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15-ї Міжнародної науково-практичної конференції

«СУЧАСНІ ЕНЕРГЕТИЧНІ УСТАНОВКИ НА ТРАНСПОРТІ, ТЕХНОЛОГІЇ ТА ОБЛАДНАННЯ ДЛЯ ЇХ ОБСЛУГОВУВАННЯ»

(СЕУТТОО-2024)

Херсон – 2024

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Сучасні енергетичні установки на транспорті і технології та обладнання для їх обслуговування. 15-а Міжнародна науково-практична конференція, 13-15 березня 2024 р. – Херсон: Херсонська державна морська академія.

У матеріалах 15-ї Міжнародної науково-практичної конференції «Сучасні енергетичні установки на транспорті і технології та обладнання для їх обслуговування» представлені тези, які присвячені проблемам експлуатації, виробництва та проектування енергетичних установок та устаткування на транспорті, а також підготовці спеціалістів у сфері транспортної енергетики й устаткування.

ADAPTIVE MULTI-PHASE CONTROL SYSTEM OF THE RECTIFIER-INVERTER CONVERTER OF ELECTRIC ROLLING STOCK

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Keywords: *control system, electric rolling stock, electromagnetic compatibility, power factor, rectifier-inverter converter, traction electric motor.*

Abstract

An analysis of the influence of the quality of electrical energy on the reliability and service life of railway devices and other objects was carried out. The shortcomings of the operation mode of thyristor rectifiers in static converters of single-phase alternating current electric locomotives have been determined. Simulation of different control modes of the rectifier-inverter converter of the electric locomotive was carried out. An adaptive multi-phase control system of the rectifier-inverter converter is presented using a diode arm connected in parallel with the rectified current circuit.

Introduction

The issues of increasing the reliability and efficiency of technical means of electric rolling stock have always been relevant and have received special attention in numerous scientific studies. A large number of works [1, 2] are dedicated to the study of electromagnetic compatibility of the "electric locomotive – contact network" system.

However, there remains the problem of ensuring electromagnetic compatibility, since during the operation of some signaling, centralization and blocking systems using rail circuits, both a traction current with a strength of hundreds of amperes and a weak current of the above systems simultaneously flow along the rails. Thus, higher voltage harmonics generated by the electric locomotive lead to the appearance of additional losses in the windings of auxiliary machines of the electric locomotive, which reduces their operational resource [3, 4].

The priority tasks were the development and implementation of more advanced technologies aimed at increasing the reliability of electrical equipment of traction rolling stock [5, 6]. In this strategy, the question of improving the quality of electric power in the power supply system takes first place, since the operational resource of the technical means of the entire railway industry directly depends on the quality of electric energy. In connection with the growing freight traffic and passenger traffic of AC mainline railways, the quality of electrical energy is being increasingly stricter.

Relevance of research

Distortion of the sinusoidal form of the voltage in the contact network affects both the operating characteristics of electric locomotives and the traction power supply system [7, 8]. Thus, higher voltage harmonics generated by an electric locomotive lead to the appearance of additional losses in the windings of auxiliary machines of electric locomotives, which reduces their operational resource.

The influence of non-sinusoidal voltage on induction and electronic devices for accounting for electricity consumed by an electric locomotive leads to an increase in the error of the measurement results of these devices [9, 10]. Harmonics disrupt the reliability of protection devices and worsen their operational characteristics. In this case, the most common are false alarms, which are most likely in the operation of protection systems based on resistance measurements.

The low quality of electricity leads to a reduction in the service life of the insulation of electric machines and devices, low reliability of the operation of signaling, centralization and blocking devices, automatic locomotive signaling, to failures in the operation of the control systems of electric locomotive converters, relay protection, automation, telemechanics, communication and computing equipment [11, 12].

Thanks to the use of thyristor rectifiers in static converters of single-phase alternating current electric locomotives, it is possible to control collector traction electric motors by smoothly adjusting the voltage on them [25, 26]. This is done by changing the opening moments of the corresponding arms of the rectifier-inverter converter of the electric locomotive within the period of the supply voltage. However, the operation of such electric locomotives, along with the advantages of the power circuits of thyristor converters, also revealed a number of their shortcomings in comparison with electric locomotives equipped with semiconductor heterogeneous diodes.

Losses of failure of technical means from non-fulfillment of electromagnetic compatibility requirements are quite significant due to the railway network. This determines the relevance and economic significance of this problem.

The main material of the study

According to the standard mode of operation of the control system on modern alternating current electric locomotives, switching in all rectifier inverter converters occurs simultaneously. At the moment of starting commutation, part of the windings of the traction transformer of each section of the electric locomotive starts to work as a short circuit. The simultaneous start of switching of all converters causes a sharp decrease in the voltage on the current receiver.

The power of the electric locomotive in the hourly and long-term modes is slightly lower than with the typical control method, and there is a slight decrease in the speed of the electric locomotive. In addition, the constancy of the angle shift by 89° does not give the full effect of reducing high-frequency voltage fluctuations of the catenary network due to changes in the inductance and capacity of the traction network, which can lead to periodic disruption of the performance of the electric locomotive. In an ideal case, the value of the delay of the pulses should be equal to the half-period of the self-oscillations of the voltage in the traction network. Due to the difference in the parameters of the traction network and the variable distance of the electric locomotive from the busbars of the traction substations, the frequency of free fluctuations of the voltage on the current receivers of the electric locomotive changes. In this connection, only partial damping of free voltage fluctuations occurs.

Thus, for the most effective reduction of distortions in the shape of the supply voltage curve, it is desirable to introduce an adjustable delay exactly on the half-period of free oscillation, taking into account the variable distributed parameters of the catenary network. In this regard, it is proposed to use simultaneous commutation with shunting of the rectified current circuit of the electric locomotive with a discharge diode arm with the development of an adaptive multi-phase corner control system. It is proposed to delay the control of the converter shoulders, which is equal to the half-period of the own oscillations of the voltage of the traction network. This will increase the power factor of the electric locomotive from 0.84 to 0.88.

Intrinsic voltage fluctuations of the traction network are determined through spectral analysis, which allows characterizing the frequency composition of the measured signal. The Fourier transform is a mathematical basis that relates a temporal signal to its representation in the frequency domain. The time-continuous Fourier transform of a signal identifies the frequencies and amplitudes of those complex sinusoids (exponentials) into which some arbitrary oscillations are decomposed.

Spectral analysis of the catenary voltage is supposed to be carried out taking into account DSP (digital signal processor) controllers, which provide fast Fourier transformation. The catenary voltage through the voltage sensor type LV 100 is supplied to the input of the voltage sensor matching unit with the DSP. The latter, according to the given algorithm, carries out a spectral analysis of the harmonic oscillations of the power supply network, selects the harmonic with the largest amplitude and calculates the change in the delay angle of the inclusion of the arms of the rectifier-inverter converter with pulses with phase *p*. According to the signals of the control unit of the rectifier-inverter converter, the control pulses are alternated and distributed with converters and their shoulders.

The structural diagram of the implementation of multi-phase control of the arms of the rectifier-inverter converter is shown in Fig. 1.

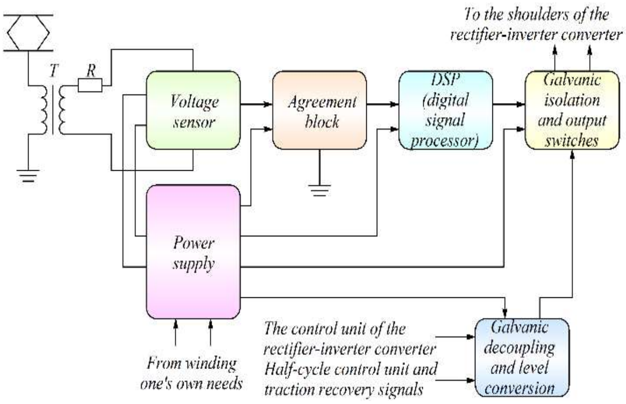

Figure 1. Structural diagram of the implementation of multi-phase control of the arms of the rectifier-inverter converter

The created adaptive multi-phase control system of the rectifier-inverter converter of the electric locomotive will allow, regardless of the location of the electric locomotive on the feeder zone (changes in the catenary network parameters), to maximally perform the function of significantly reducing the harmonics corresponding to the frequencies of these oscillations, and to reduce the distortion coefficient of the sinusoidality of the voltage curve, that is, the electric energy in contact network.

In order for the external characteristics of the rectifier-inverter converter in the sections of the electric locomotive to be the same, it is suggested to alternate the deviation of the angle for each adjustable section in different half-periods. Diagrams of the voltage on the traction electric motors and in the contact network with the proposed algorithms of the rectifier-inverter converter are shown in Fig. 2, 3.

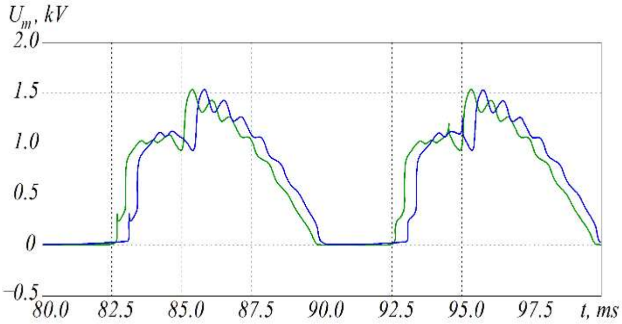

Figure 2. Diagram of voltage on traction electric motors of different sections with the proposed algorithms of operation of the rectifier-inverter converter

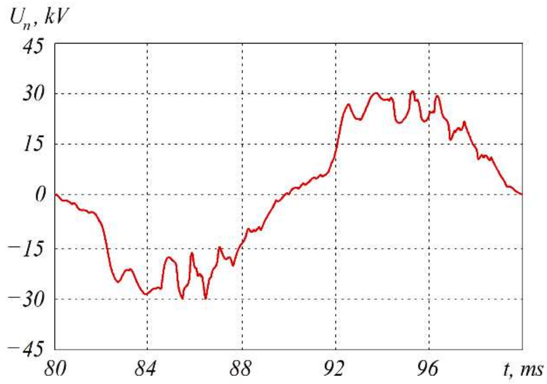

Figure 3. Diagram of the voltage in the contact network with the proposed algorithms of the rectifier-inverter converter

When using the presented control algorithms, can expect a significant reduction in voltage fluctuations and distortions in the catenary network.

For the following control algorithms, the external characteristics of the converter were calculated:

1. Typical voltage regulation algorithm.

2. Algorithm of the converting unit with multiphase control by sections.

3. Algorithm of the converting unit with the inclusion of a discharge diode in the rectified current circuit.

4. Algorithm with different phase control by sections, as well as with the inclusion of a discharge diode in the rectified current circuit.

In Fig. 4 shows the comparative external characteristics of the converter of three control algorithms.

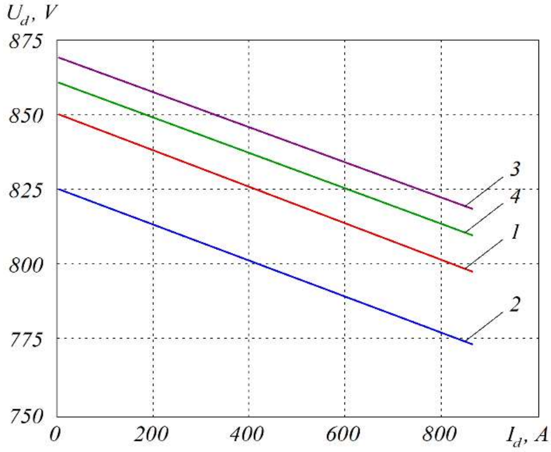

Figure 4. Comparative external characteristics of the converter under different control modes of the rectifier-inverter converter of the electric locomotive: *1* – typical work algorithm; *2* – proposed algorithm 1; *3* – proposed algorithm 2; *4* – proposed algorithm 3

When the electric locomotive is operating, the proposed control algorithm 2 is the most acceptable. Since in this case, despite the decrease in external characteristics (slightly compared to the characteristics of the third algorithm), the operating conditions of the electric locomotive in terms of voltage quality in the contact network, its electronic equipment and electrical equipment, and other equipment located in the immediate vicinity of the rail significantly improve way.

Conclusion

The use of the proposed control algorithms together with the adaptive system will allow to significantly improve the characteristics of the voltage in the catenary network, and, therefore, to reduce the negative impact on the operation of the electric locomotive. Improving the quality of electricity will make it possible to extend the service life of the insulation of electric machines and devices, the reliability of signaling, centralization and blocking devices, automatic locomotive signaling, control systems for electric locomotive converters, relay protection, automation, telemechanics, communication and computer equipment.

References

[1] Serdiuk T., Ansari H. T., Rodica B. Electromagnetic influence of AC traction network on the railway communication lines. *2022 IEEE International Symposium on Electromagnetic Compatibility & Signal/Power Integrity (EMCSI)*. 2022. P. 326–329. doi:10.1109/EMCSI39492.2022.9889435

[2] Nicolae P.-M., Nicolae I.-D., Nuca I., Nicolae M.-S. Determination of electromagnetic noise

from a power supply substation of railway traction systems. *2022 IEEE International Symposium on Electromagnetic Compatibility & Signal/Power Integrity (EMCSI)*. 2022. P. 619–624. doi:10.1109/EMCSI39492.2022.9889567

[3] Dems M., Komeza K. Designing an energy-saving induction motor operating in a wide frequency range. *IEEE Transactions on Industrial Electronics*. 2022. Vol. 69, No. 5. P. 4387–4397. doi:10.1109/TIE.2021.3082057

[4] Crotti G., D'Avanzo G., Landi C., Letizia P. S., Luiso M. Evaluation of voltage transformers' accuracy in harmonic and interharmonic measurement. *IEEE Open Journal of Instrumentation and Measurement*. 2022. Vol. 1. P. 1–10. doi:10.1109/OJIM.2022.3198473

[5] Kobenkins G., Marinbahs M., Bizans A., Rilevs N., Sliskis O. Determination of the level of vibroactivity of the traction motor-gear units. *2023 18th Conference on Electrical Machines, Drives and Power Systems (ELMA)*. 2023. P. 1–4. doi:10.1109/ELMA58392.2023.10202391

[6] Hu H., Liu Y., Li Y., He Z., Gao S., Xiaojuan Z., Tao H. Traction power systems for electrified railways: evolution, state of the art, and future trends. *Railway Engineering Science*. 2023. Vol. 32. P. 1–19. doi:10.1007/s40534-023-00320-6

[7] Graber G., Calderaro V., Galdi V., Ippolito L., Massa G. Impact assessment of energy storage systems supporting DC railways on AC power grids. *IEEE Access*. 2022. Vol. 10. P. 10783–10798. doi:10.1109/ACCESS.2022.3145239

[8] Nerubatskyi V. P., Plakhtii O. A., Hordiienko D. A., Khoruzhevskyi H. A. Study of the energy parameters of the system "solar panels – solar inverter – electric network". *4th International Conference on Sustainable Futures: Environmental, Technological, Social and Economic Matters (ICSF-2023). IOP Conference Series: Earth and Environmental Science*. 2023. Vol. 1254. 012092. P. 1–12. doi:10.1088/1755-1315/1254/1/012092

[9] Fan R., Zhang M., Wang J., Chang X., Gao L., Song J., Zhang S., Xu Y. Overview of power factor calculation method for nonsinusoidal and unbalanced systems. *IEEJ Transactions on Electrical and Electronic Engineering*. 2023. Vol. 18. P. 1763–1771. doi:10.1002/tee.23909

[10] Khomenko I. V., Nerubatskyi V. P., Plakhtii O. A., Hordiienko D. A., Shelest D. A. Research and calculation of the levels of higher harmonics of rotary electric machines in active-adaptive networks. *4th International Conference on Sustainable Futures: Environmental, Technological, Social and Economic Matters (ICSF-2023). IOP Conference Series: Earth and Environmental Science*. 2023. Vol. 1254. 012040. P. 1–15. doi:10.1088/1755-1315/1254/1/012040

[11] Salles R. S., Ronnberg S. K. Review of waveform distortion interactions assessment in railway power systems. *Energies*. 2023. Vol. 16. P. 5411. doi:10.3390/en16145411

[12] Nerubatskyi V., Hordiienko D. Analysis of the control system of a wind plant connected to the AC network. *Power engineering: economics, technique, ecology*. 2023. No. 1. P. 87–91. doi:10.20535/1813-5420.1.2023.276028

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