IMPROVING THE QUALITY OF VOLTAGE IN THE SYSTEM OF TRACTION POWER SUPPLY OF DIRECT CURRENT

Viktor G. Sychenko[1], Dmitry O. Bosiy[2], Eugene M. Kosarev[3]

[1,2,3]Dnepropetrovsk National University of Railway Transport named after Academician V. Lazarian, Dnepropetrovsk, Ukraine

[1]e-mail: elpostz@i.ua

Abstract: <u>Purpose of the work</u> is improved approaches to ensure the required quality parameters of voltage in the traction network based on modern technologies and equipment in the application of power distribution system. <u>Actuality.</u> The introduction of high-speed traffic, increase weight standards Train necessitates increasing the carrying capacity of railways. Often the carrying capacity of existing sections electrified at 3.0 kV DC power supply unit limits. Such limitations include voltage decrease on the electric current collector below the allowable value for the normal operation of 2700 (2900 for high-speed V) and heating the contact wires, thereby losing their mechanical strength. Existing power supply system of RS, which have considerable installed traction substations, can not provide the required level of power density traction network for high-speed movement within 1.5 - 2 MW / km and, respectively, the required voltage quality. At the same time, the daily loading of a powerful traction substations in providing intensive schedule of trains does not exceed 20-25%, while the energy loss in traction network peak load increases and reaches 10-15% of the energy consumed. Thus, the existing system of power traction networks is not sufficiently effective and economical, even with the application of existing methods to strengthen them. In our view, the main limiting factor for a given quality of voltage in the traction network is the use of centralized power. From this, the development of measures to improve the quality of voltage in the traction network in the implementation of high-speed traffic in a growing scarcity of energy resources is an urgent task. <u>Scientific novelty.</u> Using distributed power supply system with adjustable supply points combined into intelligent power supply, which enables adaptive change the characteristics of the transfer, conversion and consumption and optimize the mode of functioning of the traction power supply is suggested for improving the quality of voltage in the traction network in the implementation of high-speed and heavy traffic. <u>Practical significance.</u> Improving the quality of voltage in the traction network by using the proposed circuit design traction power supply will ensure the desired mode voltage and power characteristics of the traction network in the implementation of high-speed and heavy traffic while reducing electricity losses by 20-30%.

Key words: traction power supply system, direct current, voltage quality, traction network force, operation modes

1. Introduction

The system of power supply of electrified railway section is a collection of geographically dispersed and operating in parallel electric power points. There are traction substations, sectioning posts, points of parallel connection and devices of contact lines and power lines between them, united by common goals and intended for processing and transmission of necessary quality to rolling stock (RS). General requirements for the infrastructure of traction power supply systems (TPSS) of electrified routes are providing reliable current collection quality and the necessary electrical energy to power the RS. Devices of traction power supply should not limit the maximum speed below the accepted level of operational conditions and must ensure the reliable and uninterrupted power supply, resistance to unpredictable influences and high energy efficiency. At the present stage, moreover, they must be electromagnetically compatible with the environment at all levels of the transfer, conversion and consumption of electrical energy.

The features of the electricity transmission network of traction is to change the position of RS and changing modes of their work, restrictions imposed by trains at each other, depending on their relative position, and restrictions associated, in general, with the technology of transportation process.

One of the main indicators of the quality of the transmitted electrical energy has a voltage level on the current collectors of electric locomotives, which, however, depends not only on changes in the traction load, but also by changes in the load of regional customers and supply the power system. The nature of the factors that affect the voltage is linear and non-stationary. At the same time voltage level as an indicator of quality, it should be considered as a parameter that optimizes the transmission and consumption of electricity for the RS (Sychenko, 2001; Szeląg, 2013), which requires the development of new approaches to quality management stresses. To improve the quality of voltage in the traction network is necessary to create a control system operation modes of traction network, allowing, subject to specified sizes movements (providing the necessary capacity and carrying capacity) and minimize unit costs for traction, to take into account fluctuations in the voltage TPSS load changes are not traction consumers , changes in the number and weight of trains, both located in the area, changes in food patterns electrified section, that is, intellectual, self-adjusting power supply system built on modern element base.

This approach in general, meets the modern trends of energy development that are embodied in the concept of Smart Grid, which is now the main technological and methodological basis for improving energy efficiency. Some approaches to the implementation of this concept in the TPSS of electrified railways are considered in Kosjakov (2013), Stasiuk et al. (2013). They are the authors describe the general concept of the use of smart grids in the traction power supply rail transport model and the generalized structure of intellectual electric railway network. At the same time process is limited to consideration of the energy level of traction substations. It should be noted that the basic process of electric power consumption occurs in the traction network in performing mechanical work RS materials handling.

2. Actuality and purpose of the work

The introduction of high-speed traffic, increase weight standards train necessitates increasing the carrying capacity of railways. Often the carrying capacity of existing sections electrified at 3.0 kV DC power supply unit limits. Such limitations include voltage decrease on the electric current collector below the allowable value for the normal operation of 2700 V (2900 V for high-speed) and heating the contact wires, thereby losing their mechanical strength.

Existing power supply system of RS, which have considerable installed traction substations, may not provide the required level of power density traction network for high-speed movement within 1.5 - 2 MW / km and, respectively, the required voltage quality. At the same time, the daily loading of a powerful traction substations in providing intensive schedule of trains does not exceed 20-25%, while the energy loss in traction network peak load increases and reaches 10-15% of the energy consumed. Thus, the existing system of power traction networks is not sufficiently effective and economical, even with the application of existing methods to strengthen them. In our view, the main limiting factor for a given quality of voltage in the traction network is the use of centralized power. From this, the development of measures to improve the quality of voltage in the traction network in the implementation of high-speed traffic in a growing scarcity of energy resources is an urgent task.

Purpose of the work is improved approaches to ensure the required quality parameters of voltage in the traction network based on modern technologies and equipment in the application of power distribution system.

3. Analysis of the problem

Reduce the voltage on the current collector reduces the speed of trains, while maintaining power consumption is an increase in electric power and electric power losses in traction network (Szeląg, 2013; Rojek, 2012).

In addition, the difference of output voltages of traction substations caused by different values of the internal resistance and voltage deviation, if the traction load on the zone between traction substations leads to the redistribution of current between substations ("equalization currents") and, accordingly, additional losses of electric energy. For example, the difference of the instantaneous values of the rectified voltage adjacent traction substations in the value of 300-500 V causes an "equalization currents" that reach 20-40% of the traction load.

As a result, they lost the benefits of bilateral supply, there is a redistribution of power that is given to traction substations, and a further increase in the current contact network from the substation with a

large voltage source. Calculations and studies on different railways show that loss of electrical energy in DC traction network of "equalization currents" make up 1-6,4% of the energy consumption for traction (Arzhannikov, 2012).

Experience in development and research of scientific and educational institutions, a number of railways, foreign organizations and firms show that the removal of restrictions on the voltage and current stresses in the contact system TPSS 3.0 kV may be solved at the lowest cost with the help of systems and devices increasing, and automatic control rectified voltage (Arzhannikov, 2012).

The simplest solution to increase the voltage in the contact line is to increase the open-circuit voltage rectifier converters by switching the number of windings of power transformers and traction.

However, increasing the open circuit voltage transducers limits the use of the electric regenerative braking and, as a consequence, reduces traffic safety. Other technical solutions commonly used in the traction substations and allow without increasing the open circuit voltage of the converter to increase the voltage rating of the unit, was the replacement of zero and six-pulse bridge rectification circuits in twelve pulse scheme. But in this case, the increase of the nominal voltage of the converter unit at 100-120 V was not enough to ensure a significant increase in capacity and carrying capacity of electrified sections of DC.

Therefore, to ensure the required quality of the voltage applied to the traction network and other ways to gain traction power supply. There are using items connected in parallel, increase section of wires contact network, the construction of additional traction substations, install supply points, structure on the zones between traction substations of one modular catering with the different types of longitudinal power supply lines, the voltage increase in the contact system 12, 18, 24 kV, even proposed switch to AC system of different modifications. The application of the above ways of improving the system of power supply DC 3,0 kV predetermines new technological process of power transmission. There is controlling the distribution of power on area between traction substations. In Ukraine, to strengthen the system traction power supply is applied only setting in parallel connection and an increase in cross-section the contact wires and regulation control capabilities of voltage modes are

limited to the use of voltage mode devices in traction substations. In real operating conditions of the system traction power supply it will cause some problems, primarily from sub-optimal functioning of the traction network.

4. The main material

To ensure the required quality of the voltage is needed transition to the new traction network circuit design. There is the power distribution system with additional supply points. The advantage of this system is also only need of additional feeding of contact line which doesn't need additional aggregate power, and the use of alternative energy is considerably reduced consumption of electrical energy (Gonczarow et al., 2014).

Several variants the construction of distributed power supply systems are studied for today including those by using of high frequency AC to half-wave setting for feeding points for amplification of traction network.

Proposed earlier works, among other things, have a general lack of proper. Authors consider amplifying device as separate elements of the power supply system without the ability to manage each of them in real time in a single system of intellectual power. Studies are done at the department of Power supply of Dnepropetrovsk National University of Railway Transport named after Academician V. Lazarian to develop methodological approaches for the construction and calculation of the intellectual system of the traction power supply distributed type with the definition of control laws for separate supply points at work as part of a power supply system that provides the desired mode voltage in the traction network while minimizing losses (Fig. 1).

The synthesis of such a system requires the solution of several problems:

- Building, in fact, most of the decentralized (distributed) power supply, a namely:
  - select the number of supply points (SP) and their places of installation;
  - the choice of power SP, their components and circuitry;
  - development of methodology for the calculation of both the decentralized power supply and its elements.
- Construction of external power supply circuit of the distributed system of the traction power supply.
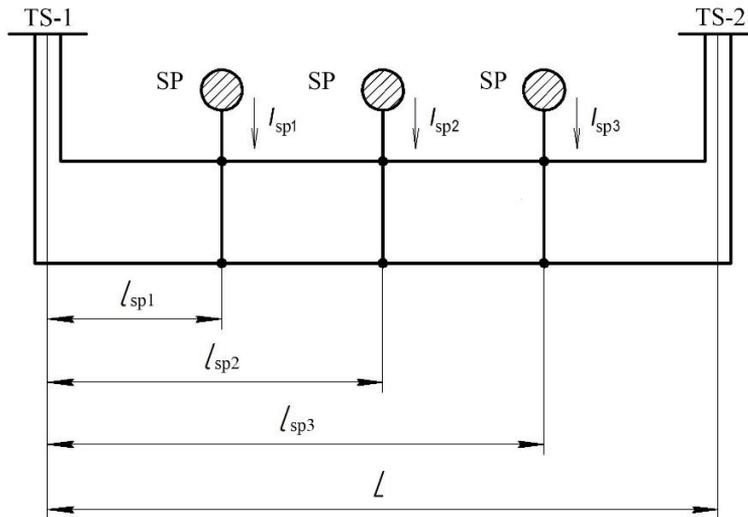
Improving the quality of voltage in the system of traction power supply of direct current

Fig. 1. Block diagram of the traction power supply network with three supply points: TS-1, TS-2 – traction substations; Isp1, Isp2, Isp3 – currents of three supply points; L – length between traction substations

To solve the tasks of today offers several kinds of energy channels of external power. There are DC and AC high voltage and frequency, and others. Growing deficiency of energy resources puts the task to investigate the possibility of using the independent (alternative) sources of electrical energy to supply the SP. Issues to be addressed include:

- the type of renewable source of electrical energy;
- compensation of weather conditions on the level of generating energy;
- circuit design, layout and element base;
- a feasibility study of the application with reference to the reliability of supply the load with the necessary traction power characteristics.

Option structure of the railway power supply DC, uses solar electric power generators installed on the strip of land alienation of the railway is shown in Fig. 2 (Goncharov et al., 2015). Solar panels are installed in alienation strip and are connected in series-parallel PV modules, each of which is connected to harmonize transducer (HT) which is used to maximize the energy received from the photo module, as well as for electrical isolation from the other parts of the system.

Output CC is performed on direct current at a low voltage of about 50 V, permissible under the terms of electrical safety. Parallel contact network (CN) at its poles, or separately in the right of way laid longitudinal line (LL) DC, which connects the individual CC modules in a single daisy chain.

In order to ensure the necessary quality of electric voltage on the current collectors must be considered optimization problem the number of installed SP, their power and the magnitude of the required level of voltage is generated. It should be noted that the number and capacity of PP must be determined by two criteria. There are compensation for loss of voltage and to provide the necessary power density standard traction network.

Under the terms of the organization of trains in normal traffic, depending on the actual length of the block areas, the distance between trains can be 3.5-5 km, therefore, to a first approximation, the example discussed above (Fig. 1) can be taken as a basis for further calculations.

Regarding the level of added SP voltage ΔU can specify the following. Accepted practice manual use booster device ΔU = 500 V. Selecting this level ΔU due to the need to provide acceptable voltage at the pantograph in the absence of the control system and increasing the open circuit voltage of traction substation (TS). When using a decentralized power supply level ΔU can be adjusted, primarily due to the redistribution of the installed capacity of TS for the power zone length.
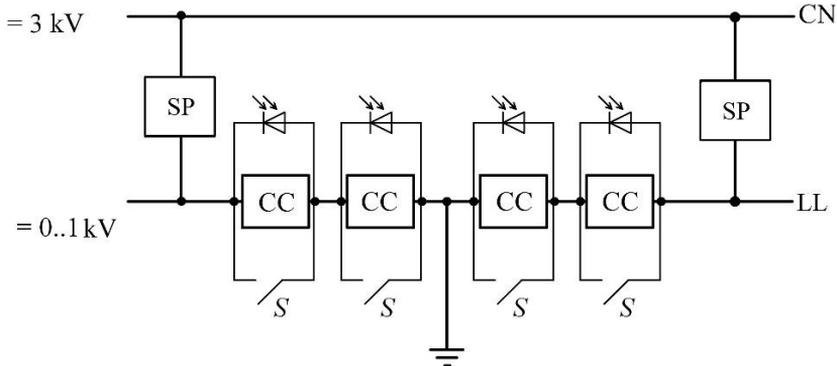
Fig. 2. Structure of the connection of distributed solar electricity generators: CN - contact network; LL - longitudinal line DC; CC - to coordinate converters; SP - traction network supply points; S - shunt keys

Each SP can be controlled on the basis of the control law, which is generated during real-time. The parameters of the law determined by the values of the current and the position of the train, which is located in the area between substations, the required level of power generation and compensation for loss of voltage to optimize mode voltage in the traction network. The objective function of optimization so will be the following:

$$\Delta P = f(I_{sp1}, I_{sp2}, I_{sp3}, U_{sp1}, U_{sp2}, U_{sp3}, x) \qquad (1)$$

Depending on the location coordinates of the train, the currents generating points amplification should have such a value that under optimal voltage level provides a minimum of the objective function ΔP, i.e. kept optimization criteria. To account for this more complicated calculation procedure is not changed; the number of points of amplification will be considered the number of terms in the formula (1) with a specific output data regarding their location and capacity.

Estimated calculations were made for the following output: the length of 20 km; electric power of 10 MW; electric current at a nominal voltage of 3000 A; the resistivity of the traction network M120+2МФ100+A185+P65 is 0,051 Ohm / km; traction power supply circuit network complete parallel; Estimated travel time 12 minutes section electric locomotive; minimum allowable voltage level on susceptor 2900 B; zone between traction substation installed on uncontrolled SP. The calculations were

performed using the analytical functions of the resistance to voltage levels on the tires traction substations: 3300, 3500, 3600, 3800; The power SP for each calculation was 0.5 and 1.5 MW.

To account for the increase of the voltage at the pantograph of an electric locomotive from the action of the SP is further defined distribution of voltage rise along the zone between substations from each of them:

$$dU(x, l_{sp}, I_{sp}) = \begin{cases} \dfrac{1}{l_{sp}} \cdot I_{sp} \cdot f(l_{sp}) \cdot x; \ 0 \le x \le l_{sp} \\[2mm] \dfrac{I_{sp} \cdot f(l_{sp})}{L - l_{sp}} \cdot (L - x); \ l_{sp} \le x \le L \end{cases} \qquad (2)$$

where:

lsp   – location of SP;
Isp   – current of SP;
f(lsp) – analytic function of resistance, with respect to the above the SP, which physically defines a pattern change in resistance for a given power supply circuit.

The voltage at the pantograph of the train when two points amplification is determined by the following formula:

$$U_e(x) = U_{ts} - I(x) \times f(x) + \sum dU(x, l_{sp_i}, I_{sp_i}) \qquad (3)$$

For a comparative analysis for each of the variants of the basic calculation was conducted without the SP, that is, Isp = 0. The currents at the connection point of SP

are calculated based on voltage values. When power points amplification of 0.5 MW current of 142-171 A, with capacity of 1.5 MW - 426-514 A. Selected results of the calculations are presented in Fig. 3, 4.
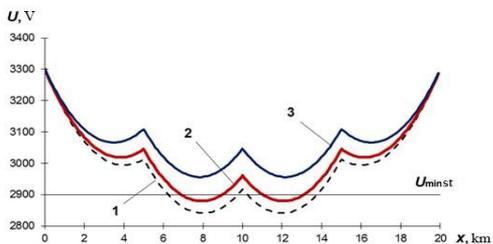

Fig. 3. The value of the voltage at pantograph at a voltage on the bus TS 3300 V:
1 – basic calculation;
2 – calculation at the 3 points amplification the capacity of 0.5 MW;
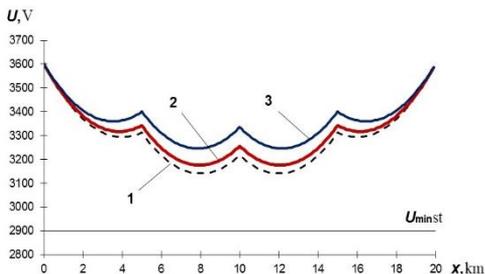3 – calculation at the 3 points amplification 1.5 MW

Fig. 4. The value of the voltage at pantograph at a voltage on the bus TS 3600 V:
1 – basic calculation;
2 – calculation at the 3 points amplification the capacity of 0.5 MW
3 – calculation at the 3 points amplification 1.5 MW

As the analysis, at a voltage 3.3 kV required quality of voltage in bus of TS is maintained at the power point amplification of about 1.5 MW. When increasing the output voltage of TS 3600 (Fig. 4), the required voltage quality in traction network can be achieved at a power of 0.5 MW, SP. It should be noted that today in devices that perform "stabilization" of the voltage as the governing parameter is used as the input current. It is known that the deviations of the average voltage across the susceptor electric range from 0 to 350 do not affect the consumption of electrical energy traction (Arzhannikov, 2012). And this, in turn, does not impose specific requirements for the automatic control system to support the quality of the voltage at the current collector with high precision. There are the basic requirement is the need to change the voltage in a given range.

The intelligent power supply system must also control the voltage levels within a predetermined range on the current collectors as they move on the area between the substations in any number of trains. At the department of "Power supply" DNURT developed a method for controlling voltage levels in the network directly to the contact on the current collectors on modern element base (Fig. 5).

Its essence lies in the fact that for a given quality of voltage in the traction network electrified section DC voltage measured on the adjacent traction substations and sectioning post in the middle of the area between the substations. This additional measure stress distribution along the length of the area between the substations using measurement devices voltage DC to wireless transmission of data through optimized within a specified distance of 1-3 km (Sychenko, 2015), then calculate the required power and regulate the value of its generation control system with Given the number of SP which are established on the area between the substations.

Electrified railway section between two adjacent traction substations 1 is equipped with devices to measure voltage wireless data transmission 5, SP 4 traction network, connected in the middle of the area between the substations to sectioning post 3, the control system 7. The control system 7 via the decoding unit 6 is supplied array voltages obtained by the accumulation of data that is transmitted network topology constructed by the cell voltage measuring devices with wireless data transmission 5, distributed on the area between the substations and in turn connected to the catenary 2 first and second track. The control system 7 is performed analysis of the resulting data set by searching the calculated point of contact network 2, which is required to obtain the set value voltage. Further, based on the array of voltage values calculated at the current distribution is determined on the area between the substations and the necessary generation capacity at the site of the SP traction network 4.
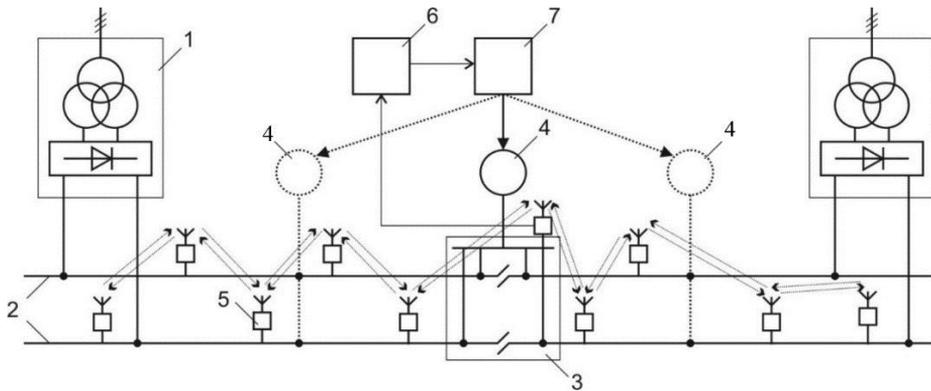
Fig. 5. The scheme of quality control voltage electrified railway section: 1 - traction substation; 2 - contact network; 3 - sectioning post; 4 - supply points; 5 - voltage measuring device with wireless data transmission; 6 - decoding unit data; 7 - control system

Based on the measured value of the voltage at the connection point SP generation current control is performed to achieve the calculated power. When changing the current generation of SP traction network voltage on the current collectors is not reduced below the rated value of 3.0 kV, as shown in the graph of voltage during operation of the proposed system (Fig. 6). It shows the time graphs superimposed voltage at the pantograph of each of the four locomotives (solid, dotted, dashed and dotted lines), which move on the area between the substations in the even and odd directions.

In the absence of regulation, the voltage on the current collectors of each of the four locomotives in different moments of time decreases below the nominal value, as shown in the graph of voltage change without stabilization (Fig. 7) which comprise superposed time graphs of voltage on the current collectors of each of the four locomotives (solid, dashed, dash-dotted line).
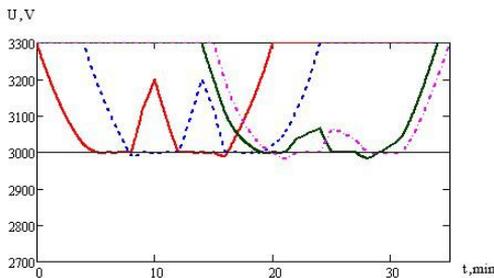

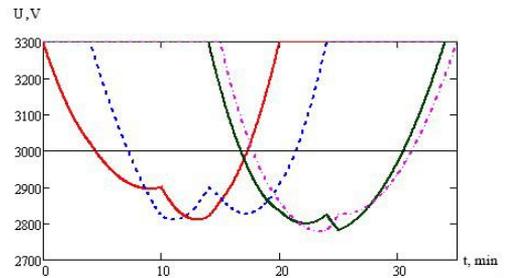Fig. 6. Graphs voltage at the intellectual TPSS

Fig. 7. Graphs voltage at the usual TPSS

Thus, regulation of the output power SP (there may be several) of traction network secures the quality of the voltage on the pantographs and on the area between the substations, according to the train situation, reduces calculations show that the loss of electricity in a contact network by 20-30%.

5. Conclusion

The increase in traffic volume and traffic speed and high-speed trains leads to the fact that the existing devices traction power supply limit bandwidth site electrified railway by reducing the voltage at the pantograph lower normalized values. Increasing the voltage quality in traction network currently used methods and means have been shown, it does not solve the existing problem fully, by increasing the power losses on the area between the substations and respective operating costs. New methodological approaches are offered for improving the quality of voltage in the traction network. They are based on

the circuitry of traction network, namely, the transition to a the power distribution system to supply points, working in a unified system of intellectual control. In the traction network voltage on the pantographs is not reduced below the nominal value of 3.0 kV, and electricity losses in the traction network are reduced by 20-30%.

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