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Features of the development of the investment program of electric power complex companies in the digital economy

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Abstract. Development of electric power enterprises currently attracts plenty of attention. The problem of replacing and modernizing fixed assets is particularly important. But no simple solution to this problem at present conditions is available due to the fact that outdated equipment with the same technical characteristics is quite often no longer available. In this case, it may be necessary to modernize the electricity sector, taking into account the newest technological base that realizes the energy-saving potential of the new technological structure, renewable energy sources, smart grids. Theoretical approaches to develop investment programs by electric power enterprises (EPE) are proposed. They differ from the previously available ones by providing convenient presentation and evaluation method and tools for assessments, determining the degree of influence of each element of the investment program (capital investment system) on achievement of target indicators, while considering type of investment object and priority of the investment direction. The developed method allows you to move to artificial intelligence systems for the formation of strategies in the digital economy.

1. Problem statement

As far as the *Digital Economy problem* is concerned one should thoroughly examine the evolution trends with regards to both the emerging opportunities and challenges in the power generating industry due to the digital economy. Nowadays, OECD countries and partner economies are taking advantage of information and communication technologies (ICTs) and the Internet to meet their public policy objectives concerning the customer interests in energy needs. In the digital economy, the linguistic formulations should be used for making comparisons to determine the exact values of the criteria for the formation of energy policy due to the complexity of decision making in the field of energy. Ahmad and Tahar consider applying the analytic hierarchy method (AHP) [1] when selecting sources of renewable energy in Malaysia [2]. Amer and Daim study the process of renewable energy selection in developing countries in case of Pakistan using AHP [3]. Original approaches were proposed by a number of researchers based on the integration of AHP and the multi-criteria optimization and compromise solution (VIKOR) for the case of renewable energy sources comparison in Turkey. For example, AHP can be used when comparing criteria and the VIKOR method can be used when choosing the alternatives themselves [4], both abovementioned methods can be applied in the fuzzy environment, and the weighting coefficients for selecting renewable energy alternatives for Istanbul

are calculated using paired AHP comparison matrices [5]. The application of a multi-criteria approach in evaluating electric power generation technologies while comprising the electricity matrix in Brazil energy planning could be considered under four dimensions: financial, technical, environmental and socio-economic [6].

Through comparative evidence, it could be understood that both policy makers and decision making persons by means of implementing the digital regulatory practices and policy options attempt to help maximizing the potential of the innovation in the electricity generation industrial sector. Thus, the investment policy of power enterprise (EPE) in digital economy could be considered as a driver for inclusive economy growth. The concept of an investment program in digital economy is closely related to the concept of investment attractiveness in a wide sense. Therefore a wide range of definitions could be studied in various well-known publications. According to a number of scientists, for example, Krylov E.I., investment attractiveness characterizes the stability of the financial state of the electric power enterprise (EPE) [7]. Investment attractiveness is determined by Professor F. M. Topsakhalova as a system of socio-economic, political, financial and management interrelations that determine the feasibility of investing in a specific business entity [8]. Professor I.A. Blank [9] believes that investment attractiveness is a more general characteristic of the investment features of a particular asset from the perspective of a particular investor. An integrated approach to the investment assessment of electric power enterprise fixed capital units is considered by professor V.V. Glukhov considering the innovative development [10], principles of management [11] and organizational behavior [12] with taking into the account large scale system functioning [13].

The investment program of an electric power enterprise (EPE) is pivotal for implementing its sustainable development strategy. In accordance with the principle of consistency, the investment program should provide long-term and sustainable competitive advantages for an EPE, since the expenditures on constructing the generation capacity represent about 60% of the cost structure of generated electricity, while fuel components are about 30% and operating expenses are about 10%.

The hierarchy of electric power infrastructure information subsystems as well as optimization of such systems has been studied in detail by L.A. Melentyev. Issues of electrical grid optimization have been researched by Yu.B. Klyuev, A.N. Lavrov and V.R. Okorokov [14]. An imitation-optimization model for electric power infrastructure has been developed by V.R. Okorokov [15]. L.P. Padalko and G.B. Pekelis. Describing the basics for technical and economic analysis in the energy sector [16], the authors note that the choice of criteria for optimal design of an energy facility boils down in general to the comparison of capital costs and operating costs.

The unsatisfactory technological potential of the domestic power industry has been repeatedly pointed out by M.P. Fedorov [17], A. Voronin [18] and V.V. Kudryavyi [19, 20] as well as E. Telegina [21]. Today, on the one hand, rapidly developing technologies, and especially renewable energy sources (RES), are changing the picture of the electric power industry. On the other hand, these technologies contain a number of limitations. For example, the area occupied by solar power plants is presently equal to the area of Spain, and the area of wind power plants in Europe is 18,000 square km. [22]. In addition, energy storage technologies used by end users begin to change energy consumption patterns. At the same time, tightening in environmental standards and social obligations for employers is forcing all participants of the electric power industry to look for new, more efficient models for investment programs. It should be noted that in perpetually changing economic environment and due to rapidly changing technologies, decisions made on investment programs quickly become obsolete and unfeasible to implement due to uncertainty. In this regard, new approaches to development and implementation of adaptive investment program by EPE are required, especially considering constantly changing technologies for generation, transmission, distribution and consumption of electrical energy under the influence of innovations. In this paper the authors propose uniform approaches to efficient investment program design by all players of electric power industry in digital economy.

2. Problem solution

The principal feature of the complex industrial systems, electric power systems in particular, is the permanent variability of the external environment of their functioning, which causes the uncertainty of future parameters [23]. This fundamental feature of uncertainty for evolving industrial systems predetermines the need for flexible adaptive investment programs, which would make possible for all participants of the economic activity in such systems to achieve their goals with higher probability. Such program in domestic and foreign professional literature is called "strategy", and actions to implement it are called "strategic management" [24, 25].

It can be shown that the most fundamental for EPE is an investment program, which, unlike separate production, marketing and other programs, is based on holistic approach to investment in assets for achieving long-term efficiency of power production and services. We formulated the author's definition of the investment program of an EPE in [26], which can be interpreted in a broader sense by looking at investment program of an EPE as a structurally ordered system of investment projects, ranked according to the time priorities of their implementation and assessment of priorities of project implementation in accordance with the three main principles of strategic planning: "the principle of consistency, the principle of risk and uncertainty assessment, the principle of multi-goal optimization".

1. The principle of consistency (in relation to the evaluation of projects) implies that an EPE functions and develops as part of a complex socio-economic system. Systems theory for electric power industry substantiates the importance of some particular features for such systems functioning, such as regulator set requirements for reliable energy supply to the consumer, environmental and energy supply security in the region, and interdependence between individual investment projects.

2. The principle of risks and uncertainties assessments in the operation of an EPE. In accordance with [27], electric power systems are characterized by uncertainty of their development and operation, which requires clear criteria for assessing risks of investing funds at the stage of developing the investment program.

3. The principle of multi-purpose optimization in the design of investment program of an EPE helps to characterize the controllability of the elements of the complex infrastructure system and allows for considering multiple criteria [15]. The inclusion of a certain event in the investment program by EPE consists of choosing the most efficient path to achieving goals as defined in the company's strategy. However, these goals as a rule cannot be described using a single criterion [14]. The problem of multiple criteria optimization arises.

All participants of the electric power industry apply the same principles in the field of generation, transportation, distribution and consumption of energy, considering needs and requirements of their consumers. The power generation technology that is rapidly changing as a result of innovations has a strong influence on all participants in supply chain. For example, widespread development of decentralized generation in Europe turns consumers into subjects of electricity generation, which must also be taken into account by transmission and distribution networks for electric energy (smart grid) [28].

In accordance with the main digital economy principles (R&D, intellectual capital, the ability to innovate) let us single out structural elements of EPE investment program at the stage of formation:
1) investment system for sustainable development of EPE;
2) investment capital flow models and analysis to ensure proper development of EPE;
3) hierarchical decomposition for managing capital investments of EPE [1].

Our approach to development of investment systems of the EPE considers not only interactions between economic entities, but also allows to implement intelligent assistants taking into account their dependencies on constantly changing circumstances and priorities of the world outside the particular enterprise in general.

3. Results

The methodology for the sustainable development investment program consists of seven consecutive actions (steps):

1. Development of a set of alternative optional investment projects for EPE.

2. Critical analysis of these projects for inclusion in the investment program of the energy company.

3. Decomposition of the investment program development process.

4. Evaluation of investment priorities of EPE using the methods of analyzing the hierarchical structures based on several criteria: technical, economical, social and environmental.

5. Evaluation of consistency level in the hierarchy. If the hierarchy is poorly consistent, the quality of comparisons should be improved.

6. Evaluation of interrelations between separate EPE projects, the degree of influence of each particular project on other projects.

7. Development of the investment program of EPE by method of selecting investment projects.

Let us consider this methodology in more detail. The analysis of investment funding sources and verification of forecasted non-negative accumulated net cash flows $C(t)$ from investments. The output is ranking of investment projects based on criteria of $C(t)$ value, which allows to proceed to the "decomposition" stage.

$C(t)$ analysis is followed by decomposing the investment program into a complete or incomplete capital investment system. The result of this step is the formulation of priorities for the system of capital investments. The investment program is being formed as a set of chosen investment projects according to certain criteria, all of them classified according to investment directions of EUE and structured into hierarchy.

Assigning priorities to investment projects included into hierarchy is split in four levels:

The first level is the choice of investment directions.

1.1. A comparison is made between investment directions in terms of contribution to the sustainable development of EPE.

1.2. Investment directions are introduced in to the matrix for pair wise comparisons. Then an expert ranks the relative importance of each investment direction for development of EPE, using the 1–9 score scale.

The second level is ranking the types of power plants of EPE or the categories of electric utility transmission networks by voltage levels (networks of high, medium or low voltage).

2.1. Matrices for pair wise comparisons of the types of power plants are prepared, reflecting their importance with respect to each investment direction.

2.2. The investments directions of EPE are consequently analyzed by an expert who fills in the comparison matrix for power plant types for each investment direction. Based on the priority of each type of power plant, or the voltage level of the transmission network for each investment direction, the priority of capital investment of EPE is determined.

The third level is the comparison of criteria.

3.1. The preparation of matrix for pair wise comparisons of criteria for each type of power plant is conducted. The economic, technical and environmental criteria are selected for evaluation of investment projects of EPE taking into account the uncertainty.

3.2. For each investment direction consequently, an expert input the results of criteria importance comparisons for each power plant type or transmission network voltage category.

The fourth level is comparison of capital investments by importance.

4.1. The expert makes judgments on each investment projects importance level based on criteria.

4.2. By fixing the criteria, the expert then determines the importance of capital investments according to comparison scale.

For each comparison matrix, the equations are solved at all levels of composed hierarchy:

$$B \times \begin{pmatrix} x_2 \\ . \\ . \\ . \\ x_M \end{pmatrix} = \lambda_{max} \times \begin{pmatrix} x_2 \\ . \\ . \\ . \\ x_M \end{pmatrix} \tag{1}$$

where $x_1, x_2, ... , x_M$ – coefficients of importance; λ_{max} is the maximum Eigen value of the pair wise comparison matrix; B is the matrix of comparisons with the element b_{hj}, which determines the degree of superiority of the element h over the element j in accordance with the scale of comparison of the elements. The indices h and j refer to the row and column, respectively. The condition to be satisfied is as follows: $1 \leq b_{hj} \leq 9$.

The number of comparisons is equal to the number of equations q:

$$q = 1 + l + u + k \tag{2}$$

where l – directions of capital investments; u is the number of types of power plants of EPE; k – the number of goals of the power company. The solutions to these equations are:

1) the weight of investment direction – f_l (contribution of the lth direction of investment in the development of EPE);

2) the degree of priority for each type of power plant – p_{lu} (significance of development of the u-th type of power plant in relation to the l-th investment direction);

3) criteria importance coefficients for each direction of capital investment direction- v_{uk} (importance of the k-th criterion with respect to the u-th capital investment direction of EPE);

4) the coefficients of importance of investments for each criterion set by EPE – ω_{ik} (degree of assigned project priority, characterizing the contribution of the i-th investment to the achievement of the goal k of the EPE).

Then analysis of consistency for each matrix and the entire hierarchy is performed. Weight measures for each type of power facility, derived as solutions to the equations, are weighted by investment direction:

$$p_u = \sum_{l=1}^{4} f_1 p_{1u} \tag{3}$$

where $l = 1, 2, 3, 4$ is the number of the investment direction of EUE; $u = 1, 2, 3, 4$ – the sequence number of the type of power facility of EPE; p_u is the significance (importance) of development of u-type stations for each investment direction.

Evaluation of priorities, obtained from equations solution, weighted over each voltage range:

$$v_k = \sum_{u=1}^{4} p_u v_{uk} \tag{4}$$

where $k = 1, 2, ..., m$ is the number of the criterion; v_k – importance of criterion k by types of power plant; v_{uk} is the weight of the k criterion relative to the significance of the development of the u-th type of power plant;

The priorities of investment projects resulting from the solution of equations weighted by criteria:

$$r_i = \sum_{k=1}^{m} v_k \omega_{ik} \tag{5}$$

where $i = 1, 2, ..., n$ is the project number; κ_i – the priority of the i-th capital investment, showing its importance relative to the objectives; ω_{ik} is a project priority that characterizes the importance of the i-th investment relative to the k-th goal of the EPE.

Further down, evaluation of correlations and interdependencies between separate investment projects is performed. Matrixes of judgments are filled in order to assess the reciprocal influence of EPE investment projects within each group of projects.

The proposed methodology helps to analyze the impact of each investment project and investment direction on EPE strategic goals by taking into consideration the importance of facilities types and criteria importance [20].

The proposed methodology had been tested at OJSC "Territorial Generating Company – 1" subsidiaries, and demonstrated efficiency in adaption of existing investment program to rapidly changing environmental requirements.

Implementation of the present methodology into investment planning will benefit private and state-owned electric power enterprises and sustainability of the industry as a whole.

4. Conclusions

Theoretical tools for investment program development by the electric power enterprise have been developed. The authors have been proposed the definition of investment program as an ordered and structured set of investment projects being ranked in accordance with the time priorities of their implementation. Main structural elements of the method highlighted. The assessment of the priorities for project implementation may be performed based on three main principles of development planning in the utilities industry: the principle of consistency, the principle of assessing all risks and uncertainties, and the principle of multi-goal optimization. The described method can be employed by electric power enterprises with the purpose to perform evaluation of each element of their investment program and present it in a suitable form. The advantage of method which differs it from previously developed methods consists of method of calculating the degree of investment program each element influence on achieving strategic goals of the enterprise, by means of both ranking types of assets and investment directions. The proposed methodology allows developing intelligent assistants for decision makers. Trial testing of method being proposed has shown the potential for developing investment programs based on comprehensive evaluation of separate investment projects by considering the importance of asset types and other criteria.

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