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IMPROVEMENT OF ENERGY EFFICIENCY OF THE SYSTEM OF ELECTRIC BRAKING OF ROLLING STOCK

The analysis of the most used electric braking systems in terms of their energy performance is carried out. A combined method of braking and a variable-structure electric braking system for DC motors are proposed. In the braking mode, the motors operate as alternators, and the current in the excitation windings is controlled by a converter.

Keywords: *electrical braking, energy performance, electric motor, excitation windings, DC-DC converter.*

Formulation of the problem

The energy efficiency of an electric braking system largely depends on its structure and method of braking, as well as on how braking energy is used. Most urban electric vehicles in Ukraine are equipped with a traction electric drive with DC motors with sequential excitation and outdated braking equipment. Therefore, the issues of improving the system of electric braking of urban electric rolling stock and increasing its energy performance are very relevant.

Analysis of recent achievements and publications

The analysis showed that considerable attention is paid to issues of increasing the energy performance of vehicles in the EU countries.

In [1, 2], the energy performance of traction electric drive systems for tram cars was improved to 35% due to the introduction of electrical equipment such as "TV Progress" based on a pulse converter from ALSTOM.

In [3], the consumption of electric energy in urban public transport systems was reduced by auditing their electric system. In this case, a mathematical model of the energy balance of the electric system of urban public transport and its components was used.

In [4], various concepts of traction drives in the Czech Republic and in the world are discussed and evaluated, the advantages and disadvantages of the new concept and the possibility of using outdated systems are considered.

The purpose and objective of research

The aim of the work is to increase the energy performance of the electric braking system of urban electric rolling stock based on an analysis of the most common electric braking systems with DC motors.

The bulk of research

The analysis of electric braking systems with DC motors of sequential excitation showed that the most common method was that the motors operate with independent excitation DC generators [5]. The excitation windings in this case are supplied from an adjustable voltage source that receives energy from the network, and the armature windings are shorted to the braking resistors (Fig. 1). Braking energy is dissipated on the braking resistors in the form of heat. Such an electric braking system provides reliable entry into the braking mode, allows you to generate braking characteristics with constant force for equidistant motion, which is very important for an exact stop. This ensures restrictions on the maximum speed, switching ability of traction motors, adhesion and maximum excitation current.

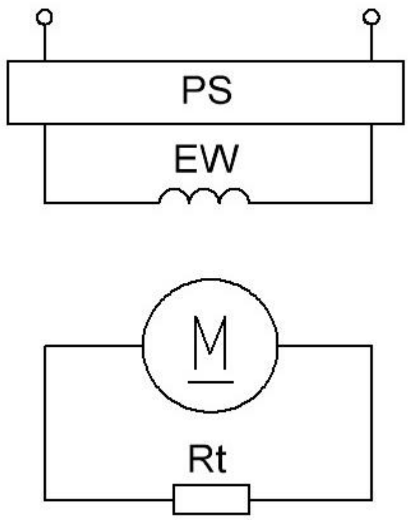

Fig. 1. Scheme of electrical braking during operation of the electric motor by an independent excitation generator

The disadvantages of such a braking system include low energy indicators, since energy from the network is required to excite the engines in the generator mode, and all braking energy is dissipated in the form of heat on the braking resistors. In addition, the system has low braking efficiency in the low-speed region, and when the network is de-energized, electric braking is generally impossible.

When mixed excitation motors are used in the electric braking system, the parallel winding is connected through the converter to the network, and the series excitation winding is connected together with the armature to the braking resistor (Fig. 2) [6]. In this case, the magnetizing forces of the windings are subtracted, since the direction of the current in the windings of the armature and series excitation changes. Regulation of braking force and braking current is carried out using a parallel winding. The braking force builds up quickly enough, because at the first moment of time there is no demagnetizing effect of the serial winding. In addition, the electromotive force of mutual induction in the series winding is directed in accordance with the electromotive force of rotation, which contributes to the growth of the braking current.

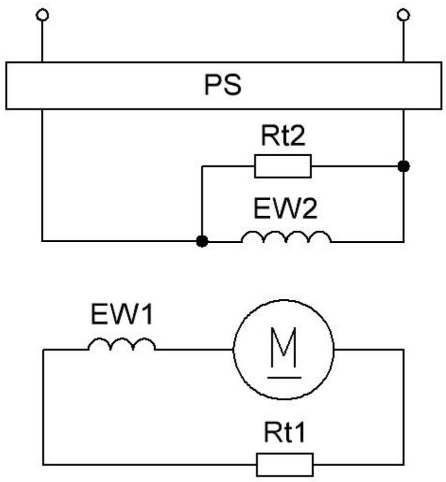

Fig. 2. Electric braking circuit using a mixed excitation electric motor

Such a braking system also has low energy indicators, since it takes energy from the network to excite the engines in the generator mode, and all the braking energy is dissipated as heat on the braking resistors. With unregulated braking resistance, the effectiveness of rheostatic braking is significantly reduced at low speeds. In addition, in the braking mode, the parallel winding is significantly overloaded with current, since the magnetomotive forces of the field windings are directed counter-current.

A system of electric braking has become widespread in urban electric transport, in which traction motors operate with sequential excitation generators (Fig. 3) and the electric energy received during braking is dissipated in the form of heat on brake resistors [7]. Generators are excited by self-excitation. The braking system generates characteristics that are more suitable for braking on a slope than for stopping. For stopping braking, the resistance of the braking resistors is gradually reduced.

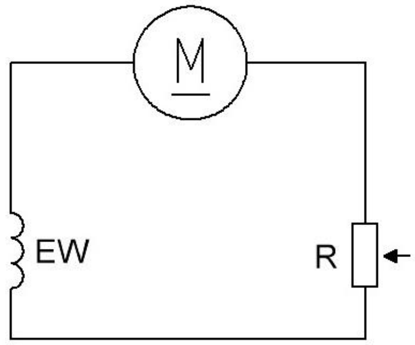

Fig. 3. Electric braking circuit when using an electric motor in the mode of a series excitation generator

The disadvantages of such a braking system include low energy indicators, since all the braking energy is extinguished on the braking resistors formed by the braking system characteristics, the entrance to the braking mode with delay in the low speed region. To accelerate the self-excitation of traction motors in the generator mode, must use additional power to the field windings from the battery or use a parallel field winding.

To increase the energy efficiency of the electric braking system of urban electric rolling stock, a combined method of electric braking and a variable structure electric braking system are proposed, which provide braking at the initial stage as with sequential excitation generators, and then automatically control the excitation current of the generators using a DC-DC converter by shunting the input of this transformer of the field windings of electric motors [8]. In this case, braking characteristics are formed with constant force and there is no need to consume electric energy from the network to excite electric motors. The energy from the output of the converter can be used for own needs.

In order to increase the braking efficiency in the low-speed region, the resistance of the braking resistors is smoothly regulated by shunting them with transistor switches.

To implement the combined method, the structure of the braking system is required, in which the current in the field windings during braking does not change direction. For this purpose, the structure described in [9, 10] is most suitable. In an electric braking system with a variable structure, the pulse converter is made according to the scheme of a single-phase transistor bridge with reverse diodes, the diagonal of which includes series-connected anchor windings of electric motors for reversing the direction of movement (Fig. 4).

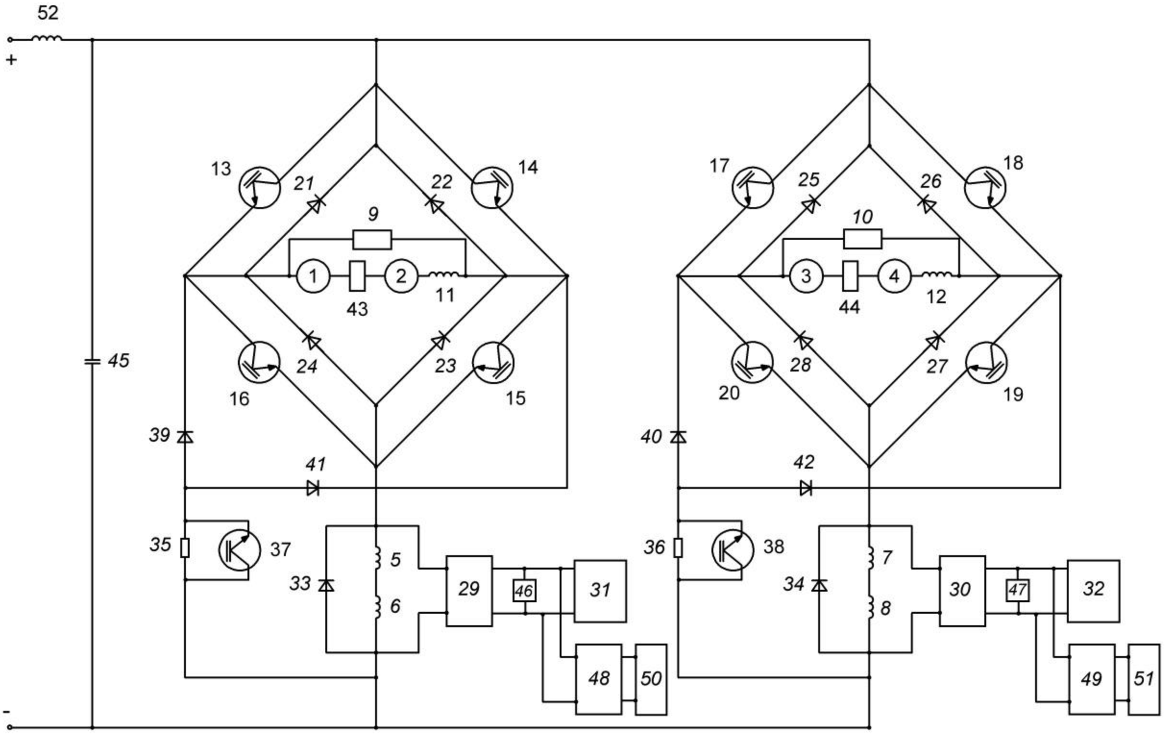

Fig. 4. Diagram of a variable structure electric braking system

The scheme works as follows. In the "Braking" mode, when the vehicle moves in the "Forward" direction, transistors 15, 19 and 37, 38 are turned on. After the current flows through the armature windings of the electric motors 1, 2 and 3, 4 and the field windings 5, 6 and 7, 8, the first DC-DC converters 29, 30 for regulating the current through the field windings 5, 6 and 7, 8 and turn off the transistors 37, 38. In this case, the mode of electrical resistive braking occurs and part of the energy through the first DC-DC converters 29, 30 goes to energy storage 31, 32 and through other DC-DC converters 48, 49 goes to the chains of their own needs 50, 51. At the same time formed as a braking performance from an independent generator excitation. In the low-speed range, transistors 37, 38 turn on and go into pulse-width modulation mode to increase braking efficiency.

Further improvement of the electric braking system with a variable structure is possible due to the accumulation of braking energy of the power circuit in the drives with its subsequent use in traction mode. Such a technical solution is shown in Fig. 5.

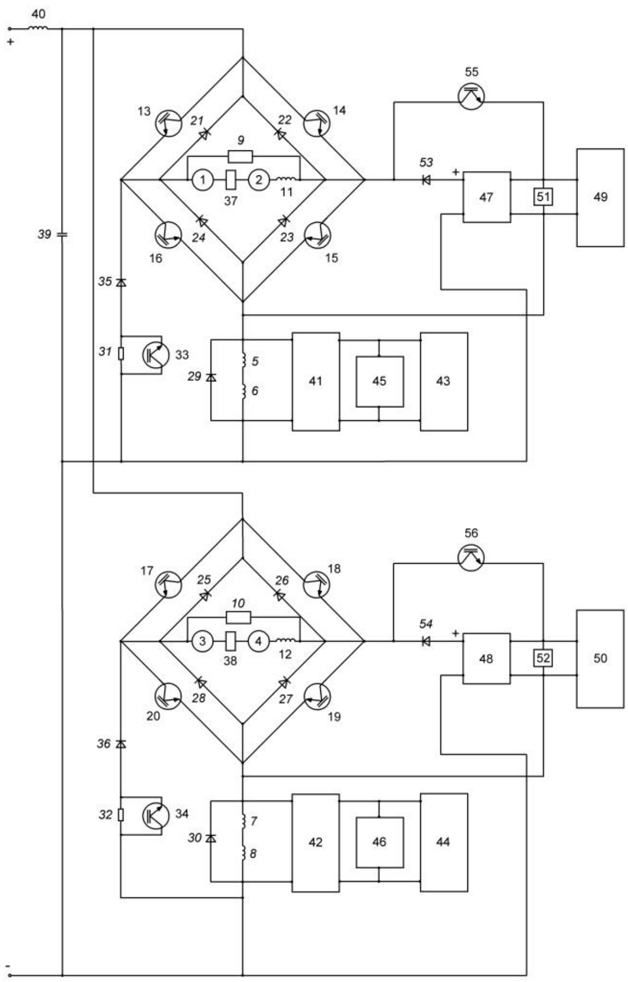

Fig. 5. Improved circuit design of electric braking system with variable structure

An improved circuit of the electric braking system with a variable structure works as follows. When the electric braking mode is switched on, transistors 15 and 19, 33 and 34 are turned on. In this case, the armature windings 1 and 2 and the field windings 5 and 6 of the motors, as well as the anchor windings 3 and 4 and the field windings 7 and 8 are turned on as sequential excitation generators and short between each other. Due to the residual magnetization in the field windings 5, 6 and 7, 8, an electromotive force will appear on the armature windings 1, 2 and 3, 4, under the influence of which a current will flow, which is measured by current sensors 37 and 38. After the current reaches the set value, the transistors 15 and 19 and turn on transistors 55, 56, as well as the first DC-DC converters 41 and 42. Braking current will flow through transistors 55 and 56, the inputs of the second drives 49 and 50, the field windings 5, 6 and 7, 8, transistors 33, 34 and anchors of engines 1, 2 and 3, 4. The first DC-DC converters 41 and 42 by their inputs shunt the field windings 5, 6 and 7, 8, and thereby regulate the current in them as if the independent excitation of the electric motors. From the outputs of the first DC-DC converters 41 and 42, energy is supplied to the first drives 43 and 44 and used for their own needs. If the other drives 49 and 50 are full and the braking continues, the transistors 55 and 56, 33 and 34 turn off and the transistors 15, 19 turn on and the braking energy turns into heat on the brake resistors 31 and 32. In the low-speed zone, transistors 33 and 34 go into pulse width modulation mode and reduce the equivalent braking resistance, effective braking is ensured. In this case, braking characteristics are formed as in independent excitation generators. The energy stored in storage 49, 50 is used in traction mode.

Conclusions

The analysis of the most common systems of electric braking of vehicles is carried out, on the basis of which a combined method and system of electric braking with a variable structure is proposed. When implementing this method, DC motors operate as sequential excitation generators. The current in the field windings is regulated using a DC-DC converter. Energy in the power circuit is accumulated in the energy storage and then used in traction mode. When the energy storage are full, the energy in the power circuit is extinguished by the braking resistor, and the energy from the output of the DC-DC converter is used for own needs. In this case, braking characteristics are formed as in independent excitation generators. An advanced system of electric braking can significantly increase energy performance.

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ПІДВИЩЕННЯ ЕНЕРГЕТИЧНОЇ ЕФЕКТИВНОСТІ СИСТЕМИ ЕЛЕКТРИЧНОГО ГАЛЬМУВАННЯ МІСЬКОГО ЕЛЕКТРОРУХОМОГО СКЛАДУ

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Енергетична ефективність системи електричного гальмування багато в чому залежить від її структури й способу гальмування, а також від того, як використовується енергія гальмування. Більшість транспортних засобів міського електричного транспорту в Україні обладнано тяговим електроприводом з двигунами постійного струму послідовного збудження і застарілим гальмівним обладнанням. Тому питання вдосконалення системи електричного гальмування міського електрорухомого складу і підвищення її енергетичних показників дуже актуальні.

Метою роботи є підвищення енергетичних показників системи електричного гальмування міського електрорухомого складу на основі аналізу найбільш поширених систем електричного гальмування з двигунами постійного струму.

Проведено аналіз найбільш поширених систем електричного гальмування транспортних засобів, на підставі яких запропоновано комбінований спосіб і систему електричного гальмування зі змінною структурою. При реалізації зазначеного способу електродвигуни постійного струму працюють генераторами послідовного збудження. Струм в обмотках збудження регулюється за допомогою DC-DC перетворювача. Енергія в силовому ланцюзі накопичується в накопичувачах і потім використовується у тяговому режимі. При заповненні накопичувачів, енергія в силовому ланцюзі гаситься на гальмівному резисторі, а енергія з виходу DC-DC перетворювача використовується для власних потреб. При цьому формуються гальмівні характеристики як у генераторів незалежного збудження.

Удосконалена система електричного гальмування дозволяє істотно підвищити енергетичні показники.

Ключові слова: *електричне гальмування, енергетичні показники, електродвигун, обмотки збудження, DC-DC перетворювач.*