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DEVELOPMENT PROSPECTS OF EXTERNAL POWER SUPPLY ELECTRICAL NETWORKS OF TRACTION SUBSTATIONS

In the paper on the basis of the analysis of classical power schemes traction substations of railways and urban electric transport conceptual directions of development of electric networks of external power supply of traction substations in the conditions of market economy and normative requirements of the electric power industry of Ukraine are developed, which allow to provide energy saving modes of their operation. Based on system analysis of domestic and foreign traction power supply systems of railways and electric transport of large cities, the concept of their development is substantiated and proposed by increasing the supply voltage of traction substations and minimizing capacity upflows and energy losses, which provides resource and energy savings.

It is suggested that the investment programs of the structures that are part of Corporation «Ukrzaliznytsia» and the municipal services be synchronized according to their technological indicators, as well as according to the criteria of energy efficiency and quality of energy supply with similar investment programs of external energy. For reduction of energy losses, it is proposed: realization of rational schedule of train movement and deep high voltage inputs with the prospect of transition to own 110 kV distribution networks, modernization and equipping of modern rolling stock electrical equipment and infrastructure of the main and perspective directions of the railways.

The need to expand tram and trolleybus lines and modernize power supply devices in terms of resource conservation requires new technologies for the design, construction and operation of the facilities of municipal enterprise «Miskelektrotransservice». Such technologies have been implemented by the «DAK-Energetika» enterprise in the manufacture of modern electrical equipment of municipal enterprise «Miskelektrotransservice» TS. The most important tasks are the improvement of stationary and mobile substations and other linear facilities of traction power supply by completing functional modular blocks with modern switchgear with digital relay protection and diagnostics of traction networks; local and remote control of switchgear devices, as well as switch diagnostics and self-diagnosis.

Keywords*: *external power supply, traction substations, electrical networks, power systems operation modes.

Formulation of the problem

A common drawback of traction substation schemes for electrified areas in the past is that virtually all substations were connected to 110 kV regional power supply organization networks, and some of them to 110 kV networks that connected different power systems. Parallel operating 110 kV, 220 kV, or 110 kV, 330 kV networks are heterogeneous and the power transmission through them occurs with reduced efficiency of the network as a whole. Traction substations for electric traction networks of urban electric transport are connected to the networks of 10 kV regional power supply organization, and the need to expand tram and trolleybus lines in terms of resource conservation requires new technologies for construction and operation of traction substations.

Thus, in a market economy, and given that Ukraine's railways are licensees for the transmission and supply of electricity, it is necessary to have a vision of promising circuit solutions that provide an appropriate category of reliability for the connection of traction substations to networks and reduce losses in power networks. Traction substations for electric traction networks of urban electric transport are connected to the networks of 10 kV regional power supply organization, and the need to expand tram and trolleybus lines in terms of resource conservation requires new technologies for construction and operation of traction substations.

Purpose and objectives of the study

The **purpose** of this paper is to increase the reliability, electricity supply security and electricity quality and reduce the cost and construction time of new traction substations. To achieve this goal, it is necessary to develop conceptual directions for the development of external power supply electrical networks of traction substations to ensure the energy security of the transportation process by electric transport in the development conditions of the fuel and energy complex of the country.

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Analysis of the recent research and publications

The development of external power supply traction substations (TS) schemes, taking into account the requirements of the Ukrainian electric power industry, is based on the connection to the networks of NPC «Ukrenergo» (220-330 kV) in order to improve the quality of electricity and reduce the costs and time of construction of new TS and to improve the reliability and security of TS power supply through the creation of transport and energy corridor on railways exclusion zone [1–8].

New approaches directly affect the energy security of the transportation process. With this in mind, measures of both organizational and financial nature aimed at the implementation of the above priorities by the respective railways, municipal utilities and interaction with the NPC «Ukrenergo» should be defined.

On the balance sheet of NPC «Ukrenergo» there are 22,93 thousand km of main and interstate transmission lines with voltage of 35-800 kV and 133 electrical substations with voltage of 220-750 kV. Only electrical installations of a licensee for the transmission of electricity to local electrical networks or electrical installations intended to produce electricity may be connected to the backbone and/or interstate electric networks.

Today, railways are licensees for the transmission and delivery of electricity, enabling them to use connection to such networks and thus improve the quality of electricity for rail users. The «Specifications» of the connection are issued by the owner of the electrical networks in case of the new electrical installation connection, the electrical capacity increase of the electrical installation due to reconstruction or technical re-equipment, change of the customer's requirements for the reliability of the electrical supply of the electrical installation, change of the connection point. The network owner shall ensure, in accordance with the terms of the connection agreement, the technical possibility of connecting the customer's electrical installations at the connection point and timely connection of the electrical networks to the connection point, as well as increasing their throughput. For example, the project of external power supply of the Poltava–Kremenchuk–Korystivka electrified section provides for temporary use of the mobile TS 154/27,5/10 kV «Kremenchuk traction», which has a power supply of the 330 kV substation «Kremenchuk» of the Northern ES of the NPC «Ukrenergo» (Fig. 1). This greatly increases the energy security of the railways, the reliability of the power supply to the TS and reduces the energy losses during its transmission.

Fig.1. Mobile TS «Kremenchuk traction» of the regional branch «Pivdenna zaliznytsia» (Southern railways) of the Corporation «Ukrzaliznytsia» (Ukrainian railways)

A great function in the external power supply reliability is the perfection of the electrical network's operational management and the interaction of the energy-dispatching apparatus of the power transmission organizations and NPC «Ukrenergo» with the energy-dispatching centers of railways. In addition, railways can use a unique automated commercial metering system to analyze and adjust the modes of power network, taking into account power network modes and minimizing capacity upflow and reducing power losses.

Current laws and regulations allow the financing of capital construction, reconstruction and maintenance of facilities intended for the common needs of electricity companies and enterprises of other industries, to be carried out at the expense of customers (owners) and users of these facilities. Energy suppliers are obliged to provide reliable electricity supply in accordance with the terms of licenses and contracts. Such points of the law are aimed at the development of electric networks of railways and urban electric transport and allow the connection of traction substations to the electrical networks of power systems.

The main drawback of the regulatory framework of the Ukraine power industry regarding connected electrical installations to the electricity networks is its imperfection in the part of transfer of property (technical means) created as a result of technical conditions fulfillment by the forces and means of the customers to the balance of the electric networks owners, and this impedes the development and reconstruction power networks in general, and creates an economy collision.

Reducing the cost of external power supply for electrification of new sites requires an increase in distances between traction substations up to 80-100 km

and the application of new power schemes with the implementation of deep high-voltage inputs (connection to overhead power lines 220, 330 kV) and the prospect of switching to their own distribution 110 kV networks. It is possible in the future to interconnect with external power systems (EPS) through DC circuits and solve the problem of electromagnetic compatibility.

The prospect for today is high-voltage power lines (voltage class 35-110 kV, as well as external overhead power lines) are promising for today, laying in the railway's exclusion zone on freestanding pillar in limited profile, as an exception, placing in the profile of the pillar of contact network. As a rule, these are double-circuit or three-circuit overhead power lines, which are built on both electrified and non-electrified sections. Pillars of overhead power lines in places with limited dimensions of the exclusion band are used to secure the contact suspension. As a result, a transport and energy corridor are created, through which 110 kV own lines are supplied.

Germany and other countries have such lines in the railway's exclusion zone [9–11]. The combination of different communications in one route has great advantages in their construction and operation. Roadside highway, as public roads, shorten the construction and electrification of railway lines, allow high-quality and short-term implementation of planned and emergency repair of these lines and power networks.

For reduction of energy losses, it is proposed: realization of rational schedule of train movement and deep high voltage inputs with the prospect of transition to own 110 kV distribution networks, modernization and equipping of modern rolling stock electrical equipment and infrastructure of the main and perspective directions of the railways.

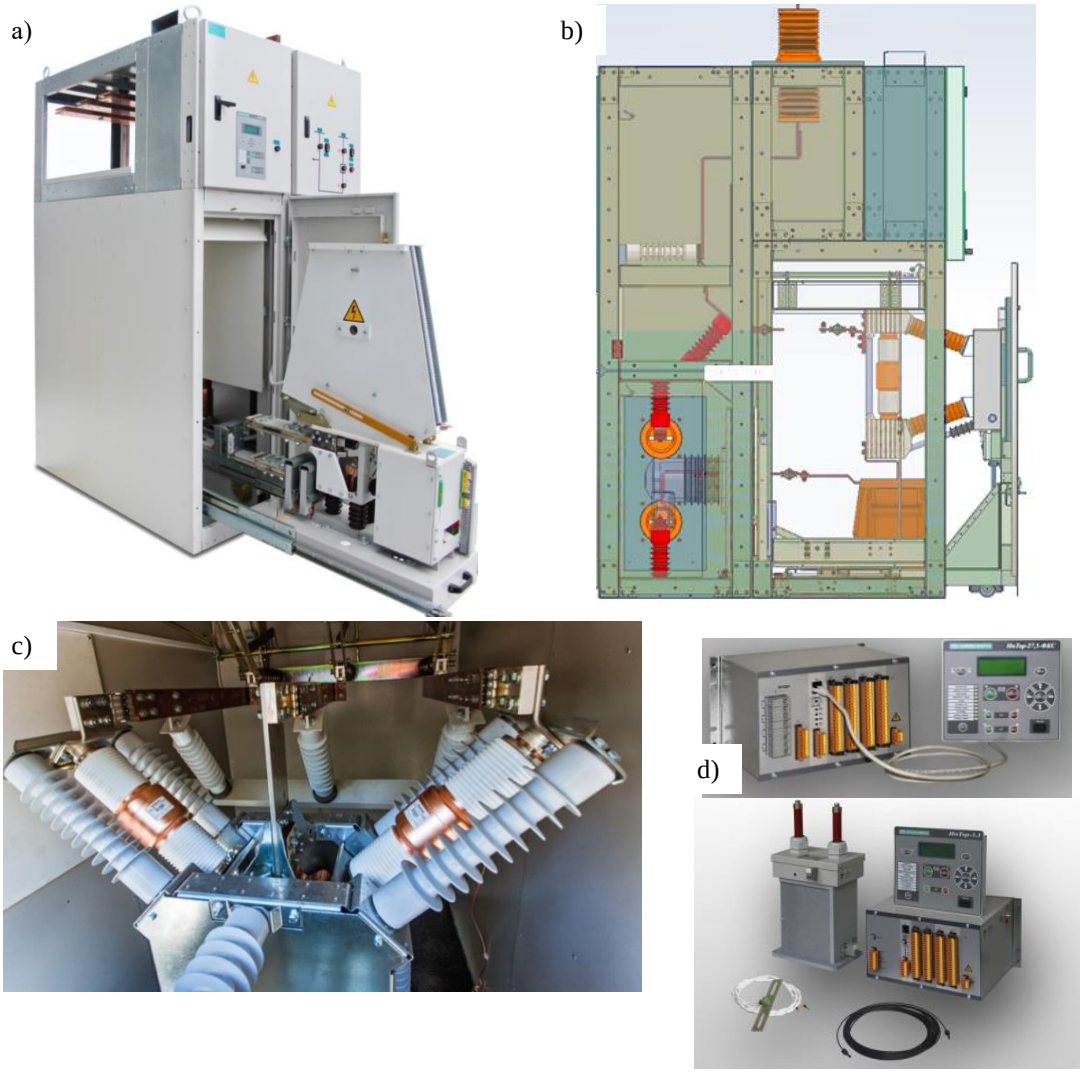

Fig. 2. Modern switchgear, relay protection and diagnostics of electrical traction networks: DC cell with withdrawable high-speed switch ВАБ-206 (*a*); AC cell with withdrawable switch (27,5 kV) (*b*); grouping switch of the coupling station (*c*); *г* – intelligent devices for digital protection and connection automation 27,5 kV and 3,3 kV (*d*)

Statement of the main material

Development conceptual directions of external power supply electric networks of traction substations. The most important tasks are the improvement of stationary and mobile substations and other linear facilities of traction power supply by completing functional modular blocks with modern switchgear with digital relay protection and diagnostics of traction networks; local and remote control of switchgear devices, as well as switch diagnostics and self-diagnosis (Fig. 2).

The need to expand tram and trolleybus lines and modernize power supply devices in terms of resource conservation requires new technologies for the design, construction and operation of the facilities of municipal enterprise «Miskelektrotransservice». Such technologies have been implemented by the «DAK-Energetika» enterprise in the manufacture of modern electrical equipment of municipal enterprise «Miskelektrotransservice» TS [5, 6]. For the first time in Kharkiv in 2019 a new generation modular traction substation of urban electric transport with dry transformers, 12-pulse rectification circuits, digital protections and diagnostics of equipment providing operation for condition (Fig. 3).

Fig. 3. Modular design traction substation of urban electric transport ТПМ-МТ-3-1000-6/600 in Kharkiv

The concept of development of external power supply schemes for traction substations, considering the requirements of the electric power industry of Ukraine, is based on the following basic provisions:

– connection to the networks of NPC «Ukrenergo» (220-330 kV) to improve the quality of electricity and reduce costs and time for construction of new TS;

– creation of transport and energy corridors in the railway's exclusion zone, which is effective in the construction of new railway lines in energy-scarce regions;

– improving the reliability and safety of TS power supply through the development of its own 110 kV power supply networks and new generation mobile substations with switchgear RP-110 kV;

– substantiation of own capacities creation of electric generation and thermal energy for stationary power engineering;

– reduction of capacity upflow and energy losses in traction power networks and power supply systems;

– reduction of money for the purchase of electricity through the development of TS connection schemes to the external power supply networks in the first class (35, 110, 220, 330 kV).

Such stages of realization of the concept of external power supply of TS under the existing modes of operation of power systems are promising:

– development and feasibility study of proposals for correction and interconnection of investment programs for the development and technical re-equipment of electric networks of Corporation «Ukrzaliznytsia», NPC «Ukrenergo», regional power supply organization for improving the reliability of power supply of railways and urban electric transport TS;

– calculations of modes of operation of electric networks of external power supply of TS and

preparation of recommendations for improving the reliability of existing circuits, reducing capacity upflows and energy losses.

Providing energy security for the process of transportation by electric transport in the conditions of development of the fuel and energy complex of the country. Innovative scenarios and forecasts of socio-economic development of Ukraine for the period up to 2020-2030 are focused on reforming the fuel and energy complex (FEC).

The long-term investment programs of its modernization and development are aimed at ensuring the growing demand for electricity, increasing gas production to 40-45 billion cubic meters. m per year, increasing the cost-effective production of energy coal up to 75 million tons per year, as well as liberalization of energy resources markets and improving energy efficiency by reducing the specific consumption of energy in the economy by 30-35% by 2030, which will significantly reduce the load on economy, will increase the energy independence of the state and the competitiveness of its gross domestic product (GDP) [5, 12–15].

In the baseline scenario, the average GDP growth from 2020 will be 5% per year by 2030. In the baseline scenario, the ratio of services sector GDP to industry GDP will approach the level of developed countries by 2030 (services and transport will be 70 % of GDP, industry about 21%, the remaining 9% will be agriculture). GDP growth rates are as follows: industrial sector (5,2% annually), services and transport (6,9% annually) and agriculture (7,1%).

Provisions of the Ukraine Energy strategy for the period up to 2030 are the basis of the Energy strategy of railways and electric transport of large cities in terms of the prospects for the development of technical means and technologies that are focused on the respective types of fuel and energy resources (FER). Energy and transport are one of the sustainable manufacturing sectors of the Ukrainian economy. At the same time railway and electric transport of big cities is a stable consumer of a wide range of energy resources produced by the fuel and energy complex and completely depends on the state and prospects of its development.

Among the most important for energy supply in the field of energy transportation services are the following benchmarks, which are forecast for 2030:

– increase in FER production for domestic consumption by 12-39%, including increase in electricity production by 1,3-1,7 times, production of diesel fuel by 43-126%, gasoline by 37%, gas production by 1,5-2,3 times, coal by 70% (with 1,8 times increase in enrichment);

– increase in the probability of trouble-free operation of power systems from 0,996 to 0,997 and decrease in the specific consumption of FER in the production of heat up to 30%;

– increase of efficiency of power plants: coaly from 34,0% to 41,0%, gas from 38,0% to 53,0%, nuclear from 32,0% to 36,0% and reduction of losses in electric networks - from 13,0 % to 9,0%.

These trends in the growth of production of the main types of energy resources indicate a favorable forecast of sustainable energy supply for the process of transportation on urban electric transport, subways and railways in the long run.

Over the last 5 years, the share of nuclear power plants accounted for 47–48% of the total electricity production in Ukraine. During the period until 2030, it is planned to keep the share of nuclear power generation at the reached level - about half of the total domestic production.

Thus, the noticeable increase in the efficiency of power plants and the reduction of losses in the power grids should affect the stabilization of electricity tariffs, which will increase the motivation to increase the pace of development of electric traction networks of urban electric transport and the transfer of freight sections of railways from diesel traction to electric traction.

With favorable indicators of the development of electricity production in the whole country in the electric power industry there are number of problems of regional character. Today, most of the generating assets and power networks are worn out and inefficient; to maintain the reliability of the networks, a full-scale program to modernize these assets is required:

– 84% of thermal power plant units have exceeded the limit of physical wear and tear in 200,000 hours of operation and require upgrading or replacement. Wear of the equipment leads to fuel consumption and environmental degradation;

– nuclear units are nearing the end of project life: more than 70% of nuclear units will need an extension of their life in the next 10 years;

– power balance of the Ukraine energy system is characterized by a shortage of both maneuvering and regulating capacities; the share of hydroelectric power plants that provide the bulk of maneuverability in the total capacity balance does not exceed 9% at the optimum level of 15%. As a result, coal-fired thermoelectric power stations (TPS) units designed for baseline operation are used to support the variable part of the power system load schedule;

– presence of excess capacity in number of power systems in the absence or insufficient throughput of their electrical connections with other power systems leads to the presence of so-called «closed» power, which is projected in 2012-2030. Positive is the use to regulate new coal and nuclear units;

– at present, 35% of 220-330 kV power lines have been in operation for more than 40 years, 55% of

the main equipment of transformer substations have fulfilled their planned technical resource;

– in distribution networks, a significant number of facilities have also spent their resources: 31% of electricity grids and 32% of transformer substations require renovation or replacement. Insufficient equipment of low-voltage networks with reactive power compensators results in significant deviations of voltage from normative values. UAH 134 billion should be invested in the distribution networks development by 2030.

Without the implementation of modernization programs for existing facilities and the construction of new facilities, the peak capacity deficit will be observed as early as 2020-2025.

Rating system of energy safety of the transportation process. When analyzing the risks and threats to the energy supply of the process of transportation of railways and urban electric transport and subways by external power supply it is first proposed to use the ratings system of the energy security state by aggregate of the following indicators:

– the ratio of the total capacity of power plants to the maximum electrical load of consumers in the region;

– the ratio of power sum of the power plants and the bandwidth of interconnections to the maximum electrical load of consumers in the territory of the region;

– opportunities to meet the needs of boiler-furnace fuel from the region's own sources;

– share of dominant resource in total boiler-fuel consumption in the region;

– share of the largest power plant in the installed electric power capacity of the region;

– the level of potential provision of demand for fuel under conditions of sharp cooling in the region;

– the reliability of the energy supply system, considering the high level of deterioration of the main production assets of the region's energy industry;

– the ratio of the average annual input of installed capacity and the reconstruction of regional power plants over the previous 5-year period to the installed capacity of the region.

Based on a system analysis of the operating modes of the NPC «Ukrenergo» power systems, it is established that by the number of indicators the level of risks and threats to the sphere of transport services and areas of new electrification of railways by external power supply systems is large (3–4) and medium (1–2) for different directions and major cities for the period 2020–2025.

It can be noted that these risks and threats extend to power systems to the greatest extent in the period 2020–2025. As the Energy strategy of Ukraine (2020–2030) continues to implement, their number should significantly decrease. With this in mind, have to prepared to take action:

1) construction in coordination with the NPC «Ukrenergo» of traction power facilities (TS with measures of overhead power lines of regional power systems);

2) an increase in the number of TS that have a power source from substations (220-330 kV) of NPC «Ukrenergo». An example is the construction of the mobile TS 154/27,5/10 kV «Kremenchuk traction», which has a power source: 330 kV substation «Kremenchuk» of the Northern ES of NPC «Ukrenergo». This greatly increases the energy security of the railways, the reliability of the power supply of the TS and reduces the energy losses during its transmission;

3) contracting with regional block stations for the delivery of power for the benefit of the railways, mainly in peak mode, for example, in case of power supply failures from centralized networks, as well as the construction, if necessary, of overhead power lines that connect the block stations to the railway customers and TS;

4) creation with participation of the enterprises of railways and urban electric transport and subways as guaranteed consumers, power centers based on the use of local primary (peat, oil shale, etc.) and secondary energy resources;

5) participation of railways, subways and urban electric transport enterprises of large cities in the development of perspective regional energy balances of subjects in their sphere of activity and construction of new electrified lines of railways and electric traction networks of urban electric transport;

6) cooperation with Ukrainian networks in the creation of smart networks, as well as the introduction of static semiconductor converters that support the set value of the power factor of consumers relative to the power supply network.

In addition, in order to ensure the energy security of the process of transportation on electric transport and subways and the functioning of railway infrastructure, the following set of measures should be implemented:

– backup or duplication of energy networks and systems;

– application in the contact network of modern systems against ice;

– extended use on self-lock and electricity supply overhead lines self-supporting insulated wires;

– creation of mobile modular (mainly railway) sources of energy supply (new TS, diesel or gas power plants, lighting sources, etc.);

– reservation of traction equipment (for example, temporary replacement of electric rolling stock by vehicles of autonomous traction);

– creation of own railway transport systems of energy supply, independent of external energy systems;

– implementation of software and hardware for the exchange of information between the railways and the reliability and power management organizations of NPC «Ukrenergo».

Conclusions

1. Based on system analysis of domestic and foreign traction power supply systems of railways and electric transport of large cities, the concept of their development is substantiated and proposed by increasing the supply voltage of traction substations and minimizing capacity upflows and energy losses, which provides resource and energy savings.

2. It is suggested that the investment programs of the structures that are part of Corporation «Ukrzaliznytsia» and the municipal services be synchronized according to their technological indicators, as well as according to the criteria of energy efficiency and quality of energy supply with similar investment programs of external energy.

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ПЕРСПЕКТИВИ РОЗВИТКУ ЕЛЕКТРИЧНИХ МЕРЕЖ ЗОВНІШНЬОГО ЕЛЕКТРОПОСТАЧАННЯ ТЯГОВИХ ПІДСТАНЦІЙ

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На основі аналізу класичних схем живлення тягових підстанцій залізниць та міського електротранспорту від енергосистем розроблені концептуальні напрями розвитку електричних мереж зовнішнього електропостачання тягових підстанцій в умовах ринкової економіки і нормативних вимог електроенергетики України, які дозволяють забезпечити енергозберігаючі режими їх роботи. На основі системного аналізу внутрішніх та зарубіжних систем електропостачання тягового транспорту залізниць та електротранспорту великих міст обґрунтована та запропонована концепція їх розвитку шляхом збільшення напруги живлення тягових підстанцій та мінімізації перетоку потужностей та втрат енергії, що забезпечує ресурс та економію енергії.

Пропонується синхронізувати інвестиційні програми структур, що входять до АТ «Укрзалізниця» та комунальних служб відповідно до їх технологічних показників, а також за критеріями енергоефективності та якості енергопостачання з аналогічними інвестиційними програмами зовнішнього енергопостаччання. Для зменшення втрат енергії пропонується: реалізація раціонального графіку руху поїздів та глибоких входів високої напруги з перспективою переходу до власних розподільних мереж 110 кВ, модернізація та оснащення сучасного електричного обладнання та інфраструктури рухомого складу головного та перспективного напрямку залізниць.

Необхідність розширення трамвайних і тролейбусних ліній та модернізації пристроїв електропостачання з точки зору енергозбереження потребує нових технологій проектування, будівництва та експлуатації об'єктів комунального підприємства «Міскелектротранссервіс». Такі технології впроваджені підприємством «ДАК-Енергетика» у виробництві сучасного електрообладнання комунального підприємства «Міскелектротранссервіс».

Найважливішими завданнями є вдосконалення стаціонарних і пересувних підстанцій та інших лінійних засобів тягового електропостачання шляхом комплектації функціональних модульних блоків сучасними розподільними пристроями з цифровим релейним захистом та діагностикою тягових мереж; локальне та дистанційне управління пристроями розподільних пристроїв, а також діагностика комутаторів та самодіагностика.

Ключові слова*: *зовнішнє електропостачання, тягові підстанції, електричні мережі, режими роботи енергосистем.