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Methods for Assessing Energy Power System Facilities Safety

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ABSTRACT
One of the most important factors of the sustainability of the system of social, economic and environmental parameters that determine the quality of life of the population and indicators of the effectiveness of regional management is ensuring energy security. Today, the introduction of a trend towards process optimization, the relevance of distributed generation and the development of digitalization, lead the energy industry to create template analysis methods and an algorithm for assessing energy security. To optimize the identification of threats and the preparation of a development forecast, there are basic, universal assessment methods energy security of the consumer. Each of the methods has advantages and disadvantages, unique features applicable to the objects of the energy system of different levels. In this paper, three main methods of assessing energy security are considered: the indicative method, the hierarchy analysis method and the fuzzy sets method, in addition, the fundamental evaluation criteria for all methods are introduced.

Keywords: *Energy security assessment methods, Indicative method, Hierarchy analysis method, Fuzzy set method, Energy security assessment criteria, Energy security.*

1. INTRODUCTION

The energy security of a consumer is the position of an object in the aggregate of all its connections, from the standpoint of adaptability to functioning, self-regulation and progression under hazard conditions - both local, produced within the power system, and external, as well as the action of unforeseen factors (especially difficult to predict). The main goals of ensuring energy security are the uninterrupted availability of energy sources at an affordable price, high quality of energy received by the consumer, an acceptable increase in the tariff for energy resources, the provision of services that are economically beneficial for the consumer, and the satisfaction of the economic demand for the service provided. It is believed that the system performs its functions in full, provided that the state of protection of citizens, society and the region's economy is ensured. All this determines the growth of the social, economic and environmental aspects of the region, as well as the country, and leads to the coupling of the energy system with the consumer, the creation of an instrument regulating the management of energy resources in accordance with the needs of the consumer. [6]

According to the Ministry of Energy of Russia dated February 26, 2021 No. 88, by 2027 an increase in the average an increase in demand for electrical energy, which puts energy security problems at the forefront. [8] In order to use financial and energy resources optimally, in order to achieve or improve energy security, it is necessary to be able to analyse. Those components must be monitored and assessed, changing which can affect the entire energy security system. Based on these components, an assessment should be made of the likelihood of risks that negatively affect the power system and its safety. [9]

2. ANALYSIS OF METHODS

The complexity of the assessment largely depends on the sources of risks and the ability or impossibility to truly predict them. First of all, the laboriousness of identifying criteria for analysis is associated with the changing energy policy of the regions, changes in the technical characteristics of the energy system, the region's susceptibility to natural or man-made disasters. Any energy safety assessment system should be distinguished by ease of assessment and quick identification of risks and subsequent response to them.

Currently, several methods for assessing the energy security of a consumer have been developed and applied: an indicative method, a hierarchy analysis method, and a fuzzy set method. The most widely implemented is the simplest – indicative method. Improving the effectiveness of this method serves as the basis for a more comprehensive hierarchical method. The limits of accuracy of the hierarchical method are increased by passing to the method of fuzzy sets (Figure 1).

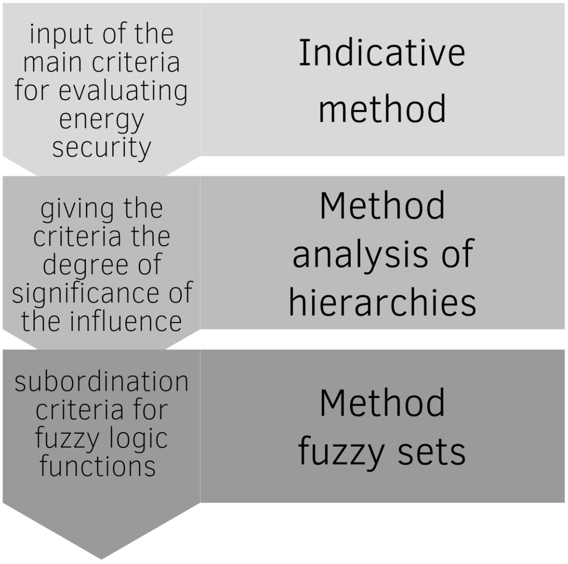

Figure 1 The structure of existing methods for assessing energy security.

The choice is directly proportional to the level of energy security. Each new method is more precise about the degree of research indicators. This increases the range of detection, which allows you to start actions to eliminate them at an early stage. Indicators for all methods of assessing energy security of the state of the external and internal environment of an object of the energy system, which are purposefully or indirectly at this object. For all three methods, they can be the same, but different in completeness and development. In addition, indicators can be ranked for the impact of the external environment on the power system and indicators that characterize the internal environment.

So, an indicative indicator of assessment and diagnostics, on the basis of which the level of energy security is assessed. Each indicator has its own normal and critical values, upon reaching which the normality or abnormality of the situation is assessed according to this indicator. The more indicators there are, the more accurate the assessment of the level of energy security. The indicators themselves and their threshold values are formed by analysing the energy resources of the region, financial indicators, analysis of the energy entity, etc. [9] Study of indicators for the implementation of measures to normalize energy security.

The disadvantage of this method can be considered the obsolescence of new indicators in the long term. Also, this method does not identify priority criteria that meet the rating criteria.

The components of the evaluating parameters of energy security, depending on the technical equipment of the region, are included and the indicators that depend on the financial, economic, social and geographical position of the region are included and removed. In this regard, there is a method for ranking the indicators of the point of achieving the priority development plan of the region [12]. Depending on what level of energy development is most relevant for the subject, the level is manifested, which can affect its achievement on its achievement. The selected criterion is assigned a specific importance group. The thresholds of the more important criteria are compared with normal values and planned, thereby increasing the response to any changes in the power system. The bulk of expenditures for the energy region will be related to development trends.

Diagnosing energy security is part of a multi-criteria analysis, therefore, in the analysis process, it is worth moving from a quantitative assessment of many indicators to a qualitative, verbal one. However, with the transition to the method of fuzzy sets, the determination of the boundaries of the threshold values, with the parameters “high” and “low”, passes to the functions of the mathematical apparatus.

By following that the thresholds of many criteria change over time or by changing other indicators, the most effective results can be achieved by logical methods. In the method of fuzzy logic, a certain variability is added to the criteria, that is, the indicators describe the distribution functions of fuzzy logic. Functions can be like a triangle, trapezoid or Gaussian distribution, exponential function, etc. The choice of a function depends on the parameters with the flow of some factor. The boundaries of the transition from normal values to critical values and vice versa are blurred. For the method of diagnostics of fuzzy sets, threshold values for each indicator are required - individual. The proposed indicators form a set in which all are of equal importance for assessing energy security. The growth of a separate positive criterion is associated with an increase in the general level of energy security of the power system object, when in turn, lowering the negative criterion also gives a favourable effect for energy security. Proceeding from the fact that some are based on each other, the rules of simple arithmetic operations on fuzzy sets are introduced [7]. Thus, when entering the data system, it compares it with the distribution system and simulates the prediction of parameters for energy security.

The fuzzy set system allows you to flexibly respond to changes in the energy policy of the region, taking into account the time. But it still needs to add indicators and changes, as it is not able to model new indicators.

3. RISK ASSESSMENT

Risk assessment should be carried out in an independent way, for the most accurate determination of the level of threat of one or another factor. Determination of the nature of the risks depends mainly on the initial assessment of energy security and the main problems of the power system at the moment. The collection of information necessary to determine the current level of safety may include a review of regulatory documents, technical inspections, interviews or surveys of individual employees of energy organizations, domestic and foreign expert assessments, statistics of energy companies. When assessing, it is necessary to divide the risks into certain parameters depending on their properties and only after that form the criteria for assessing the energy security of the objects of the power system. Risks affecting energy security can be of various types of threats and can be economic, environmental, socio-political, man-made and resulting from cyber-attacks.

The most important assessment of energy security is the determination of indicators that directly affect the performance of the most important tasks of the power system, such as interruptions in continuity. For each such risk, it is necessary to clearly define the gradation of criteria in order to further reduce the impact in the event of a crisis situation. For such risks, the likely irritants affecting them should be listed and methods for correcting and controlling critical situations should be described.

Indicators that have an impact on safety can be considered in measuring their duration and impact on the power system. Short-term, but highly probable, disruptions to the normal operation of the power system can lead to significant damage to the power supply systems. The main problem with such threats may be that the possible solutions are instantaneous or calculated for a short time, which entails constant financial losses. Unlikely power system disruptions can have a high enough level of threat due to the fact that monitoring, eliminating or protecting against such risks is financially impractical. Such risks are extremely rare and cannot be accurately predicted, so it is difficult to assess them using the methods presented earlier.

Potential risks form an individual set of indicators for an individual enterprise, settlement, region and country. The criterion is described as a mathematical formula, any process that affects energy security. Indicators can be written in the scale of correspondence of the numerical ranges of the parameter and the described names of its gradations [5]. Parameter distribution functions can be constructed on the basis of such scales. To assess critical points, in some cases, it is possible to simulate adverse, stressful threats. Based on the assessment of the possible consequences of these threats, a conclusion is made about the influence of the quantitative characteristics of the indicator on energy security.

4. RESULTS AND DISCUSSION

The term “consumer”, in this work, means both settlements and their aggregate - municipalities, regions, the whole country as a whole. The criteria identified in each of the methods for assessing energy security differ for some types of consumer gradation. There is a dependence of indicators on the significance of the scale of the consumer. Let's consider in more detail in the table.

Table 1. Applicability of energy security assessment methods to consumers of various levels

Energy security assessment criterion	**Analysis object**				
	Company	*Locality*	*Municipal entity (counties and districts)*	*Region*	*Country*
Share of own sources in the energy balance of the facility;	-	+	+	+	+
Share of own sources in the balance of boiler and furnace fuel;	-	+	+	+	+
The ratio of the available capacity as a whole in the area of the interconnected power system, including the power system of the facility, to the maximum electrical load;	+	+	+	+	-
The share of the dominant fuel resource in generation;	-	+	+	+	+
The share of the installed capacity of the largest generation, in the total installed capacity, as a whole in the area of the interconnected energy system;	-	+	+	+	+

Average degree of depreciation of fixed assets associated with the production and distribution of electricity and heat;	+	+	+	+	+
Average degree of depreciation of fixed assets associated with the extraction, processing and distribution of fuel resources;	+	+	+	+	+
The risk of undersupply of electrical energy as a result of the loss of the dominant fuel resource during its production;	+	+	+	+	+
The risk of undersupply of energy as a result of the loss of the dominant fuel resource during its production;	+	+	+	+	+
The risk of dissatisfaction with own electrical loads due to the loss of intersystem electrical connections;	+	+	+	+	- *
The risk of significant losses due to inefficient production of electrical energy;	+	+	+	+	+
The risk of significant losses of electricity due to its inefficient transmission;	-	+	+	+	+
The risk of ineffective work of the fuel and energy complex as a whole;	-	-	-	-	+
The ratio of the total available capacity of the facility's power plants to the maximum electrical load;	+	+	+	+	-
The ratio of the sum of the available generating capacity and the throughput of the intersystem connections of the facility with the neighboring ones, to the maximum electrical load of consumers on its territory;	-	+	+	+	-
Opportunities to meet the needs for high-quality power supply;	+	+	+	+	+
The share of the dominant resource in the total consumption of CBP on the territory of the facility;	+	+	+	+	-
The share of the largest generating unit in the installed capacity of the facility;	+	+	+	+	-
The level of potential supply of demand for fuel in conditions of a sharp cold snap on the territory of the facility;	+	+	+	+	+
The degree of wear of the OPF of the energy facilities of the facility;	-	+	+	+	+
The ratio of the average annual commissioning of the installed capacity and the reconstruction of the generating units of the facility for the previous five-year period to the installed capacity of the facility;	+	+	+	+	+
Emissions of harmful substances into the atmosphere from electric power enterprises per unit area of the territory;	+	+	+	+	+
The ratio of overdue accounts payable (at the end of the year) of energy enterprises to their annual production volume;	+	+	+	+	+
The ratio of overdue accounts payable (at the end of the year) of enterprises of the fuel industry to their annual production volume;	+	+	+	+	+
Energy intensity of the gross regional product.	+	+	+	+	+

* (provided: country - isolated power system)

Criteria "Share of own sources in the energy balance of the facility"; "The share of own sources in the balance of boiler and furnace fuel"; "Share of the dominant fuel resource in generation"; "The share of the installed capacity of the largest generation, in the total installed capacity, as a whole in the area of the interconnected energy system"; "The risk of significant electricity losses due to its ineffective transmission" and "The ratio of the sum of the available generation capacity and the throughput of the intersystem connections of the facility with neighbouring ones to the maximum electrical load of consumers on its territory” cannot be applied to such an object of energy system analysis as an “enterprise” according to due to the absence of the ratio of the shares of assessment and, in this case, the impossibility of applying methods for assessing the energy security of the consumer. Also, the application of the criteria “Risk of ineffective operation of the fuel and energy complex as a whole” and “Degree of wear and tear of the OPF of the energy facilities of the facility” is relevant exclusively to the facilities of the energy system of a higher level, namely, in relation to the fuel and energy complex - exclusively at the level of the country, and for assessing the level of depreciation of assets – all larger objects, starting with the settlement.

On the other hand, it is not possible to identify quantitative indicators for the criteria “The share of the dominant resource in the total consumption of CBP on the territory of the facility”; “The share of the largest generation unit in the installed capacity of the facility”; “The ratio of the total available capacity of the facility's power plants to the maximum electrical load”; “The ratio of the sum of the available generation capacity and the throughput of the intersystem connections of the facility with neighbouring ones to the maximum electrical load of consumers on its territory” and “The ratio of the available capacity as a whole in the area of the interconnected energy system, including the facility's power system, to the maximum electrical load” is the ratio of such a large power facility, as a country. Separately, it is worth highlighting the criterion “The risk of dissatisfaction with own electrical loads due to the loss of intersystem electrical connections”, since its use is justified only in the case of considering interstate, intercontinental, world and similar connections of this level.

The analysis of the table allows us to tweak the previously put forward assumption that the choice of the method for assessing the energy security of the consumer is directly proportional to the level of energy security. Each new method more accurately describes the degree of change in indicators. This increases the range of threat detection, which allows you to initiate actions to eliminate them at an early stage. For example, for the consumer category of the “enterprise” level, it is sufficient to use an indicative assessment method, since the fullness of the methods for analysing hierarchies or the method of fuzzy sets does not justify the result of the analysis, due to the incompatibility of the entire range of standard criteria.

Based on the table, we can conclude that all three methods based on the formation of the main criteria for assessing energy security, namely: the indicative method, the method of analyzing hierarchies and the method of fuzzy sets, are most used and fully relevant to use in relation to settlements, municipalities and regions. Such consumers should be attributed to the average level, based on the analysis of the states of objects of this level (its components – power systems), it is possible to fully assess the reliability of the functioning of upper-level facilities (for example, interconnected power systems). We include such large consumers as the country and all related, similar and larger-scale energy systems to the upper level. At the same time, the state of objects of the middle and upper level can be estimated on the basis of their own characteristics, however, in this case, information about the states of the constituent parts is lost. For a more detailed analysis, it is necessary to take into account the lower level of the system of energy consumption objects, namely, the enterprise. Guided by the principles of the systemic approach, complex objects must be regarded in a complex manner, in the aggregate of all significant connections between the subsystems of the object, direct and reverse. Undoubtedly, the criteria of methods for assessing energy security are not able to touch upon all logical connections and components of threats, especially hidden ones, however, they provide the necessary and sufficient level of detail for the formation of a forecast of energy security. [13]

5. ALTERNATIVE METHODS

In addition to the methods we mentioned earlier, there are alternative options for assessing the level of energy security of an object. Monitoring is inferior in prevalence. This method implies an individual analysis and detailed calculation of all indicators of a power facility. The advantages of monitoring lie in an overly detailed and clear analysis of all components, but it is worth noting the negative qualities. For example, such a method of analysis is not applicable to power facilities of the upper scale level and is difficult to apply in relation to the average level, since the analysis of all components of energy security cannot be performed for the whole country within the required optimal time frame. With the help of the analysis of energy security by the monitoring method, it is extremely difficult to make a forecast and track the dynamics of changes in the energy security of an object, due to the large amount of non-standardized information and the lack of its structuredness. The complex of resources spent on making a forecast based on the monitoring method, as a rule, does not justify the result, especially for identifying short-term prospects. However, monitoring can be applied in conjunction with energy security assessment methods based solely on rationing, standardization and identification of criteria. The monitoring component will complement the analysis with the indicative method, the hierarchy analysis method and the fuzzy set method, making it possible to obtain more accurate results and reduce errors. [12]

Completely different from all, the method of diagnosing the energy security of an object of the power system is the method of expert opinion. This method is idiosyncratic and, in practice, is poorly implemented in other, more standard, assessment methods. As a rule, for the implementation of the analysis by this method, a commission is formed of experts in various fields that have an impact on the energy security of a power facility. As a result, a coefficient of significance is assigned by the conclusion and assessments of experts, but on the basis of which the level of energy security is determined and a plan of further measures is drawn up. [4]

6. CONCLUSION

Paying due attention to the energy security of the power system facility, in particular, methods of assessing energy security, it is possible to identify areas of increased environmental hazard and vulnerable components of the power facility itself. On the basis of such diagnostics, it is possible to develop program-targeted measures to eliminate and neutralize threats to energy security. An undeniable positive effect is also the versatility of the application of the indicative method, the method of analysing hierarchies, the method of fuzzy sets to many objects of the power system. Ensuring energy security is an ongoing process. With preliminary forecasting, the possibility of loss of resources for the individualization of each object and personal calculation of risks is not allowed, however, standardization and the identification of universal criteria is the optimal solution for establishing the level of energy security.

Energy security stimulates the economic growth of the region and the country as a whole. From continuity and energy reliability depends on the viability of many consumers. Energy consumption can be called the main factor in the sustainable development of enterprises for a modern industrial society. [10] Despite this, the energy system of our country is in a state of crisis, according to the Ministry of Energy of the Russian Federation, in some regions there is an increase in accidents from 15 to 190% associated with the deterioration of the equipment of the grid complex [7]. With the development of the system, the assessment of energy security, many emergencies will be prevented, increasing the quality of electricity and its continuity.

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