possible to carry out on a single battery charge a train consisting of 5 wagons, with a mass of 160 000 kg, at a speed of 8 km / h, about 800 m.

Fig. 4. Board system of power accumulators on supercondensers in the carriage of an underground train.

In the period of 2012-2013 on the Filevskaya line of the Moscow Metro, works were carried out to install electric power storage devices in the traction power system with subsequent testing. Stationary energy accumulators of an uncontrolled type were installed at two railway sub-station T-23 and T-24 with the main functional purpose of accepting excess energy recovery, ensuring the rolling-out of the rolling stock on its own with the main power disconnected, increasing energy reliability and saving electricity. Experimental operation of storage devices lasted about 1.5 years, but work on the study of drive efficiency was interrupted [8-11].

In figures 5 and 6 presented cabinets with storage modules. Figures 7 and 8 show oscillograms of currents and voltages of traction substation and energy storage, as well as the effect of reducing the installed power of the transformer.

Fig. 5. Blocks storage.

Fig. 6. Storage modules inside the cabinet.

To assess the operating results of traction substation and stationary energy storages, a long-term monitoring of the currents and voltages of the objects under investigation was carried out. The dimensions were carried out on the railway sub-station T-23 (Studencheskaya Station) of the Filevskaya line of the Moscow Metro. The result fragment of the monitoring (dependencies of the current traction substation and stationary energy storages as a function of time) is shown in Figures 7 and 8. The obtained measurement results allow us to compare the performance of traction substation, stationary energy storages, assess the effect of regenerative braking currents on the redistribution of energy transfer in the traction power system, and determine the loading of feeders.

These measurements allowed determining the main performance indicators of T-23 and stationary energy storages, namely:

- the output capacity of the stationary energy storages turned out to be at the level of the calculated one, the maximum currents of the stationary energy storages were at a charge of 1800A, with a discharge of 1500A;

- the regular processes of stationary energy storages charge are mentioned due to regeneration pulses, which correspond to calculations taking into account the size of train traffic;

- the maximum peaks of the charge and disruptive energies of stationary energy storages were 10.5 MJ at the charge and 11.0 MJ at discharge;

- in accordance of actual measurements the average efficiency of the stationary energy storages was ~ 95.5%;

- the continuous monitoring of the performance measure of the stationary energy storages has shown the possibility of increasing the energy preparedness of the traction substation with a negative change in the conditions of the electric supply of the primary network;

- statistical data manipulation has showed that the average economies calculated on the basis of the statistical treatment results, taking into account the average temperature in Moscow (6-7 ° C), amounted to 4-5% of the energy consumed by the traction.

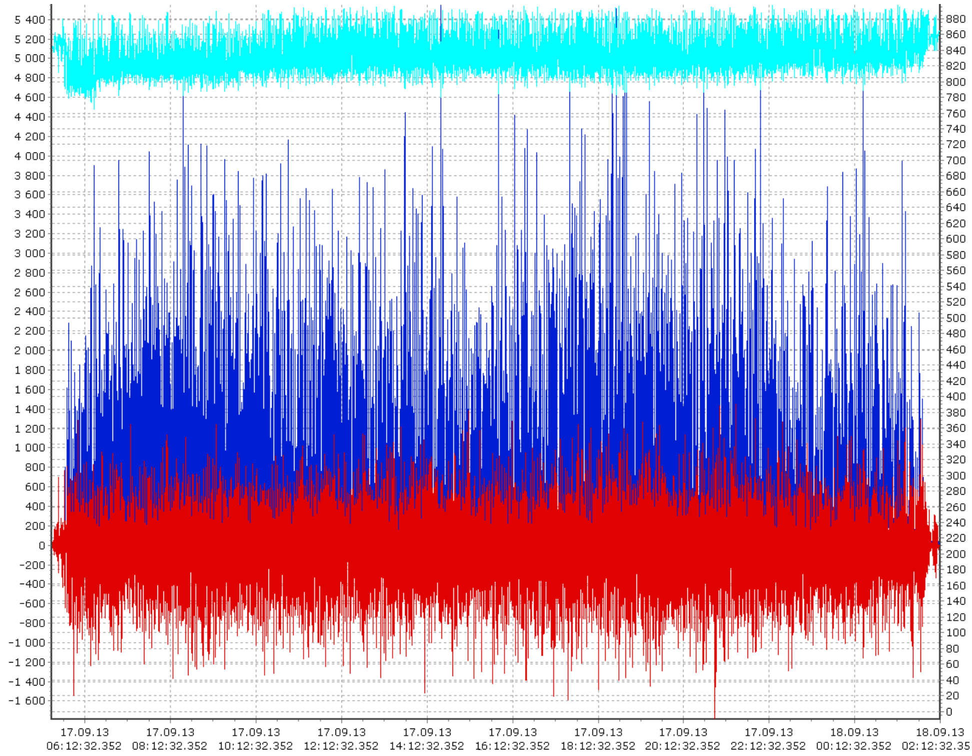

Fig. 7. Current oscillogram and pressure of traction sub-station and traction power supplying system within 24 hours.

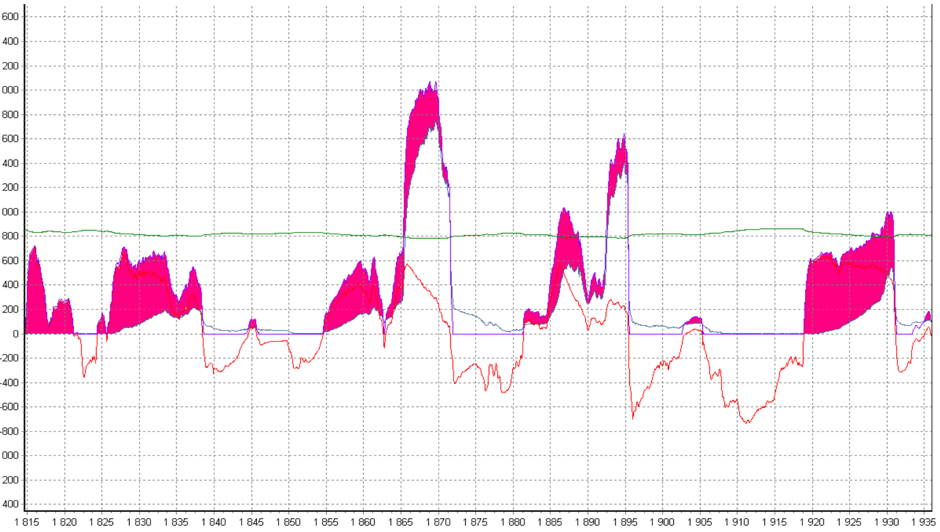

Fig. 8. Currents of traction sub-station, power accumulators and their sum (exit into electric traction network for supply trains with power) in time function within 2 minutes by results of full-scale experiment.

At the present time, a controlled energy storages system is being developed to use stationary energy storages in DC of 3000V based on lithium ion charges. According to preliminary data, such a system will be effective on the Moscow Central Circle, intensive passenger suburban traffic and to airports, as well as in special cases of local enforcement of stationary energy storages and console power supply in the areas of difficult supply of power lines and construction of new traction substations.

5 Conclusions

When analyzing the circumstances that influence the economic aspects of the use of electrical power devices based on high volume output battery in traction substations on the base of accumulators of a high capacity, a number of criteria should be singled out that reflect the specific energy consumption in the traction power supply system, the partial or total damage from which can be reduced by use of energy storage. At the moment, not everything is quantifiable, but, potentially, the use of energy storage in the traction power supply system of the railway can contribute to the following:

- rectification of minute and hourly load curves for leading to a decrease in current loads off-peak load of railway substations, which will contribute to better use of station capacity with increasing amount of traffic and tonnage of freight, and even reducing the total capacity of the railway substation, at which it will be possible to reduce number of locomotive units or choose their lower power, as well as reduce the temperature of semi-conductor units and transformers, which will favorably affect the term of service hardware pulp;
- improving power quality;
- increasing and stabilization of voltage compensation in the electric traction network and on the collectors of electrics going in traction condition, which is directly related to the speed of trains, fulfillment of a movement schedule and the efficiency of electric locomotives.
- providing of the necessary conditions for regenerative brake duty.
- providing with dynamic and static stability of the power system.
- use of economy electricity stored at night to compensate for the power shortage during peak hours.
- better energy utilization of recovery, and loss reduction of energy in the traction network, with a refusal to return energy to the primary network and while providing the necessary braking torques on the shaft of electric vehicles and electric locomotives.
- use of fewer supply cables 10-20kV, and in some cases, their complete absence.
- strengthening of existing railway substations with increasing amount of traffic and trains weights without strengthening primary voltage cable lines.
- Simplification of projects on reconstruction of traction energy system.
- Reduction of dependence on the supply points of the primary electricity supply system.
- Local system gain of traction energy system in difficult parts of the track (for example, mountain road).
- Reduction of the declared capacity from feeding centers;
- Facilitating the redundancy of feeder supply lines.
- reduction of energy losses in railway substations and traction network;
- saving of expense due to a flexible multi-tariff grid.

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