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INTELLIGENT TECHNOLOGIES FOR EFFICIENT POWER SUPPLY IN TRANSPORT SYSTEMS

Summary. The main directions of development of the energy-saving technologies in electrified transport systems are considered in the article with taking into account the flexible regulating features of modern power equipment. The proposed theory and principles of functioning allow understanding the optimal control laws for converters, accumulators, and renewable energy sources in their integration into traction power supply systems. Research opens the possibility of the installed power of the required equipment in minimizing and reducing the capital costs for energy-saving technologies. Also, combination of all developed approaches will provide the system effect.

1. INTRODUCTION

The transport system of any European country has a strategic importance in the society, economy, and security. In countries where the rail transport dominates, the transport system provides the needs of all internal, international, and transit traffic. For example, the Ukrainian railways operate about 80% of cargo and over 50% of passenger traffic. It ranks fourth among the Eurasian continent and has a traffic density of 3-5 times higher than that of European countries.

The traction consumption for electrified railway is about 80% of all energy resources. Currently, the cost of energy component in rail transport is estimated to be 21 ... 25% and has a trend to increase. Reducing this index requires the development of innovative energy saving technologies and is directly associated with the implementation of the State Program for energy independence and reduction of harmful emissions by 20% by 2020 (compared to 1990).

Implementation of energy saving actions at lower levels of power system by optimization their operation can provide systemic effects at higher levels. Similarly, reduction of the rail transport energy capacity by 1 unit of primary fuel can reduce primary energy cost by about 3 ... 3.5 units, with taking into account the efficiency ratio of power stations, power distribution networks, and transmission lines (Fig. 1). In this case, the overall effect of energy-saving technologies introduced in rail transport will exceed the set of energy-savings potentials in the components of its subsystems. This is the systemic effect of the energy-saving technologies.

A systematic analysis of the processes of transmission, transformation, consumption, and energy regeneration in rail transport system shows that the goal can be achieved by decomposing the system into multiple subtasks that deal with the energy-saving problem of railway transport at different levels (Fig. 2). These subsystems are traction power supply system, electric train traction, and passenger rolling stock power supply system.

Fig. 2 shows the potential places of energy losses in rail transport subsystems that can be decreased using energy-saving technology. Comprehensive implementation of effective energy-saving technologies in rail transport adapted to the existing technical state of its infrastructure and rolling stock requires solving number of problems including:

1. Intelligent control of voltage mode in traction network.
2. Neuro-fuzzy control of the regenerative braking modes.
3. Energy storage systems with alternative sources.
4. Interoperability of electric vehicles.
5. Intelligent technologies for passenger railcars climatization.

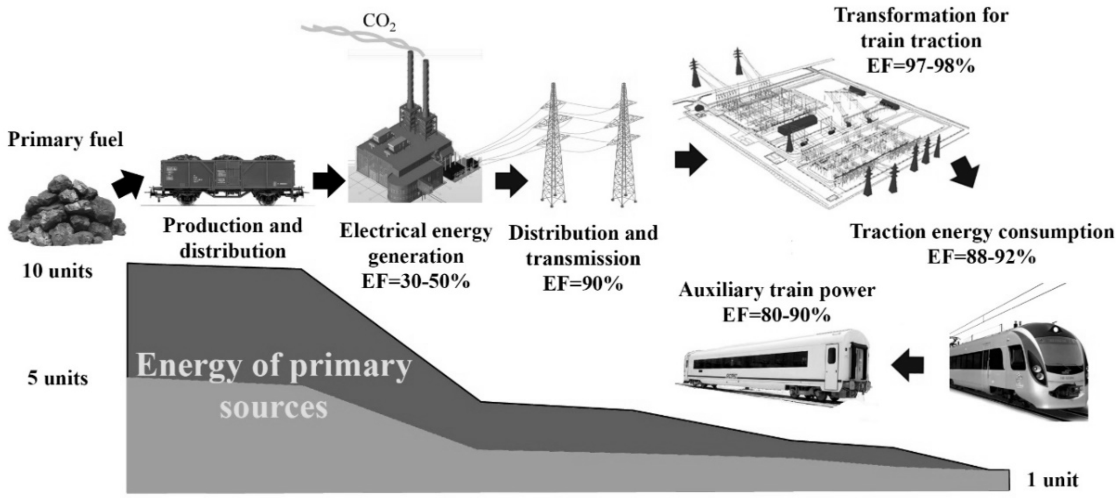


Fig. 1. Structure of transmission and conversation of electricity for railway transport system

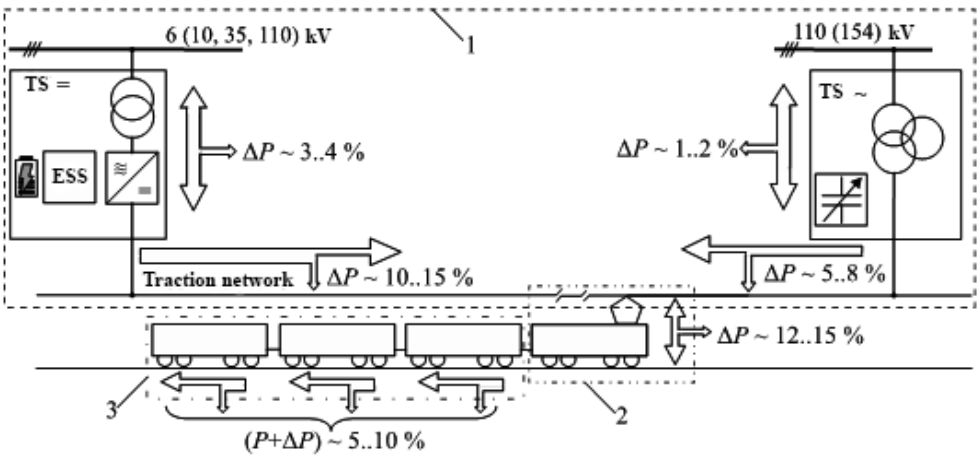


Fig. 2. Power losses in subsystems of electrified railways: 1 – power supply system; 2 – electric traction system; 3 – power supply of railcars

2. INTELLIGENT CONTROL OF VOLTAGE MODE IN TRACTION NETWORK

Improving energy efficiency mode in traction power supply systems is complicated by several reasons such as using two different systems of electrification (3 kV DC and 25 kV AC); distribution of the servicing objects in railway infrastructure, which does not match with the division of administrative units; purchase of electricity from the wholesale market; and standardized requirements for voltage mode.

In DC traction supply systems, problem of effective supply mode lies in limiting the carrying capacity and unnecessary power losses in power network. In AC traction system, voltage mode deviations can cause transit power flows that create additional load on power supply devices and lead to excessive consumption of electricity.

From known research and development, the most noteworthy is the controlled traction system with electrical power redistribution. The significant component of such system is the modern devices with contactless automatic voltage regulation. Many authors [1-4] consider these reinforcement points without the knowledge of managing each of them in real time in a system of intelligent power supply. Therefore, improving energy efficiency modes in electrified railways is complicated by immediate use of smart grid technologies.

The theoretical studies to implement above-listed technologies have been completed, which determined the dependence of current on the reinforcement point (I_{RP}) and found that changing trains' position will provide nominal voltage level on current collectors of each train.

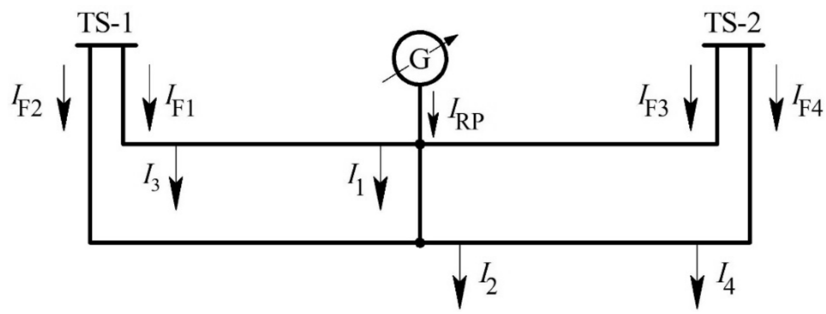


Fig. 3. The circuit of the additional power injection with the regulated reinforcement point

To solve this problem, the approaches of space-time representation for electrical quantities in the calculation of the traction power supply in the formalization of optimal control were developed.

The problems with optimal control lie in the fact that it is necessary for the adopted mathematical model

$$\Delta W(\vec{I}) = \frac{1}{L \cdot T} \int_0^T \int_0^L \left[\sum_{i=1}^{k} \Delta U_{Ki}(\vec{I}, t, x) \times \sum_{i=1}^{k} I_{Ki}(\vec{I}, t, x) \right] dx dt \, , \tag{1}$$

to identify the current of reinforcement point to minimize the objective function $\Delta W(\vec{I}) \to \min$ with restrictions for each voltage on electric rolling stock $U_{\min} \le U_e \le U_{\max}$ and for each current of the reinforcement point $I_{RP} \le I_{\max}$.

Below in the example for two-side power scheme, the optimization calculations are shown with the stabilization of voltage on electric rolling stock and with the power restriction of the reinforcement point (Fig. 4-5).

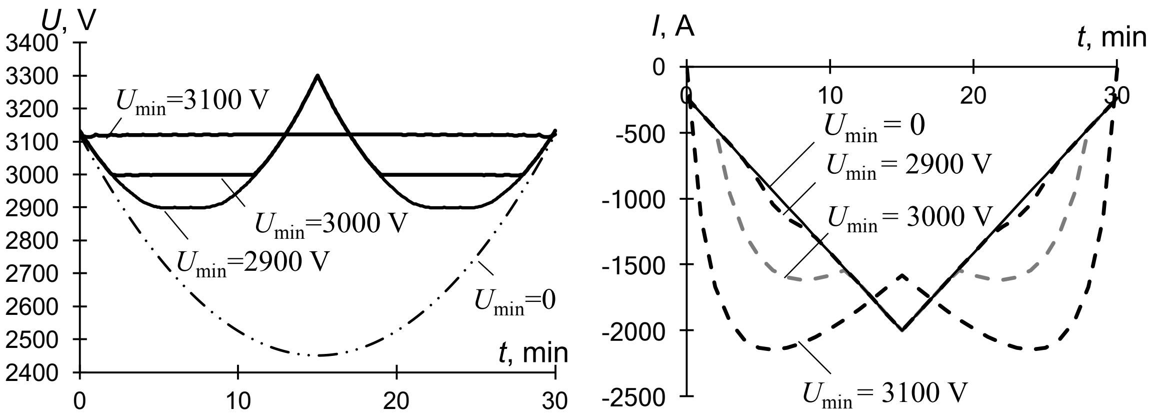


Fig. 4. Voltages on current collector of electric rolling stock (left) and currents of reinforcement **point** (right) in voltage stabilization mode for vary restriction of minimum voltage value

Comparing the results shows that the smallest power losses can be achieved in the no-restrictions mode of additional power. In the current-limiting mode reduction of the total value of capital investments in the traction network is taken into account, so that the power of reinforcement point does not exceed 2-3 MW. Thus, the minimum effect in reducing power losses in the traction power system is 40%, and it was observed for the 1.5 MW of additional power.

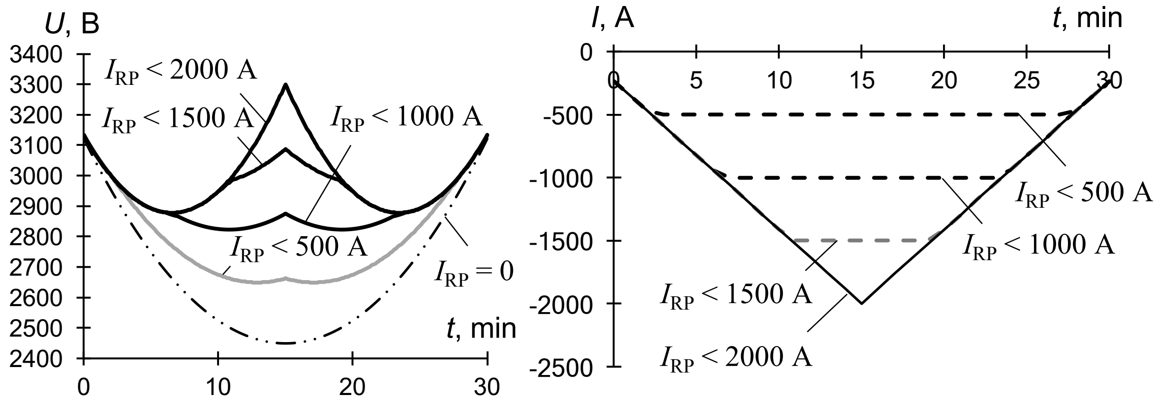


Fig. 5. Voltages on current collector (left) of the electric rolling stock and currents of reinforcement point (right) in current limiting mode for vary restriction of maximum reinforcement current

In addition, research for the district with three zones and three reinforcement points was conducted. This design scheme also takes into account the mutual influence of one intersubstation zone on another. It should be noted that the total calculation time for complex schemes that involve a few zones increases. While exploring variant calculations results that depending on the restriction of the objective function was obtained. The saving on energy losses in that case ranged from 40 to 60%. Thus, the ability to control by the reinforcement points significantly expands the functionality of the management modes in the electric traction system.

For practical implementation of the developed system, the voltage distribution along the distance should be measured. This can be implemented using DC voltage measuring devices and data transmitting via wireless interface. Fig. 6 shows a voltage monitoring system with principles of synchronous measurements.

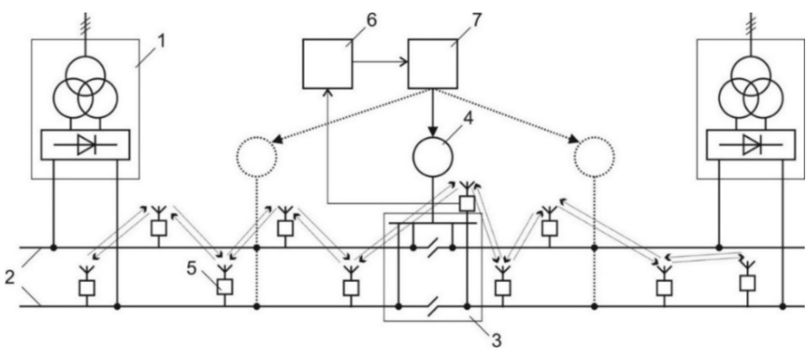


Fig. 6. Voltage monitoring system in a contact network

For voltage measurement, a resistive divider was applied. To the output of the divider, the microcontroller Atmega128RFA1 was connected. Microcontroller has built-in multi-channel analog-to-digital converter and high-frequency radio transmitter. To increase the accuracy of the measurement device, four channels of voltage reference and a cascade of operational amplifiers were used. Each of the operational amplifiers is incorporated under the scheme of differential reinforcement of primary measuring signal.

3. NEURO-FUZZY CONTROL OF THE REGENERATIVE BRAKING MODES

The mode of traction power consumption and energy recuperation $p(t)$ systems in electric transport is a stationary quasistability random process. It depends on the required speed, the profile of the district, the vehicle mass, the voltage on the current collectors, etc. The amplitude and frequency of oscillation of the process $p(t)$ affect the level of energy losses in elements of electric traction.

Fig. 7 shows the statistical and theoretical probability distribution of capacity of traction consumption and energy recovery in cargo movement. In traction mode, this dependence has two pronounced maximum in the region of small and medium loads and is typical for all kinds of electric transport. This indicates the installed traction power incompletely used in the field of low values that is not efficiency.

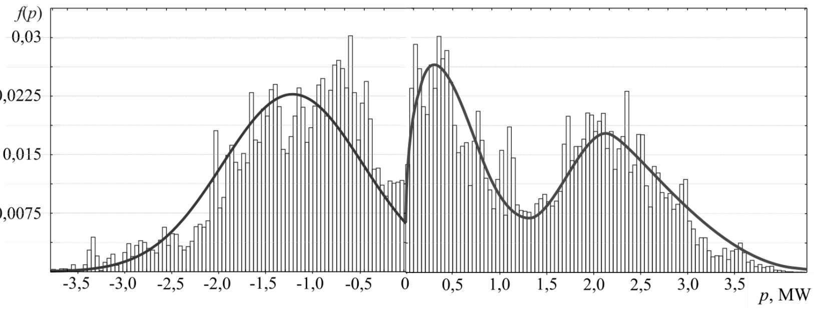


Fig. 7. The probability function of the traction power consumption

The correlation function of the process $p(t)$ of all kinds of electric vehicle (Fig. 8) has a continuous oscillatory nature. This indicates the presence of a hidden periodicity in a random process $p(t)$.

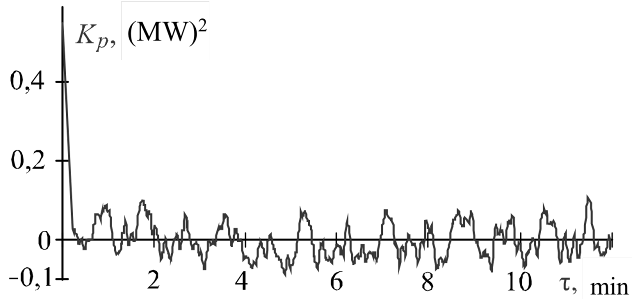


Fig. 8. The correlation function of the traction electricity consumption

The frequency and amplitude of periodic oscillations of the process $p(t)$ can be determined by decomposition of the undamped part of the correlation function $K_p(\tau)$ in Fourier series on the interval $\tau \in (\tau_K, T/5)$ (where τ_K is the correlation time and T is the duration of power consumption). This allows filtering out periodic fluctuations from the random process $p(t)$. This information is important for choosing energy storage in traction systems power supply (or rolling stock) and configuration of management system for energy exchange.

The main criterion for the efficient traction energy consumption (reduction of energy losses) is reducing uneven energy consumption

$$\left| p(t) - P_{\text{ave}} \right|_{\max} \to \min . \tag{2}$$

It also minimizes the peak load systems of traction and external electric supply.

Reduction of energy losses in elements of the electric traction system can be achieved by reducing excess capacity of the traction means. This requires the formation of additional natural traction in an unregulated region of power electric locomotives. These characteristics are obtained in the established mode of movement by a partial shutdown of groups of engines of vehicles. In the field of traction characteristics of electric locomotive, the result will be more natural characteristics of the $F'(v)$ and the blank region $F \times v$ partially filled (Fig. 9). Thus, left in the operation traction motors works in a nominal mode, which can ensure higher operational efficiency.

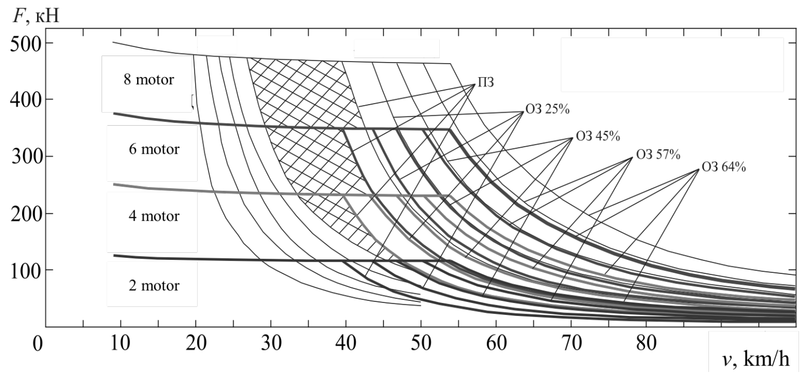


Fig. 9. Additional traction characteristics for 8-axle electric locomotive

However, owing to specifics of traction power consumption modes, the average value of regenerated energy, for example in systems of the main transport, currently does not exceed 2...3% [7]. It is mainly related to a time spread of processes of energy consumption and energy generation by the vehicles, which are on a section in the traction and regenerative modes that is especially noticeable in case of small traffic.

The problem of consumption of excess regenerative energy can be solved in several directions [8], including:

1. transmission of energy from a traction line to external power supply system;
2. optimization of train schedules;
3. using energy storage devices (SD);
4. expansion of a regenerative zone by regulation (decreasing) of voltage on buses of the traction substations (TS).

Thus, for realization of effective distribution of regeneration energy in systems of electric transport (as well as in the perspective power supply system equipped with energy storage devices, reversible TS with smooth regulation of output voltage), it is necessary to solve a number of problems with high degree of uncertainty demanding the accounting of a set of random factors such as the modes of power lines and traction loadings. These factors have to be considered while dispatching energy storage devices modes, inverters, and voltage regulators on TS buses allowing to provide rational conditions for energy regeneration. In this article, for rational distribution of regenerative energy, the problem of dispatching of the modes of energy store devices, inverters, and regulators of output voltage on TS was solved on the basis of fuzzy-logic.

For providing rational conditions for regeneration on electric transport in traction power supply system equipped with stationary operated energy store device (SD) and reversible TS with smooth regulation of the output voltage (Fig. 10), it is necessary to solve a number of problems with high degree of uncertainty. It involves taking into account many random factors such as the modes of power lines and traction loadings, which directly influence the optimum algorithms of dispatching of SD, inverters, and regulators of output voltage on TS.

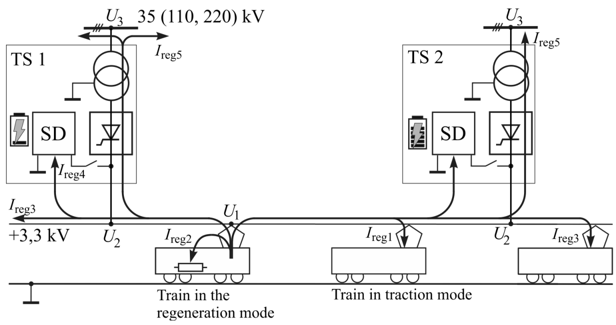


Fig. 10. Distribution of current of regeneration in traction and external power supply system

The scheme of regeneration current decomposition on electric transport I_{reg} is given in Fig. 3, where excess current is shown as a part of I_{reg}, which cannot be directly consumed on traction by passing (opposite) trains that are in a recovery zone, i.e.

$$I_{\text{reg}}^{\text{ex}} = I_{\text{reg}} - I_{\text{reg}1} = \sum_{k=2}^{5} I_{\text{reg}\,k}\,, \tag{3}$$

where $I_{\text{reg}1}$ is the part of current of regeneration consumed on traction by passing (opposite) trains; $I_{\text{reg}2}$ is the part of current of regeneration utilized in brake rheostats; $I_{\text{reg}3}$ is the part of current of regeneration that can be transmitted to adjacent zones to remote trains by regulation of voltage on transit TS buses; $I_{\text{reg}4}$ is the part of current of regeneration that is consumed by SD; $I_{\text{reg}5}$ is the part of current of regeneration transmitted to the external power supply system (via TS inverters).

For reduction of regenerative energy losses ΔP_{reg} in elements of traction and external power supply system, it is necessary to provide the minimum possible distance to the potential consumers (the trains, SD, external power system) taking their efficiency into account. The problem of rational distribution of excess regenerative energy of trains can be defined as finding out the ratio between values of current' components (3) in real time that minimize the criterion function,

$$\begin{pmatrix} I_{\text{reg}2}(t) \to \min, \\ \Delta P_{\text{reg}}\left(I_{\text{reg}3}(t),\ I_{\text{reg}4}(t),\ I_{\text{reg}5}(t)\right) \to \min \end{pmatrix}, \tag{4}$$

taking into account the restraint on vehicle pantograph voltage in the mode of regeneration [9] $U_1\left(I_{\text{reg}3}(t),\ I_{\text{reg}4}(t),\ I_{\text{reg}5}(t)\right) \le U_{1\max}$.

The requirements of modeling accuracy demand to take into account many factors defining rational distribution of regenerative energy of train, development of difficult mathematical models and measurement methods, which demands big expenses. The expert assessment can serve as a basis for decision-making process [10].

The priority of transmitting excess regenerative energy to SD, external power supply system, or to trains on remote section (respectively, currents $I_{\text{reg}3}$, $I_{\text{reg}4}$ or $I_{\text{reg}5}$) is defined depending on the location of the regenerating train on a section in relation to potential energy receivers and their state. Fuzzy regulation of operating modes of SD, inverters, and regulators of output voltage on TS has to take into account the admissible values (2) and voltage constraint in traction line according to [6, 7] in cases when $U_1 \to U_{1\max}$.

Input data of fuzzy model of regulation (according to Fig. 10) is the set of variables

$$X = \left\langle E(t),\ I_1(t),\ U_1(t),\ U_2(t),\ U_3(t) \right\rangle, \tag{5}$$

where $E(t)$ is the current charge degree SD; $I_1(t)$ is a traction consumption in a zone of regeneration; $U_1(t)$ is the voltage on a pantograph of the regenerating train; $U_2(t)$ is the voltage on the TS feeder; and $U_3(t)$ is the voltage of the external power supply system (on TS input).

The regulation parameters of the fuzzy regulator are variables

$$Y = \left\langle I_{\text{reg2}}(t), I_{\text{reg3}}(t), I_{\text{reg4}}(t), I_{\text{reg5}}(t) \right\rangle \tag{6}$$

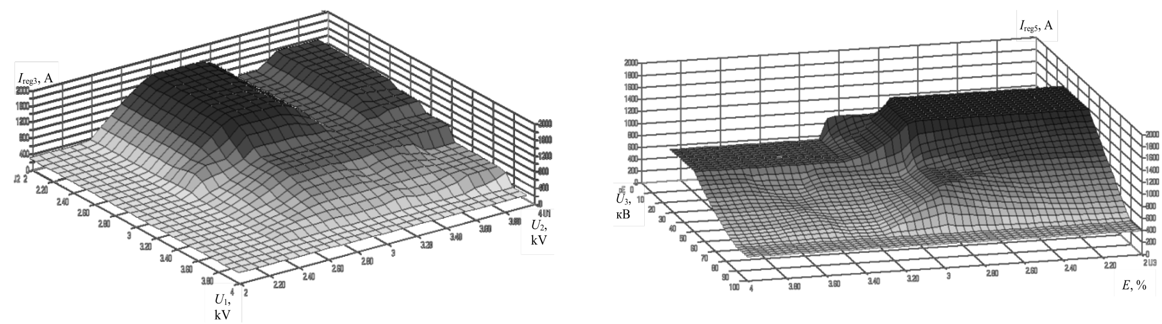
which represents the components of excess regenerative current that should be defined according to a condition (4).

Input and output variables have the ranges of definition, which are broken into three or four fuzzy ranges (terms): low level, medium low, medium, medium high, high level.

The model of rational distribution of excess regenerative energy is developed on the basis of five blocks of rules, structure of which is given in Fig. 5. Each block of rules uses Mamdani's method for an fuzzy conclusion [10]. Blocks are connected in the form of sequence for ensuring step-by-step decision-making, on set priorities. The output of the first block serves as an input for the following one that allows to determine the need of distribution of the rest of the energy according the directions with less priority. The inputs for the last block of output are all previous decisions that allow to define a conclusion only if the decision was not made yet.

If there is deficiency or lack of a traction power consumption on a section of regeneration ($U_1 \to U_{1\max}$, Fig. 10), it is necessary to make a number of commutation of the power equipment on TS for providing the required conditions for regeneration. Rules for making decisions about distribution of current $I_{\text{reg}}^{\text{exc}}$, elaborated by the expert, represent a sequence of steps on regulation of the power equipment on TS.

For the determination of accurate values of output variables in work, the method «Center of Area» of defuzzification was used. As a result of search of a set of options for various entrance conditions of model according to [10] are received the spaces of making decisions on distribution of regenerative energy on electric transport in all possible directions. The geometrical interpretations in certain conditions of these decision-making spaces are the surfaces presented on Fig. 11.



a) b)

Fig. 11. Decision-making area for equations $I_{\text{reg3}} = f\left(U_1,\ U_2\right)$ (*a*), $I_{\text{reg5}} = f\left(E,\ U_3\right)$ (*b*)

These equations show necessary algorithms of power equipment management on TS in real time depending on current state of the traction and external power supply systems (the traction loadings in a zone of regeneration and a charge of stores, voltage on TS).

The system of fuzzy management allows to make quick decisions about rational distribution of excess regenerative energy based on the incomplete data obtained by measuring systems. These decisions are the basis of intellectual regulation of the modes of traction power supply system during the regeneration of rolling stock.

4. ENERGY STORAGE SYSTEMS WITH ALTERNATING SOURCES

Traction power systems experience some of the most extreme variations in local power loads as compared to most of other large-scale electric power supply networks. These variations create challenges in the construction of reliable electric power delivery systems and in the performance of the rolling stock, which depends on power supplied by the system. Distributed traction power system with photovoltaic (PV) power sources (Fig. 12) offers a solution by smoothing out these power variations and increasing voltage as it drops. Although PV systems exhibit good power capability during steady-state operation, the dynamic response of PV during transient and instantaneous peak power demands is relatively slow. Therefore, the PV system can be hybridized with energy storage systems (ESS) to improve the performance of the PV system during transient and instantaneous peak power demands of an electric rolling stock and to recover energy through regenerative braking.

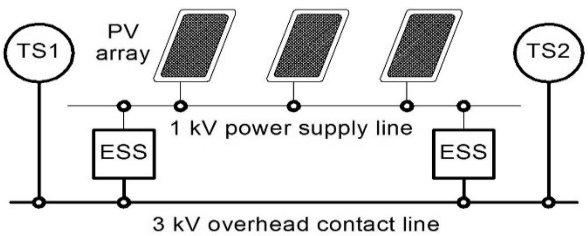


Fig. 12. Basic block diagram of distributed traction power system with PV sources and ESS

In energy recovery applications, energy storage is used to reduce energy consumption through the capture and release of regenerated energy from rolling stock. Typically, energy produced by the train during braking is consumed by other trains operating in the vicinity. In the circumstance where there are no other trains available (insufficient electrical load), the excess energy is typically dissipated as heat by an on-board, or wayside, resistor bank. Energy storage can be used to store energy that would otherwise have been consumed by the resistor bank, and then release it back into the traction power system when there is sufficient electrical load [1].

In general, electrical energy can temporarily be stored in a variety of ways including electrostatic, mechanical, and electrochemical forms [2]. Technologies for storing electrical energy are quickly evolving as research and developmental efforts are continually improving the efficiency and performance of each type of energy storage. Each technology has its characteristic strengths and benefits. In many cases, more than one technology might be suitable for a particular application.

Energy storage systems form part of an integrated traction power supply and distribution system consisting of many different types of devices, each with their characteristic behavior and operating logic. Energy storage interacts with other devices on the traction power network affecting the way they behave as well as how they interact with each other. Many of these devices operate in a highly non-linear manner, making operation of a large system challenging to predict without the use of models and simulation tools [1].

Because of the large variation in energy storage technologies and applications, a "black box" approach to model energy storage systems is presented. This generic model can be applied independent of energy storage technology or application. A generic energy storage system is represented by the system level block diagram as shown in Fig. 13. In the generic system, the flow of energy into and out of the energy storage medium is controlled by a power converter operating according to set of operating rules and parameters. This generic energy storage system can be described by a black box model.

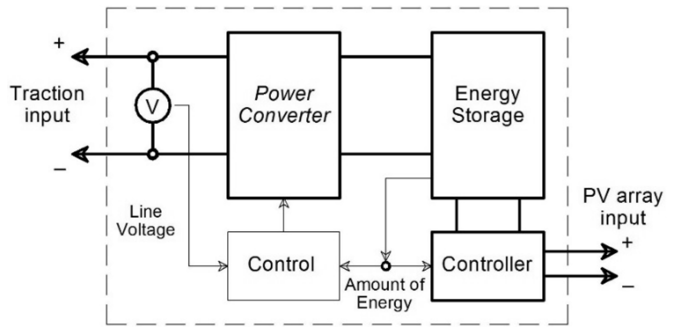


Fig. 13. Energy storage system level diagram

The black box model consists of the following three aspects: traction side current-voltage (I-V) characteristic; load side (storage medium) energy characteristic; and efficiencies and losses.

In addition to traction voltage, energy storage system control logic may use other external factors to achieve control objectives or to further optimize performance. The decision of when and what level to charge or discharge can be based on factors such as recent operating history; time-based schedule (time of day, train operating schedule, or other); traction voltage history; current state of charge; train position; train speed; adjacent substation loading; common applications of energy storage in traction power systems.

In voltage regulation applications, energy storage is used to reduce the level of fluctuation in the traction power system voltage. Trains are normally designed to operate within a given range of voltage. If voltage fluctuates outside this range, train operation can be adversely affected. Energy storage can be used to help keep voltage fluctuations within the operating limits of the train. Undervoltage conditions are caused by momentary overloading of the power system, usually from too many trains operating in close proximity or from simultaneous acceleration of several trains in a single area. Energy storage can be used to supplement the traction power substations to help mitigate excessive voltage sag. Overvoltage conditions are caused by regenerative braking of trains in locations where there is insufficient electrical load available to absorb the energy produced by the trains. Energy storage can help ensure there is sufficient electrical load available to mitigate such overvoltage conditions. This operation is similar to the energy-recovery application.

In peak shaving applications, energy storage is used to store and release energy with the intent to reduce short-term fluctuations in transit system power demand. The objective of peak shaving is to reduce peak power demands to minimize size of power delivery equipment and/or realize financial benefit through reduction of utility power demand charges.

Load shifting is similar to peak shaving applications but with the intent to shift bulk amounts of electrical energy from one time period to another. The objective of load shifting is to achieve financial benefit through reduction of utility energy and/or power demand charges by storing energy in periods of inexpensive electricity and then to release back into the transit system during periods of relatively expensive electricity.

To study the effect of the ESS implementation, some calculations were carried out for the section “D - P” of the Pridneprovska railway (Fig. 14).

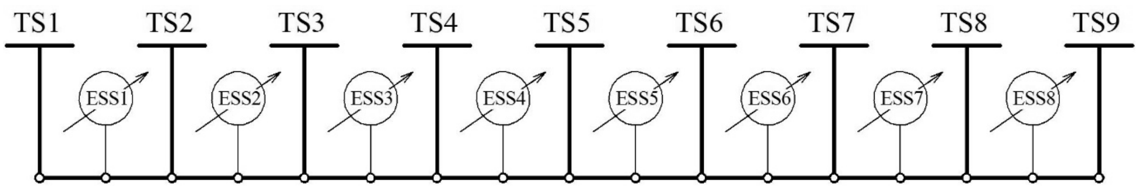


Fig. 14. Gage section of the Pridneprovska railway

This section has nine intersubstation zones. The real current load profile and power scheme parameters were used in the calculations. Each intersubstation zone has one ESS with a maximum output current of 1000 A. The optimal output current value has been determined for each ESS to reduce power losses in the traction network (Fig. 15).

The calculations showed that, using ESS, the power losses during the passage of one train decreased by almost 50%, from 2.6 MWh to 1.56 MWh. In addition, it showed that, applying ESS, the voltage in the traction network increased and the voltage fluctuations on the current collectors of the electric rolling stock decreased.

5. INTEROPERABILITY OF ELECTRIC VEHICLES

Most people today believe that electric vehicles have become widespread only a couple of years ago. However, this is not entirely true, as in 1910s only in the US there were up to 70,000 electric vehicles and these were mostly taxis. However, later, cars equipped with internal combustion engines became more and more widespread. These engines allowed to develop more power, their production was much more profitable, and the fuel was cheap. Hence, it lasted for almost a hundred years, until there were some problems with fuel and ecology, which makes today's drivers change their fuel cars to electric cars.

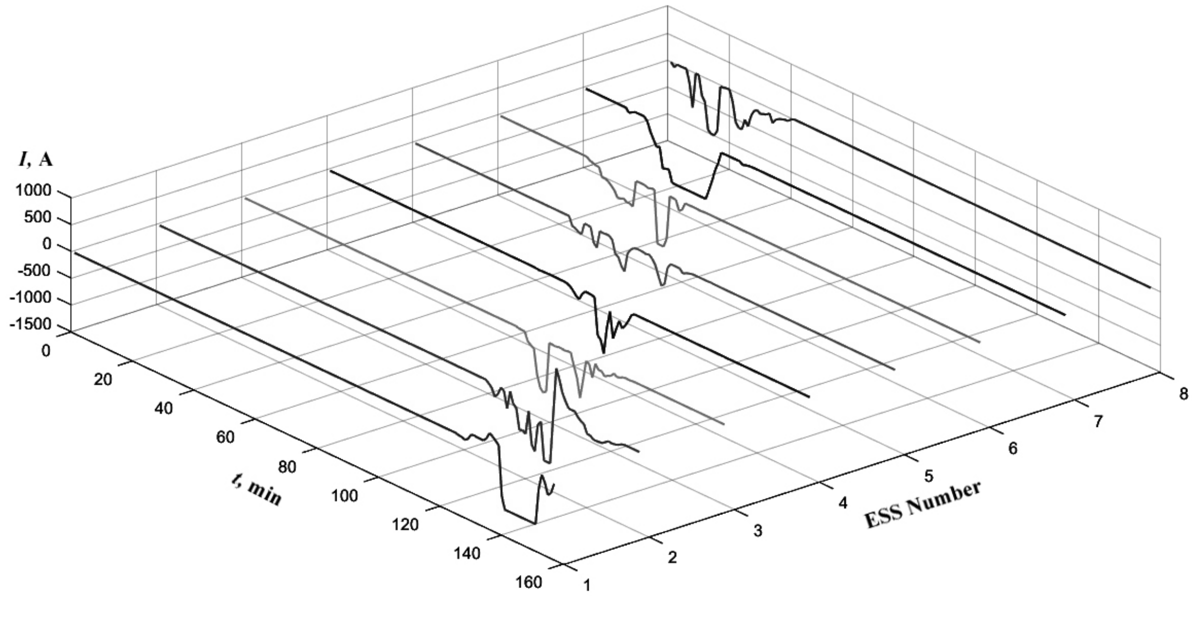


Fig. 15. Generated current of each ESS

The basic principles of operation of the electric motor, installed on a modern electric vehicle, is the principle of electromagnetic induction, because of the appearance of an electromotive force in a closed circuit when the magnetic flux changes. Electric motor converts electrical energy into mechanical, with 90-95% efficiency rate. In 2015, the total number of electric vehicles in the world has reached 1.26 million and in the future this figure will only grow. In addition, the widespread use of electric vehicles can help solve the problem of global warming. The IEA estimates that in order to avoid a temperature increase of more than 2°C due to global warming, it is necessary that the number of electric vehicles on roads in the world reach 150 million by 2030 and 1 billion by 2050. However, to charge such a huge number of electric vehicles, it is necessary to develop the infrastructure first. The growth in the number of electric vehicles requires increasing the number of charging stations as well. Nowadays, there are a lot of stationary charging stations in Ukraine.

However, the idea of electric vehicles charging during their transportation by rail has become more and more popular. This will allow owners to have a full charge on the car when they arrive at the destination and remain mobile despite a long trip. Most electric vehicles are delivered to Ukraine from the USA via sea ports. Transportation from the US to Ukraine takes a long time and occurs at different time of the year. However, at low temperatures, the performance of the batteries of one of the most common electric car Nissan Leaf is significantly reduced. Thus, if an ambient temperature is + 15... +30 C, the average mileage of an electric vehicle is 140 km, whereas when the temperature drops to -20 C, car mileage falls to less than 80 kilometers. In both cases the battery was full charged. During the transporting the sea temperature may vary widely, and an electric vehicle usually reaches the port substantially discharged. Further, for transporting them to other cities car carrier trucks or railway car carriers are used. In cases where the truck is able to deliver an electric vehicle directly to the destination, charging would be possible. However, a rail car delivers electric cars only to the final railway station. So, if an electric car was delivered by rail, in most cases it comes with a zero charge and cannot move on independently. This can be avoided by organizing the charging of electric vehicles en route directly in the rail car. This solution will help to attract new customers, because it would be very convenient to get an electric car with full charge on arrival in another city and immediately continue using.

The car-charging systems can be installed on the new rail cars as well as on the existing ones during modernization. A railway car for the electric vehicles transportation with the possibility of recharging, according to Fig. 16, should consist of the body 1, on which the cars 2 are placed. The body 1 is supported by the bogies 3, it also consists of shock-traction devices 4, power supply system 5 that are connected to chargers 6 and have charging wires 7. The cars 2 are located and fixed on both floors of the body 1 according to the loading scheme in a way that provide connecting the chargers 6 through the charging wires 7 to the accumulators 2. Power supply of the car chargers 6 may be organized either by train centralized power supply system structure connecting 5 or directly from the locomotive.

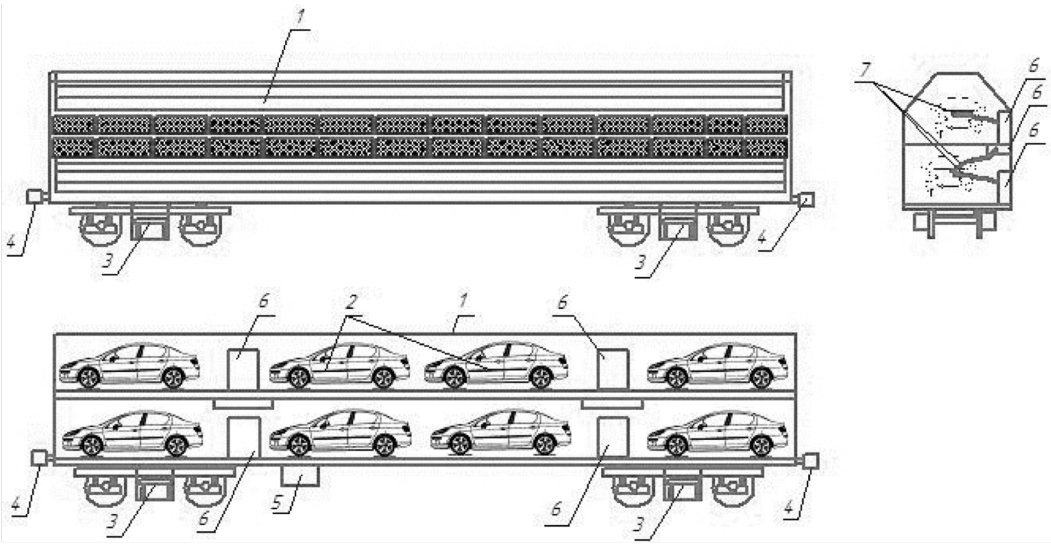


Fig. 16. Rail vehicle for the electric car charging during transportation

6. INTELLIGENT TECHNOLOGIES FOR PASSENGER RAILCARS CLIMATIZATION

Modern passenger car with a metal body, large area of windows, large number of passengers, with the need to cool large quantities of fresh air and equipped with lots of electrical equipment that generates heat during operation is rather difficult object for air conditioning and requires climatic units of significant capacity to provide the necessary comfort to passengers. With regard to consumption capacity, air-conditioning system of the car is second after high-voltage heating. But the heating system uses current directly from a contact network for the operation on the networks with direct current or with minimal transformation by lowering the voltage while operate on alternating current networks. That is relatively cheap electricity. However, the air-conditioning system needs more quality electric power that requires equipping cars with powerful high-voltage converters. In addition, this in turn leads to an increase in weight and cost of the car.

More complicated situation arises when generator power supply systems of the passenger car is used. In this case, air conditioner power supply source is locomotive traction. In the both cases listed above, the cost of electricity for the power supply the air conditioner in several times exceeds the cost of energy in a contact network. Therefore, reducing the power consumption of the air-conditioning system not only saves expensive electricity, but also significantly reduces the cost of the car. Achieving reduction in the energy consumption is possible using equipment that is more economical and using the best modes of its operation. For example, an air conditioner with inverter compressor that operates for longer period and has partial load on the compressor consumes significantly less energy than by a similar with its capacity compressor that operates at maximum capacity for the same period, but occasionally turned on or off.

Usually, regulation of air conditioners operation in railcars is made by measuring the inner temperature. Such control system in modern conditions is outdated because it does not take into account many factors that directly affect passengers comfort, such as humidity, carbon dioxide concentration.

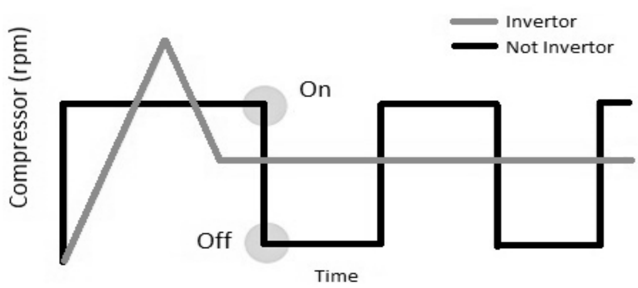


Fig. 17. Operation of invertor and not invertor compressors

The working of the air-conditioning system is also affected by many factors such as external air characteristics, the thermal inertia of the car interior, state and charge level of batteries, the ratio between the recirculation and fresh air, fullness the car with passengers, train schedule, etc. Most of these parameters are not taken into account in the management of the existing air-conditioning systems of the railcars. Modern air-conditioning system control schemes use the principles of fuzzy logic to process large number of input parameters and accordingly choose the best mode of air-conditioning system that provides a desired level of comfort, with less power consumption. Testing experimental passenger car with the air conditioning system built on these principles confirmed the possibility of reducing the power consumption of the air-conditioning system of the car by 20-25%.

7. CONCLUSION

1. The intelligent system has been developed to provide a given level of voltage on the current collectors of vehicles, which allows reducing the level of energy losses in traction networks of electrified transport by up to 40-60%. The theory and principles of functioning of the reinforcement points was proposed that allow provide optimal control laws for renewable energy sources when they are integrated into traction power supply systems.
2. The control system for energy storage devices, inverters and regulators of the output voltage of traction substations based on neuro-fuzzy logic has been developed. It provides the necessary conditions for the energy recovery in electric transport and allows minimizing losses of recuperative energy in traction and external power supply systems with incomplete information of their modes.

3. The principles of interoperability of railway passenger transportations and electric vehicles are proposed, which allow using electric vehicles on interregional scale. Modes of their intellectual charge during transportation allow optimizing traction power consumption of trains.
   The energy-optimal technology for air-conditioning system of passenger train is proposed. It is based on intelligent control laws for the power supply of climate control systems. Tests of experimental passenger car with the air-conditioning system built on these principles confirmed the possibility of reducing the power consumption of the air-conditioning system of the car by 20-25% with providing the same level of comfort.
4. The use of the developed approaches in the complex is effective in the conditions of incomplete information received by measurement systems, and on the basis of additional studies it can minimize the installed capacity of the necessary energy-saving equipment and reduce capital costs for energy-saving technologies.

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