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# Simulation of the operation of a traction power supply system with various types of electrical energy storage devices

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**Abstract.** The improvement of traction power supply systems of the transport complex is associated with the search for new technical solutions that can improve operational and energy efficiency, reliability and energy security. Electric energy storage systems make it possible to solve these problems. One of the aspects of the application of electrical energy storage systems is the voltage mode at the connection points. The studies of the operating modes of electric energy storage systems on mobile vehicles and stationary objects show the short duration of charge and discharge episodes due to the traction load of electric vehicles. An urgent task is to assess the change in the voltage level of electric energy storage systems in short-term modes when operating in traction power supply systems for various electric energy storage devices. The paper describes a model of the traction power supply system and electric rolling stock containing electric energy storage systems. The change in the degree of charge and voltage depending on their capacity and the time of the applied load is shown. For the conditions of the traction power supply system, the most preferable ones in terms of the minimum voltage level were selected.

## 1 Introduction

Research in the field of improving the efficiency of electric power systems through the use of electric energy storage systems is focused on solving a number of problems related to improving operational and energy efficiency, reliability and energy security, electric power quality, ensuring the operation of renewable energy sources and a number of other issues.

The fundamentals of building energy storage systems in traction power supply systems are based on the specifics of the traction load, which is taken into account in various ways based on traction and electrical calculations using various modeling tools, for example, as shown in the example of improving the efficiency of regenerative braking in the subway and using batteries and renewable energy sources [1, 2]. A number of researchers are considering the issues of redundant power supply, for example, as shown in [3] for an electric train with an onboard battery and hydrogen cells. The results of reviews of technical solutions for the use of various technologies for storing electricity in railway transport indicate their potential effectiveness [4]. Researchers consider various aspects of process modeling, including the

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use of autonomous hybrid power plants in railway power supply systems [5]. The issues of developing technical solutions related to changing the electrical circuit of the traction power supply system [6], including various schemes for connecting electric power storage systems to lines where regenerative braking is implemented [7], are considered. A number of researchers have performed simulation of the operation of traction power supply systems in order to assess the parameters of electric power storage systems [8, 9]. In general, a review of the use of electricity storage devices in traction power supply systems shows a high potential in the field of improving the efficiency of traction power supply systems and railway transport in general [10, 11].

Thus, the tasks of improving traction power supply systems with the use of energy storage devices are relevant.

In this paper, a developed model of a traction power supply system containing an electric power storage system with various storage devices is presented. The change in voltage and the degree of charge during the operation of on-board and stationary storage systems for various energy storage devices are evaluated. The results of the work were obtained using the methods of simulation modeling and processing the results of the experiment.

## 1.1 Development of a model of a traction power supply system

The traction power supply system for various sections of railways and ranges of circulation of electric rolling stock has a different length and number of inter-substation zones. The main processes occurring in traction power supply systems when interacting with electric rolling stock can be considered using the example of one inter-substation zone.

In this regard, the model of the DC traction power supply system is designed in such a way that it contains one inter-substation zone, which receives power from the external power supply system (Figure 1). The intersubstation zone includes two traction substations with electric rolling stock units placed between them.

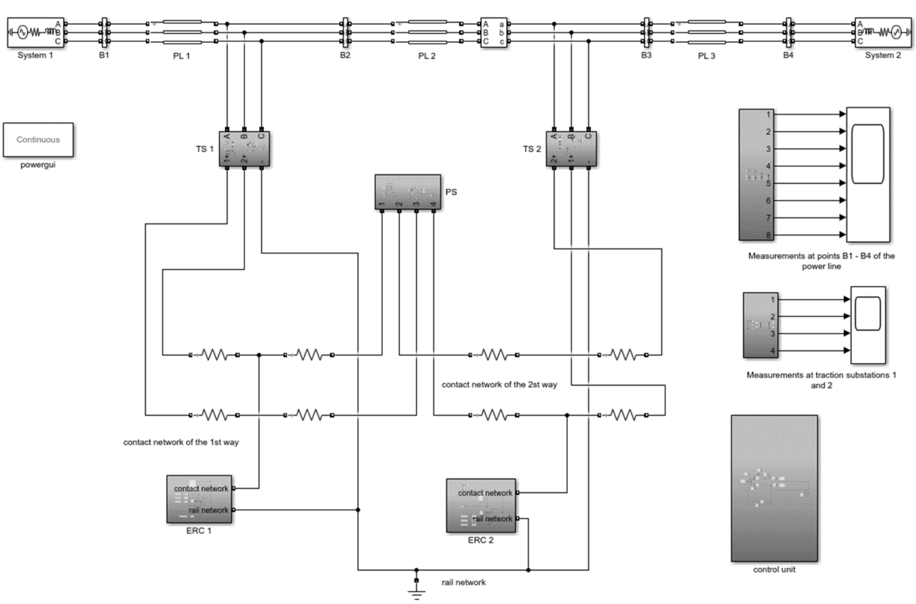
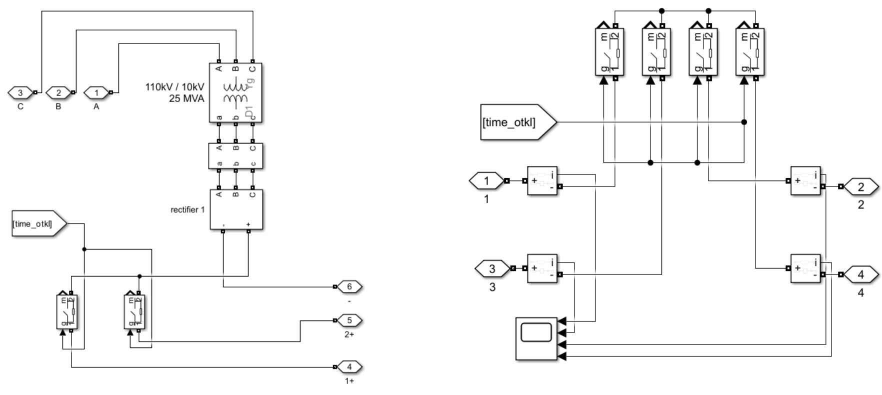



**Fig. 1.** Traction power supply system model.

Models of traction substations TP1, TP2 and sectioning post are shown in Figure 2. The traction substation contains a power step-down transformer with a primary voltage of 110 kV, a secondary voltage of 10 kV and a rated power of 25 MVA. The rectifier is represented by the "Rectifier" block, which is connected to the contact network in two ways using the appropriate switches, which are ideal switches.




a) b)

**Fig. 2.** Model of traction substation (a) and sectioning post (b).

The sectioning post is represented by a common bus to which four switches are connected. The outputs of the switches are connected to the corresponding sections of the contact network (1 - 4) of two ways. At the sectioning post, current sensors and an oscilloscope are connected, allowing you to register the load on the connections of the contact network.

The model of the rectifier converter is shown for a circuit of a twelve-pulse series-type rectifier, at the output of which a single-link resonant-aperiodic filter is connected (Figure 3).

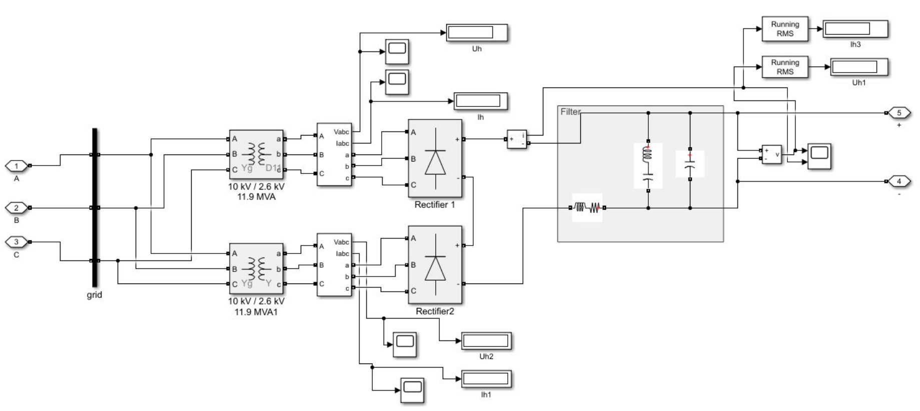



**Fig. 3.** DC traction substation model.

## 1.2 Development of a model of an onboard electric power storage system

The model of an electric rolling stock with an onboard electric power storage system is shown in Figure 4.

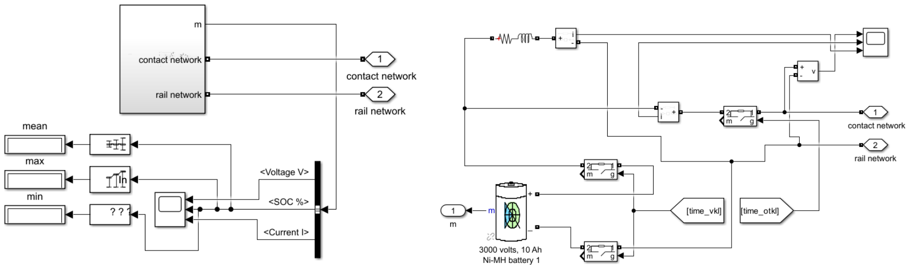



**Fig. 4.** Electric rolling stock model with an onboard electric power storage system.

To simulate the operation of the storage system, four types of batteries and one electric double layer supercapacitor (EDLC) are considered below. The battery is considered for the following types of batteries: nickel-metal hydride (NiMh); nickel-cadmium (NiCd); lithium-ion (LiIon); lead-acid (LeAc(Pb)). For the electrical type of storage, capacitors with an electric double layer EDLC (Electric Double Layer Capacitors) are considered [12].

For the purpose of emergency shutdown modeling, the following time constants are used: 0 – the beginning of the considered period of time; further - 5 s - emergency shutdown of switches at the traction substation and sectioning station; further - 10 s - switching on the electric power storage device; then 15 s - restoration of voltage in the contact network from traction substations and shutdown of the electricity storage system. The total duration of the simulation is 20 s.

The results of simulation of emergency power supply processes from an electric power storage system, consisting of various batteries or a supercapacitor, make it possible to assess the nature of the change in voltage, degree of charge, and load current. As an example, an assessment of the degree of charge of the SoC of the energy storage device for the considered simulation period is given (Table 1).

**Table 1.** Results of determining SoC for storage on electric rolling stock.

| Indicator | NiMh | NiCd | LiIon | LeAc(Pb) | EDLC |
|---|---|---|---|---|---|
| Average value | 98.77 | 98.86 | 98.70 | 98.96 | 97.74 |
| Maximum value | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| Minimum value | 96.73 | 96.99 | 96.55 | 97.27 | 93.97 |

## 1.3 Development of a model of an onboard electric power storage system

The modeling of processes for a stationary storage device at a sectioning post was performed for the following situational model: de-energizing the contact network by turning off the switches of the contact network connections, then delaying the auto-reclosing time, then turning on the sectioning post and the accumulation device, then returning to the normal power circuit.

According to the results of the calculation for the placement of the accumulation system at the sectioning post with similar characteristics of electric energy storage devices, the SoC values were determined for four types of batteries and a supercapacitor (Table 2).

**Table 2.** Results of determining SoC for storage on electric rolling stock.

| Indicator | NiMh | NiCd | LiIon | LeAc(Pb) | EDLC |
|---|---|---|---|---|---|
| Average value | 98.17 | 98.32 | 98.06 | 98.52 | 95.97 |
| Maximum value | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| Minimum value | 95.17 | 95.56 | 94.87 | 96.13 | 89.30 |

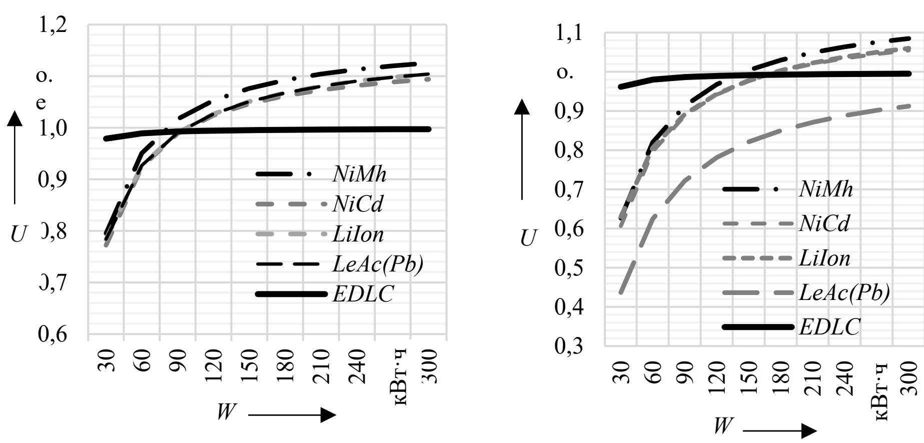
## 2 Results and discussion

The voltage drop at the output of the energy storage device when turned on is determined by the discharge characteristic of batteries and supercapacitors. In the initial period, the voltage on batteries of various types is determined by the exponential zone of the discharge characteristic. An assessment of the voltage level is required to check the operating conditions of the electric rolling stock. To avoid voltage drop below the permissible level, the energy intensity of electric power storage devices should be taken with some reserve.

Simulation modeling based on the proposed model makes it possible to obtain the characteristics of the voltage regime for the traction load and types of energy storage devices. The results obtained for on-board and stationary systems with a change in the energy intensity of the storage devices in the range from 30 to 300 kWh are shown in Figure. 5.

The assessment of the change in voltage for batteries is made relative to the open circuit voltage, taken as a base value. For the NiMh battery, the indicated voltage was 3533.9 V, NiCd - 3432.5 V, LiIon and LeAc (Pb) - 3491.9 V, EDLC - 3000 V, respectively.

The difference in the discharge characteristics of the onboard and stationary storage systems causes a voltage drop to the level of 0.8 pu. (from the nominal level) for a given load when using on-board systems and up to a level of 0.4 - 0.6 about. e. for the option of stationary placement of the energy storage system. Unlike storage batteries, the use of a supercapacitor does not require a significant increase in energy intensity for the considered conditions of short-term operation of the electric power storage system.




a) b)

**Fig. 5.** Minimum voltages for onboard (a) and stationary (b) systems.

The results of the calculations make it possible to determine the required energy intensity from the conditions for providing voltage on the busbars of the device. For the considered traction load of an electric train for an onboard electric power storage system, the required energy intensity level is 90 kWh for batteries and 30 kWh for a supercapacitor. When an electric power storage device is placed at the sectioning post of the contact network, the level of energy intensity increases: for a device with NiMh batteries - by 1.33 times (energy intensity of 120 kWh), for NiCd and LiIon - by 1.67 times (energy intensity of 150 kWh) , for LeAc(Pb) - more than three times (energy capacity over 300 kWh), and for supercapacitors - twice (60 kWh).

The traction load considered in the simulation is assumed to be stationary. The accepted assumption allows us to test the model. When determining the parameters of the electric power storage system, the traction load is taken as a variable corresponding to the actual load of the electric rolling stock. The studies performed in this area make it possible to determine the required parameters of electric energy storage systems for long-term operating modes, which are significantly higher in level, for example, as shown in relation to energy intensity in [13] for sectioning posts of the contact network up to the level of 1.5 and 12.0 MW h, respectively.

## 3 Conclusion

The paper assesses the change in the voltage level during the operation of on-board and stationary electric power storage systems, corresponding to their buffer mode of operation in the traction power supply system. The choice of energy intensity of electric energy storage systems according to the conditions for ensuring throughput and carrying capacity leads to different results and is performed on the basis of traction load simulation for various operating modes (post-emergency and forced) of the traction power supply system.

The paper presents the simulation results obtained for the options for placing power storage devices in the traction power supply system and on the electric rolling stock, for each of which the calculations were performed for various (electrochemical and electric) types of power storage devices.

The developed models make it possible to determine the energy performance of the traction power supply system in solving various problems using electric power storage systems.

Prospects for further research are related to the improvement of the simulation model, efficiency calculations of various configurations, control methods and algorithms, taking into account changes in traction load.

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