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Reserves for Improving the Energy Efficiency of Traction Power Systems

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Summary
In the article, trends in the electric power industry were analyzed, namely, constant growth in energy resources and the need to improve energy efficiency, the introduction of energy saving measures. Some methods of improving efficiency in the railway transport industry are considered.

Keywords: energy efficiency, energy efficiency indicators, energy-saving, electric traction, electrified railways, DC current, distributed power supply

1. Introduction

Today, the energy efficiency is seen as the main focus of economic growth around the world. Active realization of the potential of energy efficiency will contribute to a significant reduction of energy costs. Problems in improving energy efficiency require a comprehensive approach and are very relevant in the transport sector in general and especially in rail transport. Energy efficiency is the most important indicator of the competitiveness of railways in the domestic and foreign markets of transport services. When determining the real picture of the use of energy resources, each link in the traction power supply system and the system as a whole requires energy efficiency indicators that make it possible to assess the efficiency of energy consumption and determine the effectiveness of energy saving measures.

2. Consumption of energy &Energy efficiency system

The list of energy efficiency indicators of the equipment contains more than 40 names. But it should be noted that only some of them are real indicators of fuel or energy efficiency. Indicators can be divided into 2 groups:
- Indicators of the type of factor of usefulness: efficiency, coefficient of useful energy use [%], coefficient of electrification per useful energy [%].
- Indicators of specific losses of fuel or energy.

Calculation of energy efficiency is performed on several indicators, we will consider the main ones:
- Cost-effectiveness of consumption of fuel and energy resources: for example, fuel consumption per 1 km of road when transporting 1 ton of cargo
- Energy transmission efficiency: for example, the percentage of energy losses in transmission networks.
- Energy intensity of production: characterizes the amount of energy spent on the main and auxiliary technological processes, and is expressed in the amount of energy per unit of output.
- For rail transport, indicators such as: efficiency, losses of electric energy, percentage of losses, specific expenses of electric power for traction of trains, electricity costs for substations' own needs are more relevant. Electricity consumption in rail transport consists of several components, which are shown in Fig 1.

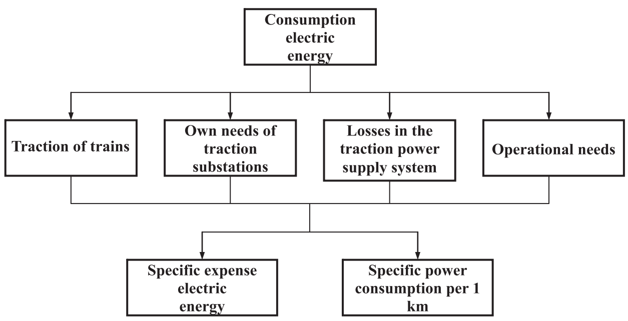

Fig. 1. Structure of electric energy consumption

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3. Methods of improving the energy efficiency

Energy-saving activity of railways is expressed by saving of fuel and energy resources, which are connected with the process of transportation [8]. Since the beginning of railways reform, the main point in developing the stages of the implementation of the energy saving strategy is to assess the potential of increasing energy efficiency in the immediate and long-term perspective. The part of the reserves (easily achievable) was exhausted over the past period. On existing traction power supply systems, there are several ways to improve the efficiency of Figure 2. Let us consider some of them.

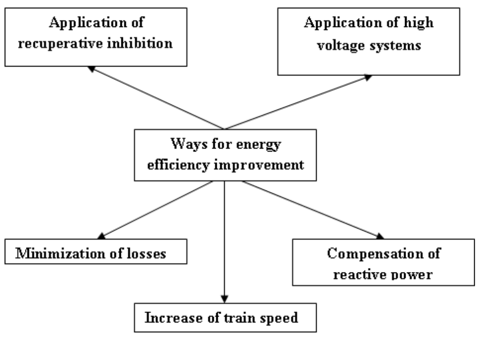

Fig. 2. Ways for energy efficiency improvement

4. Application of recuperative inhibition

Recuperation in different systems of electric transport gives the opportunity to reduce energy intensity by 30–50%, but the operating systems of traction power supply, the recovery rate does not exceed 5–10% [11]. The most effective braking is when all the recovery energy is used by other electric locomotives. The main disadvantage is the complication and increase in the price of rolling stock equipment and increased wear of the generator. There are several factors that do not allow full recovery potential [10].

- The appearance of excessive recovery energy due to the absence of trains on the line in traction mode,
- Instability of recovery energy.

The problem of excessive energy recovery is solved by reversing this energy into the external network. For this purpose, traction substations are equipped with direct current inverters, through which excess energy is returned to the primary network. But in this case there is a deterioration of its regime [9]. In systems of traction power supply of alternating current inverters for absorption of excess energy of recovery are installed on a rolling stock In addition, the return of energy to the primary system of electricity has a number of significant drawbacks:

1) the equipment of the traction substation is complicated,
2) when the inverter is turned on, there are circulating currents in the circuit formed by rectifiers – the energy transmitted to the primary network has low quality;
3) the mode of feeding of non-empty consumers deteriorates,
4) the voltage in the traction network is significantly increased.

In it was established that the energy of recovery can reach 60% of the expenditure spent on traction. The main problem of recuperative inhibition is the ability of the network to receive additional energy. This is possible with the use of this energy by another electric drive in the mode of traction or transfer it to a three-phase network. Equipping traction substations with capacitive drives, for the reception of excess energy with its subsequent return it is possible to eliminate the disadvantages [5].

5. Reduction losses and improving quality

Increasing the efficiency of the use of electricity is associated with a reduction in its losses and improving quality. The indicator of electric power losses is one of the most important indicators of the state of the electricity supply system, accounting and activities of energy supplying organizations. Electricity losses of up to 10% are considered to be physically feasible. As a result of a single-phase nonlinear traction load, the power quality indicators exceed the permissible limits. All energy losses in the networks can be divided into main (productive) and additional (non-productive). The main losses – for the transfer of active energy to the rolling stock and these losses should be reduced to such a minimum that there were no economically justifiable ways to reduce them further. Unproductive losses include: low-quality energy exchange between the traction substation and electrorolling stock, the flow of jet capacities, poor-quality electricity, etc. [7]. The reduction of conditional losses consists of two parts: reduction of calculation errors and reduction of measurement errors [4]. According to [7], power losses in the traction substation and network elements make up 5-20% of the active power of the rolling stock (depending on the location of the electric locomotive). Total losses make up 28–35%. Electricity imbalances arise due to the lack of loading of measuring transformers, in order to prevent this necessitating the loading of measuring transformers to meet the requirements of GOST 7746-2001 and GOST 1983-2001 [6].

6. Compensation of reactive power

The compensation of reactive power in traction power systems is used to reduce electricity losses, improve the voltage regime and reduce the charge for the flow of reactive power. For compensation of reactive power at traction substations of alternating current devices devices of a transverse compensation are used – a set of batteries of capacitors connected in series with the reactor. The reactor reduces reactive power but at the same time prevents the occurrence of resonant phenomena and at a certain frequency setting it reduces the harmonic component. Allows you to change the direction of jet power flow from the „energy source – consumer" circuit to the circuit, „compensating device – consumer", which removes the load from the electrical network. But in the absence of a traction load, this device generates excess reactive power, which leads to the imposition of sanctions [1]. The main criterion for the effectiveness of reactive power compensation measures is to achieve the maximum economic effect of its implementation. The basis for obtaining this effect is the reduction of network losses.

7. Application of high voltage systems

The development of modern electronics enables the introduction of high-voltage direct current systems that, by their characteristics, exceed the performance of any AC system [12]. There are several ways to increase the voltage in the DC contact network [3]:

- The constant voltage of 6–24 kV formed at the traction substation is transferred to the rolling stock through the traction network;
- Construction of the longitudinal line 6–24 kV, power supply to the contact network is carried out using transformation points 6 (24) / 3 kV.

An increase in the voltage up to 6 kV at an electric power of 3000 kW reduces losses in 4,012 times also eliminates the possibility of collapse of the contact wire and reduces the effect of wandering currents. An increase in voltage up to 12 kV for capital costs can be compared to the cost of a line of 25kV of alternating current. But for 12 kV there is a problem with rolling stock equipment. In [4] the calculations were made in which showed the level of energy losses at different values of the live voltage of the contact network and the various capacities of electric locomotives.

Analysis of these data showed that increasing the voltage in the contact network from 3 to 6 kV will reduce losses by 75%., Fig 3(a). Further increase up to 12 kV gives an additional gain in loss reduction by almost 19% – 18.73%, (b). With an increase of 24 kV, only 4.7%, (c). In connection with this, it was concluded that increasing the voltage to 6–12 kV is more appropriate, at the same time, raising to 24 kV does not make sense, since the level of loss reduction does not cover the cost of implementing this technology.

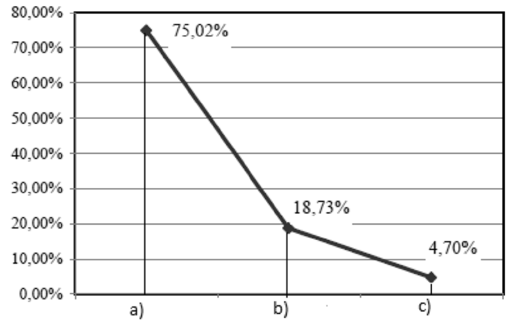

Fig. 3. Changing the value of losses when switching from one supply voltage to another

8. Increase of train speed

According to the calculations carried out at the DNUZT for the electric train Hyundai Rotem at the implementation of a maximum speed of 160 km/h, the following is obtained: for a light-type profile, energy savings are 26–39%, with an average of 22–47%, with a complex type profile of 16–35%. But the value of the train speed depends to a large extent on the voltage on the current collector of the electric locomotive, which is determined by the parameters of the power supply system and the train situation. The increase in the volume of traffic and the organization of the movement of high-speed and high-speed trains leads to the fact that traction power supply devices limit the throughput of the section of the electrified railway due to lowering the voltage on the current collector of the electromotive force below the normalized values. Improvement of the voltage regime in the traction network by the means currently used does not solve the existing problem in full, due to increased power losses in the interconnector zone and the corresponding operating costs. The use of recent enhancement means does not provide the required energy indicators in many cases and is quite expensive. The above factors create the preconditions for replacing the centralized traction power supply system with a decentralized one. The economic effect is achieved by reducing the cross-section of the wires of the contact network, reducing energy losses, maintaining the necessary voltage level in the contact network and increasing the utilization rate of the power of the main power equipment with decreasing its installed capacity. The gain on the basis of distributed power involves the transition to a new circuitry of the traction network (see Figure 4).

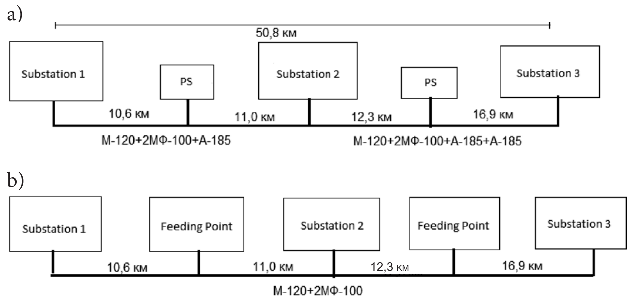

Fig. 4. Scheme of replacement of a plot: a) at a centralized feeding (PS – Post-section); b) with distributed feeding

In this case, the power consumption regulation is carried out in a single system of distributed control of active intelligent equipment capable adaptively to change the characteristics of transmission, transformation and consumption of electric energy and to optimize the mode of functioning of the traction power system in the given volumes of transportation work and in conditions of high-speed traffic.

9. Conclusions

1. The state of the equipment of traction power supply systems in Ukraine leaves much to be desired. Available methods to improve the energy efficiency of existing systems do not meet the requirements of world trends in energy consumption and energy conservation. The basic equipment funds are obsolete and require modernization. There is a need for a transition to non-traditional traction power systems that will bring Ukrainian railways to a new level.
2. It is necessary to replace the worn-out equipment fleet, reduce aerodynamic drag, reduce mass, use recuperation during braking, more efficient traction through modern engine management technologies, modernization of dispatching, repair of roads and highways.
3. The level of energy consumption and economical use of electric energy to date is one of the determining factors in introducing high-speed and heavy traffic on electrified railways. This requires, along with the introduction of new technology, the development of new approaches to the traction network circuitry. Estimate calculations show that when applying a traction power supply system of a distributed type of power loss and voltage in the traction network, it is much smaller (54.7 and 32.7%, respectively) at significantly lower traction substation power. This provides the basis for further research with the aim of technical implementation of the distributed power system on DC railways.

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Table 1

Results of simulation of comparative analysis of power schemes

Characteristic		Centralized power supply			Distributed power supply		
		without taking into account higher harmonics	taking into account higher harmonics		without taking into account higher harmonics	taking into account higher harmonics	
Average rolling stock current [A]		1945,55	1945,55		1945,55	1945,55	
Average feeder current [A]		1459,55	1459,55		982,50	982,50	
Average voltage loss [V]		372,18	451,32		250,50	304,10	
Loss of power	**kVA**	542,93	ΔS	612,11979	246,15	ΔS	329,4787
	kV		ΔP	612,11968		ΔP	329,4784
	quar		ΔQ	1,102138		ΔQ	0,5012
The share of losses from higher harmonics [%]		–	0,18		–	0,15	

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Rezerwy poprawienia wydajności energetycznej systemów zasilania trakcyjnego

Streszczenie

W artykule zanalizowano trendy w przemyśle elektroenergetycznym, tzn. ciągły wzrost zasobów energetycznych i konieczność poprawienia wydajności energetycznej przez wprowadzenie energooszczędnych środków. Rozważono również niektóre metody poprawy wydajności transportu kolejowego.

Słowa kluczowe: wydajność energetyczna, wskaźniki wydajności, energooszczędność, trakcja elektryczna, koleje zelektryfikowane, prąd stały, rozproszone zasilanie

Резервы для улучшения энергоэффективности систем электроснабжения

Резюме

В статье проанализированы тренды в электроэнергетике, т.е. постоянный рост энергетический ресурсов и потребность улучшения энергоэффективности и введения средств сохранения энергии. Рассматриваются также некоторые методы улучшения эффективности железнодорожного транспорта.

Ключевые слова: энергоэффективность, индикаторы энергоэффективности, сохранение энергии, электроснабжение, электрифицированные железные дороги, постоянный ток, распростроненное питание