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Composite structural elements of overhead lines as a means of increasing technical efficiency

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Abstract. Innovations in engineering and technologies depend not so much on emergence of new properties of the equipment, production process, system of management of the enterprise, but to a greater extent on their occurrence in the necessary set of combination. Technical and economic indicators reflecting technical and economic efficiency are usually used as characteristics. The degree of technical efficiency is determined by a combination of three properties – safety, reliability and productivity. These basic properties determine the economic effect of an innovative product performing certain functions, enabling to estimate their usefulness and significance. One of the means of increasing the overhead lines technical efficiency in the electric grid is the introduction of composite structural elements. The overhead line model is proposed for assessing the impact of elements on reliability as a component of technical efficiency. Changes in the reliability of the line when introducing innovative elements are calculated and priorities are defined.

1. Introduction

The terms "innovative products", "innovation activity", "innovative development" are used privately. However, it remains unclear how the term "innovative" differs from the others. It is not clear what criteria can be used to distinguish innovations. This determines the relevance of the work. The issues of the feasibility study of innovative techniques effectiveness and technologies are extremely important. There is no unified understanding of terminology, in most cases there has been no analysis of technical efficiency.

Taking into consideration only economic effects in the analysis of innovative products has been a priority. It has lead to creating barriers to the innovation application. It has caused a slowdown of the innovative development of the enterprise, industry and the country. These factors determine the feasibility of the study.

Often, a qualitative feature enabling to allocate innovative products is the availability of an appropriate technical characteristic, which essentially distinguishes it from analogues. It is vital to determine quantitative technical indicators the achievement of those will enable to distinguish innovation.

2. Problem definition

The objective of the work is to define objectives of innovation, as the basis for innovative development. Presenting a change in the innovation activity is supposed to be vital and understood as the process of innovation commercialization.

From the authors' view, innovation concept can be considered as the improvement of the technical efficiency of products. If this goal is achieved and the particular tasks are solved, a basis for obtaining the economic effect from the introduction and use of innovative products appears. The economic efficiency is a necessary condition for the commercialization of innovations. The activity of entities forming innovative infrastructure is aimed at that resulting in the innovative development of the enterprise, industry, country.

Tasks:

- Systematization, analysis and terminology arrangement in the field of innovation and innovative development.
- Criteria determination for comparison of technologies, their classification as "innovative".
- Analysis of the technical efficiency of innovative products by the example of composite structural elements of overhead lines.

Scientific novelty of the study. It is shown that the subject of innovation activity should increase the technical efficiency of innovative products but not as the commercialization of scientific and technological achievements. The definition of innovative development of an enterprise, industry, and country, as revolutionary and intensive changes in the technological structure in combination with the reduction of man-caused risks is proposed.

The practical and theoretical significance of the results obtained is the increase of scientific knowledge in the subject area of innovative development. Results can be used to estimate the introduction of innovations in solving practical tasks of increasing reliability, safety and productivity.

3. Materials and methods

The research is based on the application of the methodology of the systematic approach to the process of development and implementation of innovations. Authors use methods of the system analysis allowing to reveal system of interrelations of the basic concepts and to define the term "innovative development".

There is a great number of definitions of the term "innovation" [1 – 8, etc.]. Denoting "upgrade" or "improvement" the term itself came from the Latin word "innovato". In scientific research it appeared in the XIX century [1]. At the same time, some authors tend to understand innovation as a process which is considered as an invention or an idea acquiring economic content [1,2], while others treat innovation as a result. This implies the understanding of innovation activity and innovative products.

So, Th. Schumpeter identified innovation as a new scientific and organizational combination of production factors motivated by the entrepreneurial spirit [3].

Within the framework of the "Oslo Manual" (the international standard adopted by the OECD in 1992) innovation is defined as the final result of innovative activity, has been implemented as a new or improved product launched on the market, new or improved technological process used in practical activities or a new approach to social services [6].

This definition allows us to consider the innovation of any new benefit having use-value, reflecting the combination of its useful properties. Being distinguished by its inherent combination of useful properties, determines the innovation importance allowing us to judge the value of innovation. The utility should be distinguished from significance.

Values are traditionally classified as material, economic, political, social and spiritual changing the development of society, economy and technology. The importance of innovation can be characterized by appropriate efficiency. It is generally accepted that the availability of economic and technical efficiency determines the production efficiency, the increase of that indicates the development of the enterprise, industry and the country.

Economic efficiency enables to estimate the possibilities of obtaining high profits with the minimum possible cost reflecting the significance of the innovations. Allowing us to estimate the usefulness technical efficiency indicates the ability to produce a certain amount of products or services using a given amount of resources. The concept of innovation is considered to include the process of creation, improvement, dissemination and application of innovations, which including identification of the usefulness and significance of innovations, the implementation of a measures set aimed at innovation commercialization.

Naturally innovation infrastructure is required for innovation activity requires necessary for the organization and arrangement of this activity. The presence of this infrastructure determing, first of all, economic relations and interconnections allows us to talk about the transition to innovative development in technology and other areas that ultimately determine the level and quality of life of people.

The very understanding and defining of the "development" concept can be multisided, and the lack of clear criteria for distinguishing development from other changes is crucial to practice. It is now clear that not every change, even if it is aimed at achieving a certain goal, can be considered as development [9 – 12].

In literature and practice, the combining the noun "development" with various adjectives does not make the definition of this concept clear and certain as it allows to identify differences in order to change the objects and the methods and means chosen for this. Types of development opposed and different from each other towards the growth of the number and its transition to a new quality are so widely known:

- intensive and extensive;
- evolutionary and revolutionary.

Often, the concept of development is used in relation to an individual enterprise and entire sectors of the economy, particular countries and continents in general representing a particular system. By carrying out certain targeted changes, condition of achieving the goals set, the results of these activities are often related to the socio – economic, scientific, technical and other development of systems. A certain interpretation of the term "innovative development" is presently widespread. In economic science and practice, the issues of developing a new theory of economic development taking into account the innovative orientation of technological, managerial, organizational, institutional and other systemic transformations in the economy are being actively discussed [13]. However, there are no generally accepted criteria to distinguish innovative development of the enterprise from other types of development. Therefore, innovative development is widely believed to be the process of introducing effective innovations into production and/or its management systems.

The authors propose to consider that the distinctive feature of innovative development is the approach to environmental management. Innovative development is aimed at keeping environment safe, as a basis to keep human life sustaining activity. The emergence of environmental safety standards stems from an understanding of the value of nature. Therefore, it is possible to estimate the innovative development by reducing land pollution by industrial and household waste, reducing harmful emissions into the atmosphere and other indicators characterizing changes in the ecosystem as human habitat.

Innovative development is proposed to be related to the enterprise in a combination of intensive and revolutionary development of the business entity providing a substantial, multiple increase in its production efficiency due to radical changes in both the technology and technology of production, as well as organization and management of the enterprise. At the same time, environmental measures, reduction of consumption of limited natural resources, reduction of risks of man-made accidents and catastrophes are necessarily taken.

Actually, the innovative development of the enterprise is based on activities aimed at the production of new or improved consumer goods, which have a new quality and useful and significant properties for the consumer.

Due to their usefulness and significance, innovative products have high use value and value. Sometimes this enables the company to have a short-term monopoly on the market and this provides a significant increase in economic efficiency in a market relationships.

The above stated enables to note that the increase in efficiency achieved through the use of scientific achievements and advanced technologies in production and the development of modern innovative management can serve as a characteristic of innovation in improving engineering activity and technology. However, if this leads to an increase in the risks of environmental degradation, then this cannot be considered as an innovative development, and if the task is to achieve it, then it requires determining what innovations can provide this.

The development of science and technology is obvious to provide more opportunities for creating new technology with the desired combination of properties. It can be achieved by applying knowledge about methods and methods of creating technical means for the effective performance of specified functions under certain conditions. To match the technical means one can use the same technical indicators characterizing their properties. The choice is made according to the technical efficiency, reflecting the importance of certain properties, i.e. their value for the specified conditions. And only if there is multiple similar technical efficiency of the options, one should compare their economic efficiency. Therefore, any innovative technical solution, first of all, should have increased technical efficiency. This is a crucial condition for the carrying out innovative activity.

It is important to distinguish between increasing the technical efficiency of performing certain functions and the economic effect derived from this. Naturally, the presence and size of the effect depends on improving the quality, increasing the number and volume of functions performed. However, experience shows that often an innovative solution at the stage of its appearance is inferior in economic efficiency to existing, outdated analogs. This can be explained by the need for the transition of economic entities to a new order of relationships and the abandonment of established relationships. Innovations require a reassessment of established values, leading to certain difficulties in society due to its conservatism. There is a well-known, rule "the best is enemy of good".

One can point to a sufficient condition allowing to rely on success of innovation. As it is known the main problem is to arouse the interest of investors seeking to get revenues from the commercialization of innovations.

But often to achieve this it is necessary to create a market demand for an innovative technical solution, demonstrating and proving the usefulness and significance of innovation. The emergence of demand is a sufficient condition for the commercialization of new technical products, considering it an innovation.

The availability of necessary (utility) and sufficient (significancy) conditions enables individual enterprises, entire countries and industries to change their technological structure. This ensures the growth of their productivity and competitiveness. The innovative infrastructure should create favorable conditions. Often speaking about innovative development, one means the development of this infrastructure, within which there is a quantitative growth of qualitatively new use values, primarily those created in the service sector.

Basing on the notion that innovative technology and technology have a certain combination of properties, determining their technical effectiveness, you can point out three main properties. These properties include - safety, reliability and productivity, figure 1. Their combination enables to obtain an economic effect, but the value and significance of each of these basic properties depends on many factors.

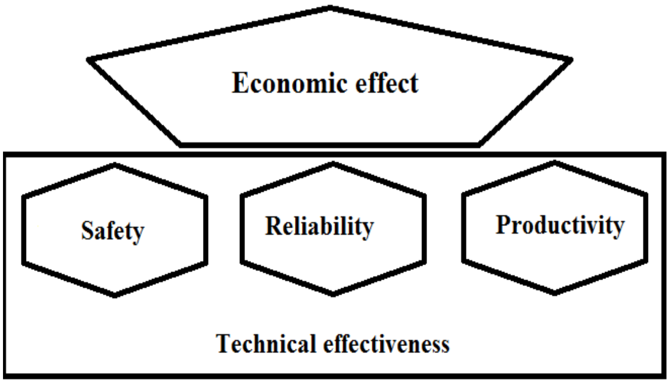

Figure 1. Basic properties of technical efficiency.

Being complex each of these basic properties includes certain properties. Technical security is a property characterizing the ability to prevent internal and external threats when using new equipment and technology and indicates the degree of protection of a person, society, objects and the environment from the threats connected with their introduction into the production process. Maintenance of technical safety means the creation of appropriate technical products and technologies. Providing technical safety means the creation of appropriate technical products and technologies. These include process equipment that provides control and management of emissions of hazardous substances, energies and information. This requires the introduction of modern diagnostic and monitoring tools, various types of automation, designed to prevent and protect against dangerous failures, accidents, and disasters. Therefore, the probability and risks of technical accidents and man-made disasters, as defined in [14], can be classified as complex indicators of technical safety. Innovative products as a result of innovation should ensure the reduction of these indicators.

Technical reliability is a complex property reflecting the ability of an object to be in working condition under certain internal and external influences. The main components of this property are reliability, maintainability and durability. The main indicators are the ratio of readiness and conservation of efficiency, allowing us to estimate the structural reliability of the system, i.e. on the existence of a sufficient number of interrelations between the elements forming the system that are necessary for the reliable performance of its functions. Shaping of this property is quite a difficult task, often its solution affects the economic efficiency, because requires not only redundancy of elements and connections, but also functional, temporal and information redundancy. However, if we seek a solution based on the principle of "improving reliability without reducing productivity", then this provides innovation activity aimed at improving technical efficiency to be considered Pareto optimal.

Technical productivity is a property indicating the ability of the system to perform a certain number of functions to provide services and the maximum amount output, using the specified size and type of resources. The technical performance of the system is determined by the basic production parameters of its elements and links, and is calculated per unit of time in relation to the operating conditions of the object when it is fully loaded.

Technical productivity depends on the influence of internal and external factors, reflecting the nature and conditions of the facility. In essence, the technical performance indicators reflect the production potential of the enterprise. Naturally, it is often used not to the full extent, but only in the demand for products and services provided. Therefore, coefficients of utilization of installed capacity and certain raw materials and other resources, such as electricity are used to characterize it.

Innovations aimed at productivity growth are usually implemented by science and technology achievements aimed at reducing the size and changing the type of resources used by the system, especially limited and non-renewable in nature. Usually productivity growth does not change the range of products and a service provided but affects the economic performance of their production. Therefore, they usually do not require radical changes in the system of economic relations and connections, therefore, the role of innovation infrastructure is not so important for the commercialization of these innovations.

Innovations aimed at increasing safety and reliability often depend not only the replacement of morally and physically obsolete elements and links with more reliable and safe ones, but also with changes in the structure of the system. With the appearance of new or exclusion of existing elements and connections, the quality of the system changes, which is manifested by a change in these properties.

Below, as an example of the proposed methodological approach to the analysis of technical efficiency, one of the options for solving this problem is shown for an electric grid enterprise by using composite materials for manufacturing the basic structural elements of overhead transmission lines.

4. Results

Since the 60s of the 20th century, various composite materials have been developed. Today in the world, as in Russia, these materials are experiencing their second wave. Presently the most significant reasons for their appearance include the development of the material itself (improvement of the properties due to the introduction of various additives) and the emergence of technologies for manufacturing products from composite materials.

Modern manufacturers offer a great number of products for the power grid complex. Mainly, composite materials are introduced in overhead transmission lines (OL). The properties of overhead lines are largely determined by the choice of their structural elements: wires, insulators, traverses, supports and other additional equipment. All the elements are closely related to each other and the low quality of one of them can eliminate all the advantages of the others, which can ultimately lead to a breakdown in the electricity supply to consumers.

There is a great number of composite insulators, wires, poles, insulating traverse of domestic and foreign production on the market. Composite structural elements (CSE) are widely used abroad. Russia is lagging behind. The creation of demand for these products is facilitated by the policies of technical and innovative development of enterprises based on foreign practices and on the observed, including in the field of experimental equipment in Russia, the effects of increasing safety, reliability and productivity.

Insulators were the first to appear in the Russian market of composite materials and presently they are massively used.

The composite wire was also in demand. Due to the increased conductivity and the ability to withstand high operating temperatures and the uniqueness of the core, it enables to double the transmission capacity of the line. The smooth surface of the composite wire with eco-friendly coating, its compact internal structure, the strength of the core and low corrosion resistance ensure an increase in trouble-free operation and long service life of the overhead line. The research of the authors show that the use of a composite wire makes it possible to reduce the frequency of wire failures and the recovery time of OL by 15% and 23%, respectively [15].

From the of innovative development point of view, the reduction of the negative impact on the environment is of greater importance. Minimizing the slack of the wire enables to significantly reduce the elimination of land under the line, and consequently, avoid deforestation when overhead lines go through resort or protected areas. The use of conductive material in the conductor makes it possible to reduce transmission losses, in comparison with aluminum wires of the AC type, by almost 20%, and correspondingly, associated emissions to the atmosphere. Together, this indicates a significant reduction in environmental impact [15, 16].

Composite power line pylons are being most often considered as quick-mounted emergency reserve ones presently in Russia. This enables us to identify the features of design and operation of composite power line pylons and determine the opportunities for their application for the construction and reconstruction of lines of various voltage classes. Such an attitude is due to the simplicity and short installation time, small weight of the support and the convenience of transportation and storage (it is a set of cone-shaped parts) [17 - 22].

However, their technical effectiveness is obvious and caused by the properties of the material itself. Power line pylons can withstand severe weather, they are invulnerable to woodpeckers, termites and, of course, for decay and corrosion, because they are waterproof. Composite power line pylons are also fire-resistant and can become completely incombustible when coated with fire-resistant solutions. The increased elasticity of such supports made it possible to make a more secure installation of the pylons along highways, since when colliding with a composite support, the harm to human health is minimal if compared with a collision with a metal or reinforced concrete pylon [20]. From the environmental point of view, the use of composite pylons is not contaminating during disposal, similar to those caused by creosote coated wooden pylons. Composite pylons are 100% recyclable, non-toxic, contain no styrene and dangerous air pollutants or volatile organic compounds. The possibility of painting the support in any color enables you to fit them into any terrain and make the line almost invisible [18].

As for strength, these pylons are comparable to steel, and their service life is about 70 years [17, 19]. In addition to increasing the durability, it should be noted that the composite pylon has a reliability almost 40% higher compared with the metal and 30% - compared with the reinforced concrete one. And due to the speed of installation, the recovery time of this pylon is only 4 hours instead of 32 for the classical version [18, 22].

Crossbeams made of composite materials have proved to be more attractive economically due to their operational, technological and environmental parameters abroad. Like other CSE, isolating composite crossbeams (ICC) are used in the reconstruction and construction of high-voltage lines of various voltage classes [19].

Reliability and environmental friendliness makes ICC highly effective. No linear insulation has made the reliability of the overhead line already increased by 30%, and the recoverability by 23%.

As for the impact on the environment, several factors can be pointed out. Firstly, the required width of the clearing, under equal operating conditions, when using ICC s is less by 35% (for example, in plantations of Group I forests, parks and orchards, for 110 kV it is 21-31 m compared to 42-51 m for metal crossbeams). For a voltage level of 6-10 kV, the use of ICC solves the problem of mass death of birds as a result of electric shock. Also these crossbeams are impenetrable for insects and woodpeckers. Do not contain harmful chemicals [23 - 25].

The insulator extraction, eliminates the appearance of a high potential near the reinforced concrete pylons. The maximum possible convergence of the overhead lines during the use of ICC makes enables to reduce the intensity of electric and magnetic fields under the overhead lines. These factors are relevant today in terms of security.

5. Evaluation of the technical effectiveness

Peculiarities of the introduction of CSE during the reconstruction and construction of overhead lines are the set of their various combinations and the number of lines to be replaced (from 1 span to the entire length of the overhead line). In this regard and the technical efficiency of the use of the CSE can be different depending on the action being implemented.

Obviously, the reliability of the overhead power lines is determined by the reliability of its

constituent elements. Therefore, a mathematical model of overhead line for analyzing the technical efficiency of CSE has been developed. The model reflects the influence of the main structural elements on the failure-free and recoverability of the line [26]. The OL is modeled as spans having a serial connection. The failure of one span leads to the failure of the line. Therefore, the failure rate is determined by the number of spans, their type and reliability:

$$\omega_l = \sum_{z=1}^{Z} (\omega_{span_z} \cdot r_z) \quad (1)$$

where ω_{span_z} - failure rate of z-type span, Z – the number of spans types in the lines, r_Z - the number of z-type spans in the line.

The failure rate of the span is dependent on the reliability of its structural elements: pole, cross-arms, insulators and wires.

$$\omega_{span} = \omega_p + \gamma(\omega_{is} + \omega_c + \omega_w) \quad (2)$$

where $\omega_p, \omega_{is}, \omega_c, \omega_w$ - the failure rate of pole, insulator, cross-arm and wires, respectively, γ=3 for earthed neutral, γ=3 for OL with low-grounded neutral, γ=2 for OL with isolated neutral.

If the influence of structural elements on the OL failure rate and recovery time is known, then the OL recovery time can be determined:

$$t = \sum_1^4 d_e \cdot \tau_e \quad (3)$$

where d_e and τ_e - the percentage and recovery time of OL due to elements failure.

In most cases, these indicators are known from the statistics of observations over the lines. Using the OL model [26] and information about the properties and features of CSE [15 - 25 and etc.], the influence of CSE on the OL reliability was calculated.

In table 1, a possible change in failure-free and reducibility when introducing composite wires, supports and crossbeams on the 110 kV line is shown. The selection of this or that option, with a certain effect on technical efficiency, is an optimization task, depending on the objectives of the introduction of the CSE.

Table 1. Influence of CSE on 110 kV overhead line reliability.

Option	Classical	ICC	Pylon	Wire	ICC and Pylon	ICC, Wire and Pylon
Failure rate per 100 km, times / 100 km	9.4	6.49	9.01	8.65	6.09	5.34
Recovery time of the line 110 kV, h	16.7	12.70	12.84	15.47	8.87	4.98
Change in failure rate, %	-	31	4,2	8	35.2	43.2
Change in recovery time for a complete reconstruction, %	-	23.8	23	23.3	46.8	70.1

The composite structural elements of overhead lines are obvious to have an increase in all three basic properties: safety, reliability and productivity. The necessary condition for innovation has been fulfilled. The infrastructure of the power industry, the policy being implemented, are aimed at shaping the demand for CSE in the electric grid complex - a sufficient condition for innovation activity. Therefore, there is reason to expect the economic effect. Orientation towards the environmental friendliness of this innovative product, the implementation of which is accompanied by environmental measures, makes us speak about innovative development.

6. Discussion

As a result of the system analysis the following system of concepts is offered: "innovative activity", "innovative infrastructure", and "innovative development". This differs from existing views.

In accordance with the interrelationships in this system, the result of innovation is innovative products having high technical efficiency. The objectives and tasks of innovation are reduced to increase the safety, reliability and productivity of products. Manifestation of these properties is crucial for the comparison of innovations. Technical indicators known as technical properties enable to quantify the efficiency. Only an increase of some indicators without a decrease in others let us consider improve-

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ments. Technical efficiency of new products must at least meet the technical requirements of consumers.

The presence of high technical efficiency can be a necessary condition. The emergence of demand is considered to be a sufficient condition for the commercialization of new technical products. Entities forming an innovative infrastructure should eliminate various barriers preventing commercialization of innovative products. Having the purpose to launch mechanisms of innovative development it is the object of their activities.

The analysis of technical efficiency of using composite materials in the electric power industry has been made. The appearance of composite structural elements of overhead lines increases the technical efficiency of lines and networks.

7. Conclusion

Crucial and sufficient conditions for the implementation of innovative activities have been determined. An explanation of the term innovative development has been proposed. Innovative development is a combination of revolutionary and intensive changes combined with environmental measures, reduction of consumption of limited natural resources, reduction of risks of man-caused accidents, i.e. a set of factors indicating the environmental friendliness of innovations. Analysis of composite structural elements of air lines as innovative products has showed that their use in electrical networks leads to a significant increase in technical efficiency. But the shortcomings of existing techniques of feasibility study prevent this innovative product from being widely used in practice. Therefore, it is required to improve the methodological support for the innovation infrastructure. This can be the scientific task of further research.

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