NATIONAL MANAGEMENT ASPECTS IN ENERGY EFFICIENCY OF ELECTRIC EQUIPMENT AT THE ENTERPRISE

ЗАГАЛЬНОДЕРЖАВНІ АСПЕКТИ УПРАВЛІННЯ ЕНЕРГОЕФЕКТИВНІСТЮ ЕЛЕКТРОУСТАТКУВАННЯ ПІДПРИЄМСТВА

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The article studies justification for the necessity in the organization of energy efficiency management at the enterprises, with account of oblique energy savings and energy resources that are obtained outside of the object of the electrical equipment modernization and definition of the ways, which contribute to the improvement of management. On the basis of the conducted analysis of statutory documents during the period of 1994-2017 and methods of energy audit, it was scientifically substantiated for the first time the expediency of making in these documents supplements, which in the process of organization of energy efficiency management at the enterprises stimulate a certain priority direction of modernization. Based on the analysis of technical literature, the following conclusion was drawn- the priority direction here is the modernization of the electric drive and mechanisms that provide a large multiplicative and synergistic effect. The practical significance of the article a multiple increase in the economy of energy resources and expended foreign currency on their purchase by the state.

Key words: *energy efficiency, energy intensity, modernization of electrical equipment, energy audit, energy management.*

В статье рассматривается обоснование необходимости при организации управления энергоэффективностью предприятий учета косвенной экономии электроэнергии и энергетических ресурсов, получаемых вне объекта модернизации электрооборудования и определение путей совершенствования управления. На основе проведенного анализа нормативно-правовых документов за период 1994-2017 гг. и методик энергоаудита, впервые научно обоснована целесообразность внесения в эти документы дополнений, стимулирующих, при организации управления энергоэффективностью предприятий, определенное приоритетное направление модернизации. На основании анализа технической литературы был сделан следующий вывод – приоритетным направлением является модернизация электропривода и механизмов, обеспечивающая большой мультипликативный и синергетический эффект. Практическая значимость статьи – многократное в масштабах страны увеличение экономии энергетических ресурсов и затрачиваемых государством на их приобретение валютных средств.

Ключевые слова: *энергоэффективность, энергоемкость, модернизация электрооборудования, энергоаудит, энергоменеджмент.*

В статті розглянуто обґрунтування необхідності при організації управління енергоефективністю підприємств обліку непрямої економії електроенергії і енергетичних ресурсів, одержуваних поза об'єктом модернізації електроустаткування і визначення шляхів удосконалення управління. У роботі використано системний підхід. Зроблені: з'ясування проблеми, аналіз стану способів її рішення, техніко-економічний аналіз нових технічних рішень, визначення шляхів вдосконалення вирішення проблеми. Проведено аналіз показника енергоємності України в період з 2009-2016 рр. в порівняні з країнами світу та Європи і визначено, що хоча він має тенденцію до зменшення, однак Україна продовжує залишатися країною з одним з найвищих показників енергоємності ВВП у світі. Наведено, що за оцінкою Міжнародного Енергетичного Агентства Україна належить до найбільш енергозатратних країн світу, в якої щорічний обсяг втрат національної економіки від неефективного використання енергоносіїв оцінюється на рівні 15-17 млрд. дол. Зроблено висновки про доцільність доповнень на державному рівні нормативно-правових актів, що стимулюють діяльність підприємств з модернізації електроустаткування, який забезпечує великий непрямий ефект економії енергетичних ресурсів поза об'єктом модернізації. Встановлено необхідність обліку непрямого ефекту при виконанні енергетичного аудиту підприємств і визначенні заходів щодо підвищення енергоефективності. На основі проведеного аналізу нормативно-правових документів за період 1994-2017 рр. і методик енергетичного аудиту, вперше науково обґрунтовано доцільність внесення до цих документів доповнень, які стимулюють, при організації управління енергоефективністю підприємств, певне пріоритетний напрямок модернізації. На основі аналізу джерел технічної літератури зроблено висновок, що таким напрямком є модернізація електроприводу і механізмів, що забезпечує великий мультиплікативний і синергетичний ефект. Практичною значимістю статті є багаторазове в масштабах країни збільшення економії енергетичних ресурсів і витрачаються державою на їх придбання валютних коштів.

Ключові слова: *енергоефективність, енергоємність, устаткування, приладів безпеки, енергоаудит, енергоменеджмент.*

Formulation of the problem. Improvement in efficiency of energy resources use is important for any state, because it reduces the cost of GDP production, increases competitiveness, improves the environmental situation and saves energy resources for future generations. The latter circumstance is of prior importance because these resources are not only a source of energy, but also a raw material, which is necessary for mankind to produce such products as plastics, pesticides, paints, etc. For Ukraine, the solution of energy efficiency problem is especially important, since the structure of its economy is characterized by a high share of power-intensive industries. The electromechanical energy conversion that is carried out by means of electric drivers plays an important role in all spheres of modern society. Electric drivers are the largest consumers of electric energy. They account for more than 65% of the generated electricity. It follows thence, the rationale of the considered aspects that are related to the energy efficiency of electric drivers machines and mechanisms. In this article, we consider some issues related to management of energy efficiency at the enterprise, through the modernization of electric drivers, which, according to the authors, are not sufficiently covered in the economic literature and require more careful consideration.

Analysis of the recent researches and publications. The issues of energy saving and energy effi-

ciency were covered in the publications of domestic and foreign scientists. : A significant number of publications are devoted to general theoretical issues of energy efficiency, consideration of national priorities for energy saving [1], development of an energy saving strategy in Ukraine [2], peculiarities of implementation of the state energy efficiency policy from the point of view of world best practices [4]. In [5; 6], the initial conditions and barriers to the formation of energy saving and energy efficiency policies in Ukraine were analyzed, the current state of energy supply and energy consumption in the country was assessed. The possible directions of development of the Ukrainian energy industry to improve the energy efficiency of the Ukrainian economy in the form of strategies and expert opinions are considered [7]. In [8], the authors presented energy-capacity indicators in various countries, as well as possible ways and means of saving energy resources both in the world and in Ukraine. The role of the electric driver in solving energy resources saving problem was considered in the works of [9; 10], where the attention was drawn to the special features of the regulated electric driver as a mean of technological processes optimization. However, technical achievements in the field of energy-efficient electromechanical systems are not properly reflected in the existing, at the moment, statutory framework and methods of energy audit.

Setting objectives. Despite a slight decrease in the energy intensity per unit of GDP over the past 10 years, Ukraine is significantly behind the advanced nations in this index, which indicates that there is want of energy efficiency management. Denisyuk S.P. and Tarhonskyi V.F. in their work [6] noted that “the improvement in the economic development of the country demands the review of some regulations of national policy in the sphere of energy efficiency and energy supply to increase energy safety of the country”.

The purposes of the article to substantiate the necessity in supplements to the statutory acts and method of energy audit of stimulation the priority of the electric driver modernization that provides oblique savings of energy resources. Under the *oblique* economy we realize savings not at the enterprise, where updates are carried out, but those enterprises which are involved in previous or subsequent cycles of the process. To pay attention of economists and energy auditors to the incorrect assessment of energy saving based only on the indicators of electric meters of electric drivers before and after modernization and explain the essence of multiplicative (multiplying) and synergistic effects of energy efficiency improvement from modernization.

Presentation of the main material of the research. First of all, we are going to analyze the rationale of solving the problem of increasing energy efficiency for Ukraine and to what extent this solution can contribute to improvement of the energy efficiency of electrical equipment in comparison with saving energy resources by other means.

Ukraine belongs to those countries with average provision with its own energy resources. Currently, 67% of gas, 57% of oil products and a significant part of coal is imported, for that vast foreign currency funds are spent [12].

Awareness at the state level of the necessity in improvement of energy efficiency became measures for legal and regulatory support of energy resources saving. In 1994, the law of Ukraine “About energy saving” was adopted, and then until 2006, 6 more laws were adopted, 6 presidential decrees, 20 resolutions of the Cabinet of Ministers were issued, more than 150 normative acts that regulate the activities of all participants of the energy market were approved. Nevertheless, by September 2007, Ukraine reached the 1st place among European countries in terms of energy consumption per unit of GDP. At the same time, the energy intensity of Ukraine was more than 3 times higher than the energy intensity of advanced industrialized countries, which testified to the weak efficiency of the measures that were taken. Since 2007, 8 laws, 27 resolutions of the Cabinet of Ministers have been adopted, a number of organized structures that manage, control and regulate activities of the state and enterprises in the field of energy efficiency have been created [11].

A general indicator of the efficiency in usage of fuel-power resources is energy intensity- the specific consumption of primary energy per unit of gross domestic product of the country (GDP). The figure 1. shows the dynamics of energy intensity in Ukraine since 2009 in comparison with the Central Europe and world.

From figure 1, we see that the value of energy intensity of Ukraine's GDP during the period from 2009 to 2016 decreased [12]. However, Ukraine continues to be one of the countries with the highest GDP energy intensity. Herewith, the reduction of energy intensity is largely achieved not by improving the efficiency production, which is usually provided by the modernization of equipment, but by reducing energy-intensive industries in the metallurgy, machine-building, chemical and other industries.

The level of energy intensity of GDP in Ukraine, and other countries in 2016, calculated at the purchasing power parity (PPP) in prices for 2010 (kg. of oil equivalent per $1). USA – kg o.e./$2010), is shown in figure 2, where we can clearly see that this indicator in Ukraine is 2.5-3 times worse than in many other countries.

With the help of types of fuel-power resources we consider structure of their consumption in Ukraine (Figure 3). In 2016, the total consumption constituted 114.8 million tons of oil equivalent, which was in 4.6% higher than in 2015. Where: coal – 31,8 %; natural

gas – 34,3 %; oil products – 11,9 %; nuclear energy – 20 %; hydraulic energy – 1,9 %.

The import content of primary energy resources in Ukraine during the recent years averaged about 38%. The state imports three quarters of oil and natural gas, 100% of nuclear fuel, and today it is forced to import coal and electricity. In 2017, the supply of imported gas to Ukraine was carried out exclusively from the European gas market and vast foreign currency funds were spent (in 2017, only $ 2.9 billion were spent on the purchase of natural gas) [12].

According to the International Energy Agency (IEA), Ukraine belongs to the most energy-consuming countries all over the world. The annual volume of national economy losses is estimated at $ 15 – $ 17 billion [13] because of inefficient use of energy resources.

The above-mentioned data testify to the exceptional rationale for Ukraine in solving the problem of improving the efficiency of energy resources.

We are going to analyze to what extent the savings of electric energy and modernization of electrical equipment contribute to solving the problem of energy efficiency on a national scale.

About 70% of fuel energy resources are used in furnace-boiler production, and only about 23% of these resources are used for conversion into electric energy. It would seem that the reduction of electricity consumption is not of paramount importance.

We demonstrate that this is not the case, since the increase of the energy efficiency of some types of electrical equipment can provide a large oblique effect of energy savings, besides the direct effect (taking into account the presence of boiler units at many enterprises) and better rate of direct savings in fuel resources. Energy saving itself is an extremely effective mean of saving raw energy resources. Taking into account the energy costs for the extraction and transportation of primary energy resources to the power plant for the production of one unit of electricity, N units of energy of primary energy resources are spent equal to [9; 10; 14]

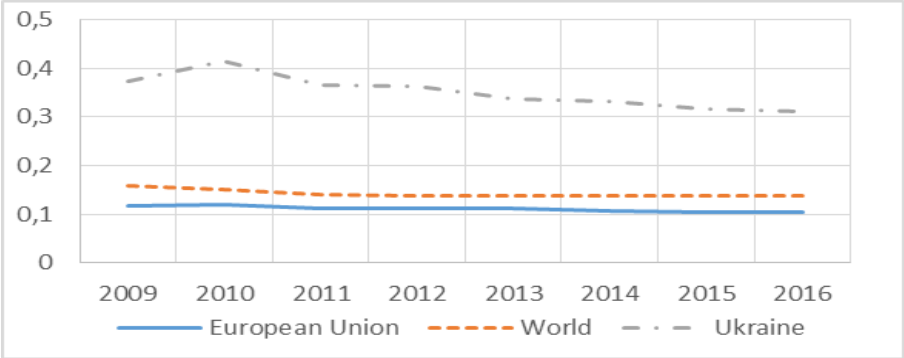

Fig. 1. Energy Intensity of Ukraine's GDP, compared to Europe and the world, 2009-2015 (kg o.e./$2010 PPP)

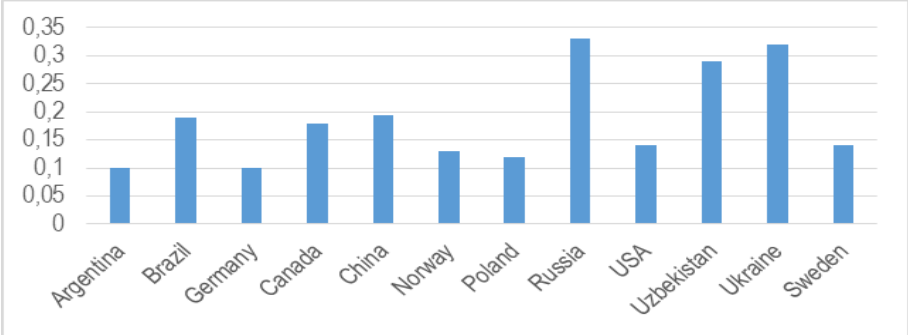

Fig. 2. Energy Intensity of Ukraine and other countries in 2016 (kg o.e./ 2010 PPP)

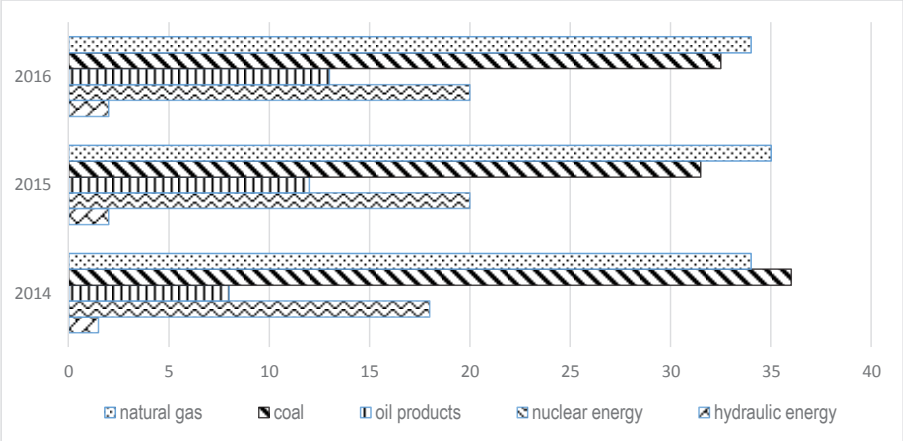

Fig. 3. Structure of fuel-power resources consumption in Ukraine 2014-2016 (%)

$$N = \frac{1 + \frac{q}{Q\eta_{ЭС}}}{\eta_{ЭС}} = \frac{1}{\eta_{ЭС}} + \frac{q}{Q\eta_{ЭС}^2}, \qquad (1)$$

where $\eta_{ЭС}$ is the efficiency of the power plant;

q – electricity costs for production and transportation of one ton of primary resources (Gcal/t);

Q – specific calorific value (Gcal/t).

The current situation in Ukraine consists in the deterioration of power plant equipment, changes in

the schedule of shift mode of operation at the industrial enterprises, the quality of coal and for this reason the efficiency of thermal power plants (TPP) sometimes is reduced to 28-25% [9]. At the same time, each saved unit of electrical energy in the energy equivalent saves about 5 units of primary energy resources. This means that out of 100 trainload of coal that came to the power plant, only 20 trainload will be completely converted into electricity, and the rest 80 trainload will be burned, polluting the environment with harmful gases, dust, ash. This important environmental factor should also be taken into account in the state organization of energy efficiency management, for example, by priority reduction of TPS loads.

We define what type of modernization for electrical equipment should be produced first of all in order to reduce the loss of electrical energy. It is known that by the transmission of electricity from the power plant to the consumer in the networks of leading countries, the regulatory losses should not exceed 7% in Ukraine-12.8% [11]. The consumer faces the main losses, and the main consumer of electric energy (up to 70%) is the electric driver [3] that represents the electromechanical system that is intended for transformation of electric energy into mechanical and movement control of working bodies of machines and mechanisms.

Usually, when developing measures to improve energy efficiency at industrial enterprises, the expected result of energy saving is estimated as the difference between the counter readings of electric meters of electric drivers before and after modernization at the enterprise where modernization is carried out. However, from the state point of view, this approach is incorrect. Technical experts drew attention to the multiplicative (multiplier), and synergistic effects when replacing a non-regulated electric driver with a regulated one [10]. The essence of these effects consists in the fact that the regulated electromechanical system, as a mean of optimization of the process saves electrical energy not only in the place of modernization, but also in the previous or subsequent cycles of the process, particularly, by saving consumables. Besides, in complex machines and units, the technological process of which is provided by several electromechanical systems, the optimization of their interaction provides a synergistic effect of savings. From the authors ' point of view, this issue is important for government agencies and economists when determine measures and organization of energy efficiency management.

We explain the essence of the above-mentioned effects on some examples:

Example 1 shows the oblique savings as a result of multiplicative effect.

Savings were offered after the modernization of the electric driver in the pumping unit at the station of the 2nd lift with the replacement of the unregulated electric driver with an adjustable one, comparing with the year that preceded the modernization: electricity meter E_e -42%, water E_w – 25%. In addition, the number of water main leaks decreased from 60 per year to 8 [6]. The economic effect of the share of savings constituted: at the cost of energy saving = 13%, water = 64%, reduction of wastewater costs =21%, and the total effect can be calculated from the formula (2).

$$E = E_e + E_w + E_{ww} \quad (2)$$

Taking into account that the energy component of water supply costs for delivery and water removal constitutes 60%, we obtain that the energy savings at the pumping stations from the place of water intake to the pumping station and its wastewater disposal is higher than the electricity meter at the station that incurred cost of modernization (3).

$$K = \frac{(E_w - E_{ww}) * 0,6}{E_e} \approx 4\,\text{times} \quad (3)$$

That is, due to the reduction of electricity consumption by the pumps of the main water supply system, as well as by the delivery and restoration of it after wastewater disposal, from the state point of view, the total five times greater savings were made, comparing to those recorded by the electricity meters at the modernization object. If we take into account the property of each unit of saved energy in the energy equivalent to save 5 units of fuel energy, the impact on energy consumption increases in many times. That is, the vast modernization of electromechanical systems that provide a multiplicative effect should be particularly stimulated on a national scale.

Example 2 synergistic effect of direct saving of energy resources.

There was a replacement of 4 unregulated electric drivers on adjustable during the modernization of electric drivers of the boiler unit with capacity of 300 MW. The following electric drivers carry out the transportation of: gas, air, water, as well as smoke removal of combustion products. The optimization of operation of these electric drivers after replacement of unregulated with frequency-regulated allows to increase the efficiency of the unit by 2-5%. Herewith, the power saving of electricity by electric meters of all electric drivers is about 90 kW. At the same time, gas savings with a 3% increase in efficiency is equivalent to a power of 9000 kW i. e. in 100 times more.

Example 3. During the modernization of electric drivers of the cold rolling mill 1700, the accuracy of metal strip thickness control was increased and rolling with a minus tolerance Δ d was provided [10]. At a rolling speed of 30 meters per second and mill operation time per year for about 5000 hours, the metal savings will be

$$M_e = SV\ \Delta d\ \gamma\ t\ 3600, \text{ where} \quad (4)$$

S – width of the strip-1.7 m;

V – rolling speed-30 m / s;

Δ*d* – negative allowance – 10мк = 10^{-5}m;

t – number of working hours per year – 5000 ;

ɣ – the specific mass of the metal is 7.8 t/m3;

If we consider that for the production of this metal is necessary to mine ore, to found iron, steel, to roll slabs, to carry out transportation of materials, it is possible to imagine what a huge amount of energy resources will be saved at these stages of production.

Almost any improvement [9; 10] in the performance of the technological process by means of a controlled electric driver provides not only a direct (at the place of installation), but also a mediate (oblique), often significantly greater, saving of energy resources. That is, the modernization of electromechanical systems is in a certain respect a unique mean of improving energy efficiency. The calculations of the International Energy Agency testify that by increasing the efficiency of electromechanical systems is possible to reduce their consumption of electricity by 20-30%, which on the average is 10% of the total generated energy [13]. These calculations do not take into account significant savings in consumables and oblique savings. Probably this can explain a well-known fact from the world experience that occurred in the United States. To overcome the economic consequences of the 1st world energy crisis in 1973 in the United States was defined the action plan on reduction energy consumption per unit of GDP, providing the modernization of equipment with more energy efficiency and assessment of the expected savings of the PDS. After a year of realization of the planned measures, it turned out that the saving of the PDS was in 10 times higher than it was estimated. In this economy, the significant contribution is received due to the modernization of electric drivers of the machines and mechanisms which provide optimization of technological processes and show thus multiplicative and synergistic effects. This is confirmed by the high percentage of the share of the regulated electric driver in the USA, which currently reaches about 40% [10]. The share of regulated electric driver in industrialized countries is 50-60 %, which (according to various estimates) is 3-5 times higher than in Ukraine.

Thus, in the organization of energy efficiency management of electrical equipment the special attention should be payed to the modernization of electric machines and mechanisms that provide, in addition to direct, the oblique energy savings.

We will analyze to what extent the regulatory framework that exists at the moment and methods of energy audit contribute to the modernization of the above-mentioned electrical equipment.

Since the statutory instruments and measures that aim to improve the energy efficiency of GDP in the period from 1994 to 2007 did not provide a radical improvement in the efficiency index that is testified by the above-mentioned fact that by September 2007 Ukraine took the 1st place in Europe in terms of energy consumption per unit of GDP, we will perform the analysis of the statutory instruments from 2007 to 2018. During this period, 8 laws related to the problem were adopted. 3 laws are related to the field of alternative energy sources, 3 laws have connection to the commercial energy accounting and energy efficiency of buildings. Other laws: The Law of Ukraine “About implementation of new investment opportunities, warranting rights and legitimate interest for economic entities to provide a large-scale energy modernization” the Law of Ukraine “About the amendments to the Budget Code of Ukraine concerning the implementation of new investment opportunities, warranting rights and legitimate interest for economic entities to provide a large-scale energy modernization” and in the supplements to them, adopted in 2015, the following was established: legal and economic principles of implementation of energy service, budget benefits and reallocation of public expenditures were identified as well as the costs of energy services by reducing taxes on utilities and energy carriers to conduct a large-scale energy modernization. However, these laws do not provide incentives for priority modernization of electrical equipment at industrial enterprises that provide a large oblique effect in saving electricity and energy resources.

Analysis of the methods of energy audit at the industrial enterprises also indicate that the factor of oblique energy resources saving is not taken into account in a due measure. The standard method of energy audit approved by order No. 56 of 20.05.2010 of the National Agency of Ukraine for the efficient use of energy resources “On the implementation and functioning of the unified energy audit and management system for energy saving in Ukraine” includes many important aspects:

– data collection, processing and analysis;

– development of recommendations for the implementation of energy-saving measures;

– requirements for drawing up an energy audit plan;

– requirements for measurements;

– energy-economic and financial-economic analysis;

– analysis of the efficiency of fuel-power resources consumption by the object of energy audit;

– assessment of the total energy saving potential of the industrial enterprise;

– and others [11].

The analysis of this technique shows that the section “Assessment of the total energy saving potential of an enterprise” does not provide the necessity to take into account the multiplicative effect and oblique savings of energy resources that were obtained outside of the enterprise.

Thus, the statutory framework and methods of audit do not stimulate the priority modernization of electrical equipment by definition of management

measures efficiency of the electrical equipment at the enterprise, which, although does not give the highest energy-saving effect directly at the enterprise, but repetitive effect out of it. However, from the state point of view, the most important is the general effect, since it is the state that spends foreign currency on the import of energy resources.

These examples lead us to the following conclusions:

– when drawing plans for improvement in energy efficiency at the industrial enterprise, special attention should be paid to the electrical equipment (particularly, electric drivers of machines and mechanisms), the modernization of which provides a large multiplicative and synergistic effects in energy saving;

– since the enterprises with private ownership do not have a special interest to take into account the effect of oblique energy savings outside the industrial enterprise, it is necessary to develop methods to stimulate the modernization of electrical equipment that provides oblique savings;

– incentive measures should be combined with policy planning measures at state-owned enterprises.

Among the measures that stimulate the priority modernization of electric equipment at the enterprises that provide multiplicative and synergistic effects, the following can be considered: purposeful increase of budget funds in the form of grants or loans; granting enterprises the right (and perhaps some responsibilities) to invest from the received savings into the subsequent modernization of electrical equipment; provide the additional tax benefits; wide promotion in the management of the updated technical achievements in the field of electrical equipment that provide a vast multiplicative and synergistic effects.

Conclusion. The problem of improving energy efficiency of Ukraine's GDP is of national importance. A significant role in its solution can play a large-scale modernization of electrical equipment at the enterprises that provide a large oblique effect in saving energy resources. The improvement of the incentive at the industrial enterprises for priority modernization of the above-mentioned equipment should be comprehensive. The aspects of its solution mentioned in the article require the involvement of a wide range of specialists from different fields of science, technology, public administration, and this should be reflected:

– in the relevant amendments to the legislative acts;

– in the development of strategies and plans for the modernization of electrical equipment;

– in the development of the state budget;

– when making supplements to the methodology of energy audit at the enterprises and in supplements to the methodology of control of energy efficiency management of electrical equipment at the enterprise;

Improvement in the energy efficiency management of electrical equipment will significantly reduce the losses in the national economy from the inefficient use of energy, which, as previously mentioned, according to the International Energy Agency in 2016 was estimated at USD 15-17 billion.

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