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Analysis of the recovery device control system

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Abstract. Energy recovery of various types is an urgent task in the development of control systems for electromechanical devices. rational and careful use of energy resources. The purpose of this work is to analyze four-quadrant asynchronous electric drives with vector frequency-current control systems and autonomous voltage inverters with sinusoidal pulse-width modulation based on IGBT modules. The design algorithm is considered and the results of modeling of such energy recovery systems are given. The proposed control system of the recovery device can be used as an integral part of a specialized controlled electric drive for escalator stations of the subway, electric transport and other electromechanical systems in order to save energy consumed.

1 Introduction

In connection with the development of "green energy", many tasks have been formed for the rational use of energy resources. One of the directions is the recovery of electrical energy. Such tasks are very often considered in the automotive industry – electric vehicles, in urban transport (trams, trolleybuses). There are also many different tasks for heat recovery in enterprises, houses, for example, heat recovery at a thermal power plant. Power electronics plays an important role in the management and transformation of modern electric power systems. In particular, considerable efforts have been made to modulate and control power electronics devices in order to integrate various renewable energy sources using DC transmissions and to provide more flexible power regulation in AC systems. Pulse Width Modulation (PWM) is a well-developed conversion technology between AC and DC power supplies, especially with the aim of reducing harmonics and optimizing energy consumption. As a fundamental method of unrelated control, vector control using PI controllers is widely used in power systems. However, during the operation of these devices, significant power losses occur, and the losses are often dissipated in the form of heat, which leads to significant maintenance costs. Although a lot of work has been done to improve the design of power electronics, so far little attention has been paid to the study of the design of the controller to reduce the power consumption of the controller (which leads to a loss of power in power electronics) while maintaining acceptable system performance [1-5].

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But we have a narrower task, due to the noticeably increased requirements for the quality of the energy returned to the grid, the task of digitally controlling the recovery device (inverter) has appeared.

Let's look at several well-known technical solutions and conduct a small analysis. To comply with stricter environmental protection legislation and improve existing AC power supply systems, especially in wind farms (Association et al. [2005]). The integration of renewable energy sources into the existing electrical grid has put forward a number of technical problems that require the introduction of high-voltage direct current transmission lines (HVDC), which consume a small capacitive current compared to high-voltage AC solutions. Voltage source converters operating as an interface between DC and AC networks have a number of advantages over traditional linear switched converters. For example, voltage source converters using high-voltage IGBT are capable of switching at a higher operating frequency, and high-voltage direct current using voltage source-powered converters can provide independent control of active and reactive power, fast and reversible power flow control and asynchronous isolation with AC networks.

As a commonly used modulation method for controlling power electronic devices, PWM is fundamental to the operation of VSC, including sinusoidal pulse-width modulation, space-vector PWM. A lot of research is mainly focused on designing the PWM structure to reduce power loss during switching and on adjusting vector control to achieve the best dynamic characteristics of the system. Although the PWM control frequency can be optimized to reduce power loss, so far little has been done to study the relationship between the design of vector control parameters and the reduction of power loss, as well as how the controller design can help reduce power loss in power electronics and at the same time maintain the desired system performance.

It is well known that significant power losses occur during the operation of these devices, and the losses are often dissipated in the form of heat. Therefore, it is important to investigate the power losses and their relationship with the real-time operation of the system and control, thereby determining the correct design of the controller used in the system. The choice and design of the PI controller determines the balance between energy consumption when controlling power electronics and the performance of the control system, which potentially leads to significant energy savings when controlling power electronics for the integration of renewable energy sources. This shows that this relationship is non-linear, and an improved controller design can provide a good compromise between power loss and system performance [6-8].

2 VSC model and vector control

Figure 1 shows a standard three-phase inverter, and Figure 2 shows a VSC inverter using IGBT switches.

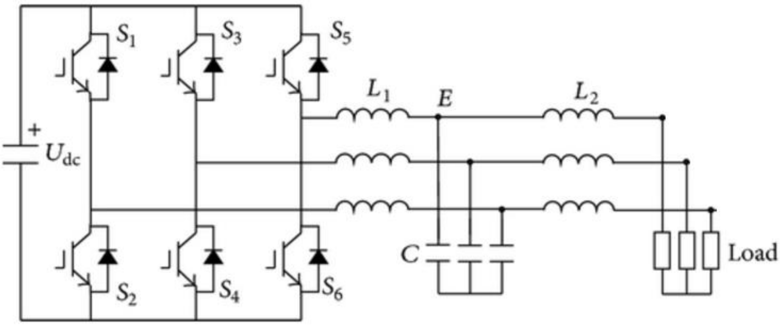

Fig. 1. Two level three phase voltage source converter.

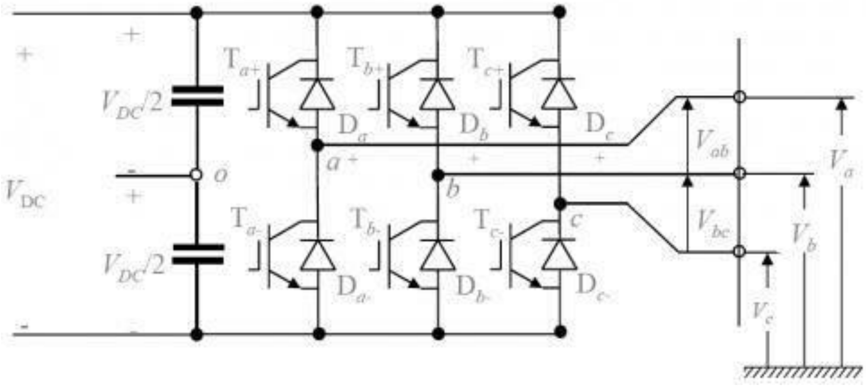

Fig. 2. The topology of a conventional two-level VCS using IGBT switches.

Each IGBT operates with an opposite diode during a half-cycle of alternating current. Switching pulse signals for IGBT are provided by a PWM modulator. Thus, the main purpose of the vector controller can be considered as providing a reference for the modulator.

The main tasks of the recovery inverter control system include ensuring four-square operation of the electric drive and, to the best of its energy capabilities, restoring symmetry and standard parameters of the industrial network, if there are distortions in it. The possibilities for improving the quality of the industrial network are limited by the installed capacity of the power equipment and the energy processes in the drive. The control system of the recovery device must be insensitive to the harmonic components of the mains voltage, resistant to voltage surges and dips, and provide frequency tracking in the range from 48 to 52 Hz. As an additional requirement, one can consider the ability of the system to keep the mains voltage frequency near standard parameters when electricity from primary sources enters.

Since the analog-to-digital control system has a rigid structure, its circuit solutions are directly dependent on the specific task being solved by the system.

According to the degree of complexity of the control system and the composition of measuring devices, the tasks can be divided as follows.

1. Simply energy recovery into the network in order to prevent overvoltage on the inverter power supply buses in the generator mode of operation of the electric drive. At the same time, the quality of electrical energy should not deteriorate.

2. Formation of a local electrical network and maintenance of its parameters within the specified limits.

3. Recovery of electrical energy into the network in order to compensate for reactive power in the network.

The simplest system is the first one, since the tasks solved by it are strictly limited. In this case, the task is reduced to synchronizing the harmonic component of the voltage in the network and building a three-phase system of current generators. In general, the task is similar to the tasks solved in the construction of modern vector control systems for asynchronous machines, where the control of machine variables is carried out using a three-phase system of current generators, whose phase is rigidly connected to the system variables. This makes it possible to use typical circuit solutions used for control systems of alternating current machines[9].

The construction of current regulators in a fixed coordinate system is due to the nonlinearity of the electrical network as a load, and changes in its parameters over a wide range due to the unpredictable connection of various users.

The algorithm of operation of this system consists in the fact that a three-phase voltage vector in the network is fed to the input of a digital-to-analog coordinate converter from a stationary system to a rotating one. If the resulting three-phase voltage vector coincides with the Y axis of the rotating coordinate system, then for the case of a symmetrical three-phase network with one harmonic component of the resulting voltage vector on the X axis will be zero. The projection on the Y axis in this case is proportional to the amplitude of the phase voltage [12-14].

The output signal of the coordinate converter from a stationary system to a rotating one is fed to the input of the PI or PID controller. The regulators provide the required astatism of position tracking.

3 Synthesis of current and voltage PI regulators

The output of the PI current regulator is actually used to compensate for the voltage drop in the AC linear resistor and the inductor. The range of parameters of the PI controller is limited by PWM modulation in VSC.If the PWM switching frequency is equal to fp, the controller operates with an interval = t = 1/10fp. The open loop current transfer function with a PI controller can be obtained using a single PWM time delay:

$$\mathrm{W(s)} = \frac{(\mathrm{K_p}+\mathrm{K_i}/\mathrm{s})\mathrm{e}^{-1/\mathrm{f_p}\,\mathrm{s}}}{\mathrm{R}+\mathrm{Ls}} \tag{1}$$

where 1/fps is the PWM delay.

We approximate,

$$\mathrm{e}^{-1/\mathrm{f_p}\,\mathrm{s}} = \frac{-s+2f_p}{s+2f_p} \tag{2}$$

Using the Rouse criterion, you can select the parameters of the current regulator Kp and Ki.

$$\begin{gathered} 0 < \mathrm{K_p} < 2\mathrm{f_p}\mathrm{L} + \mathrm{R} \\ 0 < \mathrm{K_i} < \frac{(2\mathrm{f_p}\mathrm{L}-\mathrm{K_p}+\mathrm{R})(2\mathrm{TK_p}+2\mathrm{TR})}{4\mathrm{f_p}\mathrm{L}-\mathrm{K_p}+\mathrm{R}} \end{gathered} \tag{3}$$

As in the current regulator, in the voltage regulator, you can select Kp and Ki.

$$0 < \mathrm{K_p} < 2\mathrm{f_i}C$$
$$0 < \mathrm{K_i} < \frac{2\mathrm{f_i}\mathrm{K_p}(2f_i\mathrm{C} - \mathrm{K_p})}{4\mathrm{f_i}\mathrm{C} - \mathrm{K_p}} \qquad (4)$$

After determining the permissible ranges of Kp and Ki of each regulator, it is possible to find the best value of Kp and Ki for each regulator, which will reduce power losses and system performance [1].

4 The principle of operation of the recovery device

The hardware part of the control rack of the digital recovery device is almost similar to the hardware part of the control rack of the electric drive inverter. The main differences are related to the software of the microcontrollers of the control system of the electric drive inverter and the recovery device. Communication between the controllers to ensure their consistent operation is provided via a serial CAN interface.

The software of the microcontroller of the recovery device, as well as the microcontroller of the electric drive inverter, is built on a modular principle and consists of a software modules of the microcontroller of the recovery device are unified with the software modules of the microcontroller of the electric drive inverter.

The algorithm of this system consists in the fact that a three-phase voltage vector in the network is fed to the input of the coordinate converter from a stationary system to a rotating one. If the resulting three-phase voltage vector coincides with the Y axis of the rotating coordinate system, then for a symmetric three-phase system with one harmonic component, the projection of the resulting voltage vector on the X axis will be zero, and the projection on the Y axis is proportional to the amplitude of the phase voltage.

Current setting signals for phase regulators are generated in the rotating coordinate system. In the simplest case, these signals can be obtained from the voltage regulator in the DC link, thereby implementing a recovery system that protects the power supply of the electric drive inverter from overvoltage on DC buses. In this case, the current component along the X axis is set to zero, as a result, the current vector in the phases coincides with the phase voltage vector, and the reactive component of the current is practically absent. The construction of current regulators in a fixed coordinate system is due to the nonlinearity of the electrical network as a load, and changes in its parameters over a wide range due to the unpredictable connection of various users.

If the measuring system of the electric drive is supplemented with a current sensor, then after conversion to a rotating coordinate system, signals corresponding to the active and reactive components of the current along the Y axis are obtained, and the steady-state task signal at its input is zero, a compensation system for the reactive component of the current is obtained. Figure 3 shows the functional diagram of the power recovery device [1-2].

main program and a number of software modules that provide various functions. At the same time, a number of

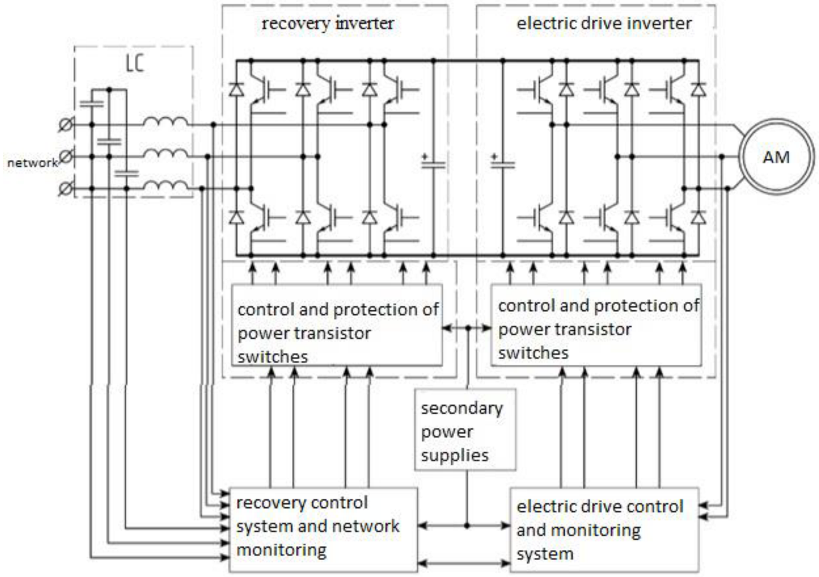

Fig. 3. Functional diagram of the power recovery device.

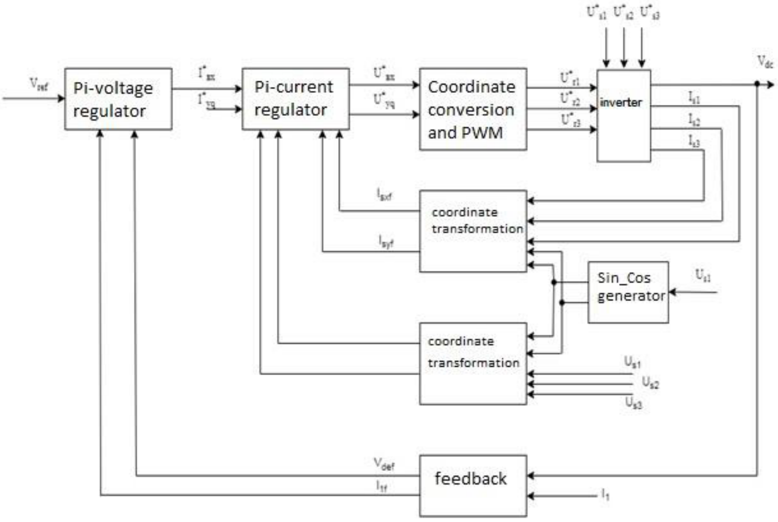

Fig. 4. Block diagram of the control system of the regenerative unit.

The high–speed digital vector control system provides high quality control indicators: the operating range of the DC output voltage when powered from a three–phase network is 380 V, 50 Hz - from 580 to 650 V; the accuracy of maintaining the output voltage with supply voltage deviations from -15% to +10% and load current changes from idle to Inom - not worse than 5%; transient deviation of the output voltage in the mode of a stepwise surge of the rated load – no more than 30 V; recovery time – no more than 50 ms; the range of change in the cosφ setting is from 0.7 lagging to 0.7 leading.

The structure of the control system includes two regulators of the active and reactive components of the input current and an output voltage regulator[9-12].

5 Simulation of a recovery device control system in MatLab environment

The Clark transform uses three-phase currents iA, iB and iC in order to calculate the currents in the two-phase orthogonal coordinate system of the stator in the axes ix and iy. The obtained two currents in the stationary coordinate system of the stator are converted to ia, iß components of the currents in the coordinate system α-β in accordance with the Park transformation.

With the help of the theory of automatic control, the synthesis of regulators of the vector control system was carried out. The mathematical model of the recovery device control system is shown in Figure 5, the mathematical model in the MatLab environment in Figure 6.

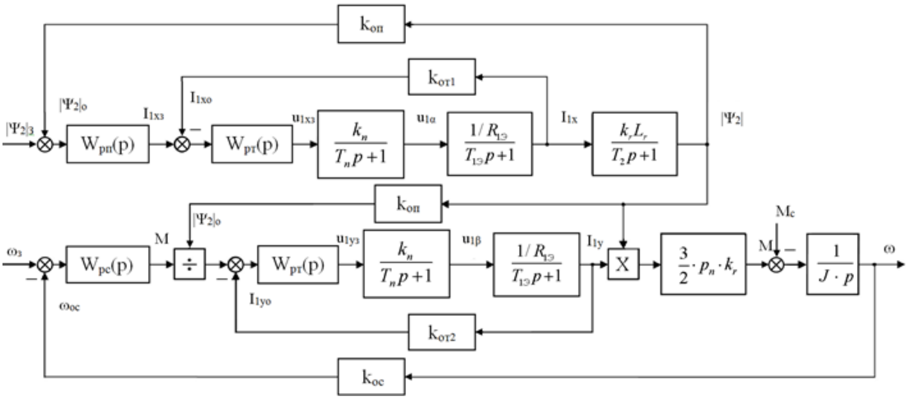

Fig. 5. Mathematical model of the recovery device control system.

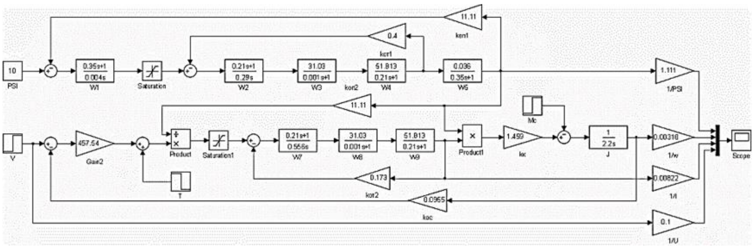

Fig. 6. Mathematical model in the MatLab.

Usually, when starting an electric drive control system, which includes a frequency converter with a vector control system, a nominal flow-coupling task is first applied. When the flow coupling reaches the set value, a speed task is given and the mechanism is set in motion.

With a vector control system of an electric drive, the nominal flow-coupling task is first supplied. When the flow coupling reaches the set value, a speed task is given and the mechanism is set in motion. Transient time for regulators: current flow τ = 1.05, τ = 0.58 speed τ = 0.53. For transients: stator current overshoot δ = 4.7%; speed and flow overshoot δ = 0. Figures 7-10 show the simulation results. Figure 11 shows examples of disturbing effects such as white noise.

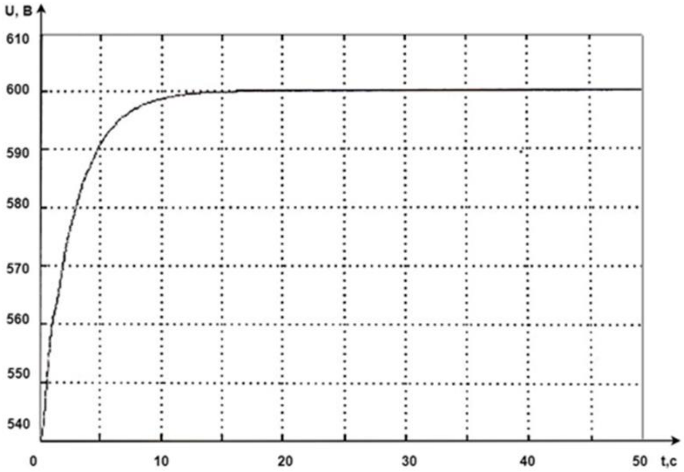

Fig. 7. The transient process of an analog model of a recovery device in the absence of a disturbing effect absence of a disturbing effect.

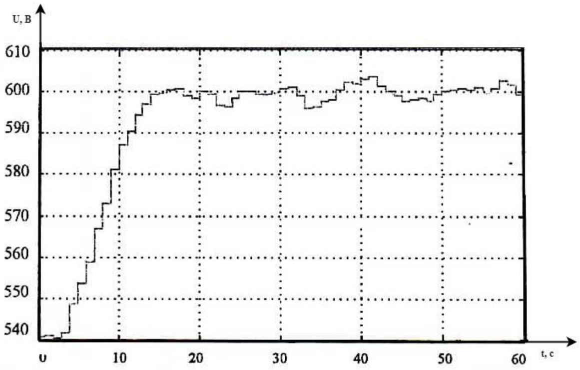

Fig. 8. Transient process of a discrete model of a recovery device in the absence of a disturbing effect.

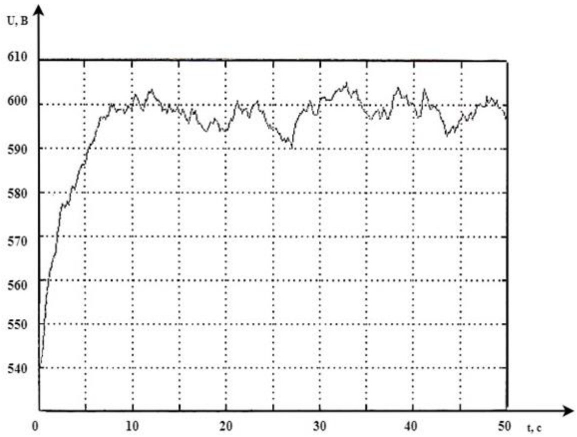

Fig. 9. The transient process of an analog model of a recovery device with a disturbing.

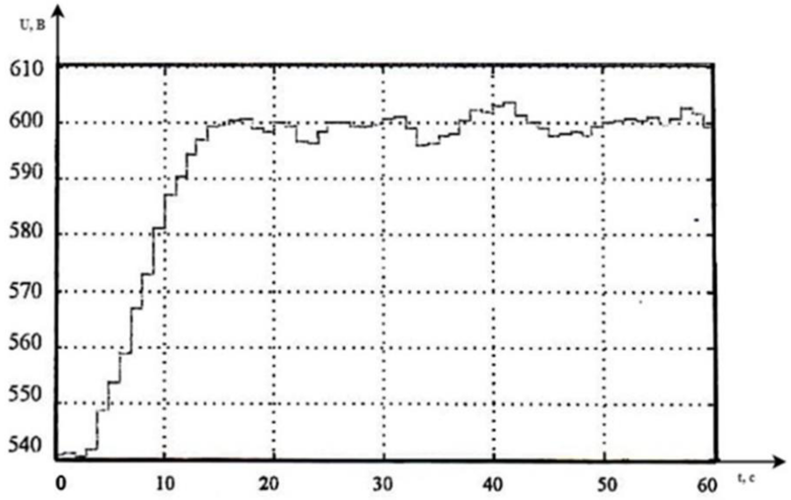

Fig. 10. The transient process of a discrete model of a recovery device with a disturbing effect on frequency.

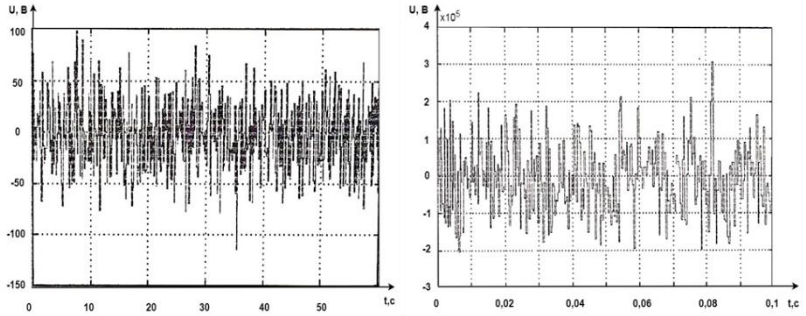

Fig. 11. Examples of frequency disturbing effects.

In the research sector of the controlled electric drive, a prototype of a four-quadrant AC electric drive with autonomous voltage inverters and sinusoidal pulse width modulation based on IGBT modules for metro escalators with a capacity of 200 kW was created and passed laboratory tests. The drive consists of two identical cabinets, the difference is only in the software of the control system built on the basis of the TMS-320 microprocessor [6-7]. It should be noted that a significant number of program blocks are the same. Data exchange between the control systems of the recovery device and the electric drive is carried out via a high-speed and noise-resistant CAN channel.

6 Conclusion

In conclusion, it is worth noting that the recovery device can be used not only in conjunction with an electric drive, but also as an independent device that converts a constant voltage into a three-phase voltage system, as well as performing the reverse conversion of a three-phase voltage to a constant. When using a recovery device for different purposes and in different modes, it is only necessary to modify the software by selecting the appropriate software modules. At the same time, the hardware changes slightly. The recovery device control system can be used as an integral part of a specialized controlled electric drive for metro escalator stations. This approach to the development of electric drive control systems can be used both for the modernization of existing escalator stations and for the construction of new ones. It is also applicable for resource saving on electric vehicles, urban electric transport, water utility equipment and fuel and energy complex.

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