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FORMATION OF RISK PROFILE FOR THE INTEGRATION OF RENEWABLE ENERGY SOURCES INTO THE ELECTRICITY SUPPLY SYSTEM

Abstract: *Maintaining the reliability, stability and efficiency of the electricity system is becoming a challenge due to the uncontrolled increase in the number of renewable energy sources. Therefore, there are issues of finding the optimal location of RES capacities with the required technical characteristics. The solution of such a task can be realized by using a risk management system.*

The work is devoted to the development of a methodology that allows, based on the risk profile, to make a generalized decision on the connection of RES to the power supply system. The article defines the concept of "risk profile of RES integration into the power supply system", proposes an algorithm for making a generalized decision on the connection of distributed generation to the power supply system. The basic principles of profile formation are also proposed in order to further consolidate the risk profile of RES integration into the power supply system at the regulatory level.

Keywords: *renewable energy sources, power supply system, risk profile, risk indicator, risk profile passport, fuzzy logic method*

Introduction

According to the Energy Strategy of Ukraine until 2035, the development of energy based on renewable energy sources (RES) is an important area that increases the level of energy security and reduces anthropogenic impact on the environment. It is envisaged to increase the share of RES in the total balance of installed capacities to 25% by 2035, which is about 24 million tons of oil equivalent under the baseline scenario [1].

In turn, the results of quarterly monitoring conducted by the State Agency on Energy Efficiency and Energy Saving of Ukraine show that at the end of 2021, there were about 45 000 households in Ukraine that installed solar power plants (SPPs) with a total capacity of 1.2 GW [2]. The capacity of such SPPs is chosen by the owner, and is usually equal to the maximum capacity defined by the Law of Ukraine "On Alternative Energy Sources" [3]. And for the construction of RES often choose land plots in rural areas with a weak distribution network.

At the same time, there are a number of risks related to the impact of RES sources on the planning, organization of operation and management of power grids. That is, the development of "green" energy takes place without considering the real needs of the energy system of Ukraine in additional generating capacities. This leads to problems such as the need to increase maneuvering capacity, deterioration of the quality of electricity, the need to modernize lines, the growth of debt under the "green" tariff, the emergence of higher harmonics and reactive power flow, as well as the introduction of non-market methods for using the constraint management system [4].

Purpose of the research

The purpose of the article is the formation of a risk profile of RES integration into the power supply system. This will allow making a generalized management decision on the connection of distributed generation sources.

Material and research results

Today, the main directions of modern energy policy in the world are harmonized with strategic environmental security in the context of sustainable economic development. Currently, more and more countries are aiming at the transition to 50 percent or more of renewable energy sources in the energy sector. According to Bloomberg [5], by 2050, wind and solar together will account for more than 50% of global electricity production, and together with energy storage systems – 80%. Oil use will peak in 2035 and then fall by 0.7% p.a. to return to 2018 levels in 2050. The peak of coal-fired electricity is forecast in China in 2027 and in India in 2030, but then the share of its use will fall and reach 18% by 2050 (in 2020 – 26%). Each country is developing its own way to achieve the goal, which differs from others in terms of implementation time, scope, target areas. This is due to the need to improve energy security and the task of preventing global climate change by reducing carbon emissions into the atmosphere.

In the research [4], it was found that further development towards increasing the share of SPPs in the generation of the power system poses a significant challenge to the effective management of the distribution network and creates problems for its normal functioning. Accordingly, there is a need to put forward requirements for the main equipment or to install additional equipment for flexible and dynamic regulation of RES operation. Therefore, decision-making on the integration of RES into the power supply system should be based on the analysis of the modes and processes that arise under different options of RES connection. Consequently, there is a new scientific and technical problem of ensuring the effective integration of RES into the power supply system. Solving this problem requires a systematic approach to avoid inefficient and irrational use of RES opportunities.

In order to assess and compare possible problems at the level of transmission and distribution system operators caused by the connection of RES, it is advisable to introduce the concept of "risk". The international document that interprets the meaning of terms in the field of risk management is ISO Guide 73:2009 [6]. In addition, they are the basis of a unified methodological approach to the perception of other international documents in this area. The risk of RES integration means an event, condition or state that may or may not occur in the future and negatively affect the efficiency of RES. The efficiency of RES is described by a set of desired results achieved with the successful implementation of RES in the electricity supply system. The emergence of possible risks is due to the presence of causes (processes or phenomena) that contribute to their occurrence and explain why the risk is inevitable. Such phenomena are called risk factors. In turn, the risk profile is considered as a description of a set of risk indicators (criteria with predefined parameters), which is the result of collecting, analyzing and systematizing information. This profile may include risks related to the entire system as a whole or some of its local parts.

When the object of study is the electric power system and its subjects, the following risks are proposed as a general classification [7]:

- risks associated with danger to human life, natural, environmental;
- production and technological (reflect the probability of failure of technical systems and their individual elements);
- financial and economic (lack of data on the real cost and technical condition of electrical equipment, the problem of obtaining objective technical and economic information on the consequences of various accidents, damages, failures, shortages of electricity);
- legal (inconsistency of the current legislation with the current problems of the electric power system);

- informational;
- socio-political;
- commercial.

To date, there is no effective, comprehensive system for assessing and managing the risks of integrating RES into the electricity supply system. Practical aspects of risk management in this segment are not sufficiently researched and covered, considering the experience of the leading countries of the world. Therefore, there is an urgent need to create a comprehensive risk management system for the integration of RES, which will be adapted to the current realities of the energy system of Ukraine. Given the described problem, we propose an algorithm for making a generalized decision when connecting RES to the power supply system (Fig. 1).

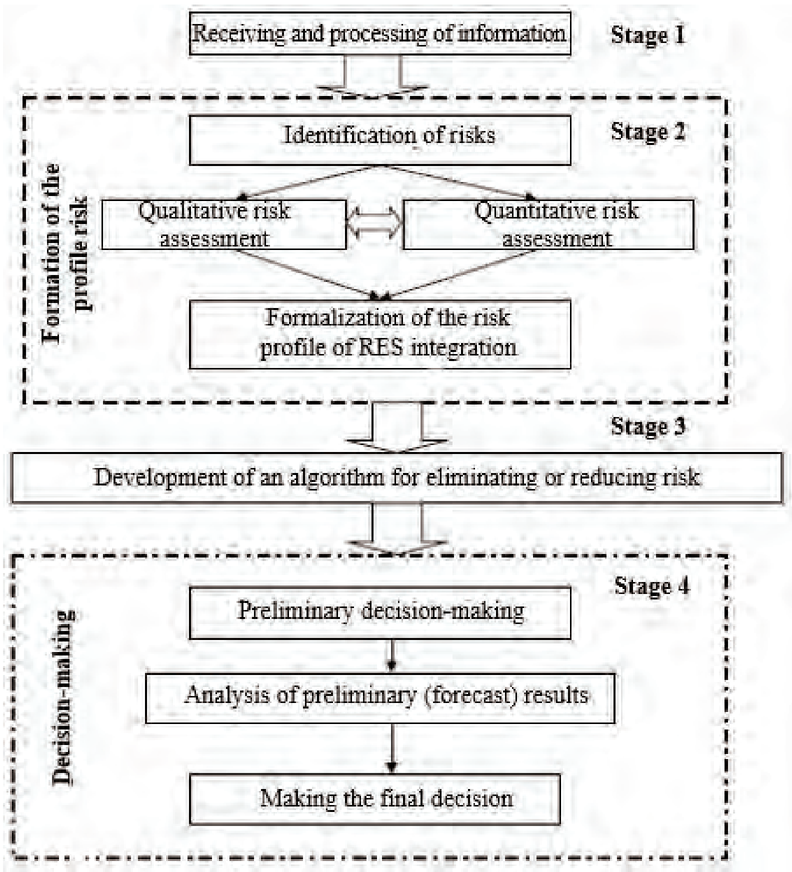


FIGURE 1. *Risk assessment and management system*

Risk management of RES integration should be based on the results of risk assessment, technical, technological and economic analysis of the potential of the electricity supply system. It should also forecast the impact of these sources on the electricity system and its entities. In addition, risk management should include a methodology for making a generalized decision on the integration of RES.

According to the proposed algorithm, the first stage is the analysis of existing system parameters. The next stage is based on the analysis, identification and assessment of risks, and includes: 1) identification of conditions and factors influencing the occurrence of risks; 2) identification of risk areas; 3) identification of risk indicators; 4) qualitative and/or quantitative assessment of the probability of risks and possible damage in case of their occurrence.

In Ukraine, the relationship between electricity producers/suppliers and consumers in the retail electricity market is regulated by the Rules of the Retail Electricity Market [8]. It is necessary to pay attention to this when determining the priority risk indicators. According to paragraph 5.1.2 of these Rules, the distribution system operator is obliged to comply with the quality indicators of electricity supply. The indicators show the level of reliability (continuity) of electricity supply, commercial quality of electricity distribution services and quality of electricity. The level of power supply reliability is associated with such a risk as imbalance of active energy. It is caused by an increase in load variability of balancing power plants. Already now, there is a lack of balancing measures, which forces the transmission system operator to apply the RES Limit Management System. In order to ensure the flexibility, safety and reliability of the energy system, it is necessary to develop highly maneuverable capacities and increase the volume of the energy storage system. However, the use of these systems is a rather extensive issue, the solution of which is beyond the scope of this article.

One of the main risks of RES integration is the mismatch of the physical parameters of the supplied electricity. In Ukraine, the parameters of electricity quality at the boundary between the transmission system operator and the consumer must comply with the parameters defined in DSTU EN 50160:2014 [9]. The main parameters for low voltage (LV) $Un \leq 1$ kV and their normalized values are given in Table 1. It is important to note that temporarily in Ukraine the standard nominal voltage between the phase and neutral conductor is 220 V. However, the state has committed to switch to $Un = 230$ V in the future to comply with European power quality standards. Therefore, this voltage value is considered further in the article.

Therefore, the following parameters can be used as primary risk indicators: indicators of the quality of electricity at the boundary of the balance between the distribution system operator and the consumer; characteristics of the supply voltage and their normalized values; indicators of the reliability of electricity supply.

Table 1. *Normalized values of power quality indicators of LV*

Name of the indicator	Allowable value of the indicator
Frequency	50 Hz ±1% (49.5...50.5 Hz) for 99.5% of the time per year
	50 Hz +4%/-6% (47...52 Hz) for 100% of the time per year
Voltage	230 V ±10% (207…253 V)
Long term severity	≤ 1 for 95% of the observation time
The total harmonic distortion	≤ 8%

The main objective and final result of the "Risk Profile Formation" stage is the formalization of the risk profile of RES integration. The issue of risk profile formation is related to the creation of its logical and effective structure. This is aimed at the possibility of further application of the methodology for making a generalized decision on the connection of RES to the power supply system. These conditions are provided by filling in risk profiles. Profiles can be presented in the form of a risk profile passport, as well as a risk profile program code. In the field of customs control, which operates in Ukraine, risk management measures are fixed by regulatory documents [10] and are implemented in practice. Therefore, the basic principles of profile formation can be used in our study, in particular in the form of a risk profile passport. The risk passport (Fig. 2) is designed to reflect the key characteristics of the risk of RES integration. It is used to form a risk profile and ensure the elimination of the risk or reduction of its negative impact.

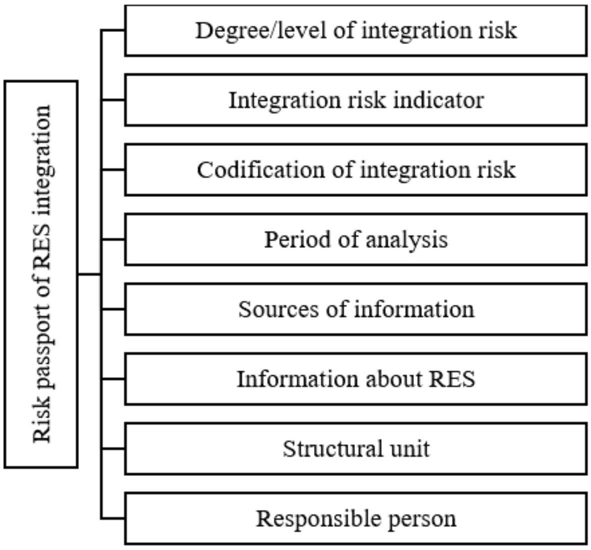


FIGURE 2. *Risk passport of RES integration into the electricity supply system*

To ensure the fulfillment of the tasks, the RES integration risk passport should contain the following indicative list of information fields [11]:

- Degree/level of integration risk. It reflects the level of risk of RES integration, which was assessed according to the established criteria (indicators). The same risk may have different degrees depending on the values of the indicators. This is the main component for risk management.
- Integration risk indicator. It reflects the criteria (indicators) for which there is a high level of risk and which have been selected for further risk assessment and management.
- Codification of integration risk. It displays a code with encoded information about the risk. This is used to effectively use the passport in terms of recognizing and identifying similar situations in other local networks. The risk code is formed by placing n indices of classification categories in a certain order.
- Period of analysis. This indicates the period of time for which the data was processed to determine the integration risk.
- Sources of information. This section specifies the information and analytical support used to identify the integration risk. Determining the risk of RES integration should be based on the processing of information and analytical data of structural units, dispatchers, etc.
- Information about RES. It indicates the available information about the facility (capacity, installation location, parameters of the main RES equipment). It is also proposed to appoint a risk owner. He will be responsible for minimizing the risk of RES integration into the electricity supply system.
- Structural unit. The unit that carries out analytical work on risk identification is indicated here.
- Responsible person. This indicates the official responsible for maintaining the risk profile of RES integration into the electricity supply system.

When forming a risk profile for the integration of RES into the electricity supply system, there are situations when decisions need to be made with significant incomplete information, lack of statistical estimates, incomplete description of the system at the point of connection. The nature of the risk factors may be unclear, with varying degrees of confidence in these factors. Thus, the risk assessment procedure is often implemented in conditions that are poorly formalized, as well as in conditions of unclear and incomplete representation of the factors affecting the risks.

Fuzzy logic algorithms are one of the most acceptable for solving the problems of modeling risk avoidance in the integration of RES. Here are the main advantages of using the fuzzy logic model [12]:

- fuzzy logic methods make it possible to qualitatively, verbally describe risk factors by introducing the concepts of linguistic variables. The content of these variables is clear to the expert, as they are defined not by numbers, but by fuzzy concepts;
- the use of fuzzy sets allows formalizing more flexible relationships between the factors of each of the studied risks. This is more consistent with the nature of the studied real interactions in the power industry, in particular in the power supply system;
- fuzzy methods make it possible to make decisions in conditions of incomplete information by synthesizing and analyzing qualitative values. This is important for making a generalized decision on the connection of RES.

Practical application

We considered the process of modeling the fuzzy logic method using the Matlab package. Fuzzy modeling in the Matlab environment is carried out using the Fuzzy Logic Toolbox extension. It implements dozens of functions of fuzzy logic and fuzzy inference. This package is one of the most common tools for risk profile formation. To describe the set of risk indicators, we used a number of factors that directly reflect the problem of effective RES integration. This category includes the following factors: higher harmonics (*Ku*), voltage deviation from *Un* (Δ*U*) and reactive power flow (cos*φ*). According to the algorithm, the selected factors were analyzed, and a scale for evaluating linguistic variables was formed. For each output indicator we proposed to use three term sets of linguistic variables: "low", "medium" and "high" (see Table 2).

***TABLE 2.** Scale for assessing linguistic variables*

Factors			Range	Scale for evaluation of indicators		
				low (L)	medium (M)	high (H)
Higher harmonics	*Ku*	%	0…10	0.9…0.94	0.92…0.98	0.96…1.0
		Rel. unit	0.9…1.0			
Voltage deviation from *Un*	Δ*U*	%	±15 (196…264 V)	0.85…0.91	0.88…0.97	0.94…1.0
		Rel. unit	0.85…1.0			
Reactive power flow	cos*φ*		0.75…1.0	0.75…0.85	0.8…0.95	0.9…1.0

At the next stage, a number of rules were formed by using expert data obtained in the previous study [4]. It allowed forming a risk profile of RES integration into the electricity supply system based on the selected indicators. Figure 3 shows the roadmap of the whole fuzzy inference process. The last graph in the fourth column represents the total weighted solution for a given system, which depends on the input values of the selected factors. It is important to note that this view of the rules allows the interpretation of the entire fuzzy inference process at the same time. It also shows how the shape of certain membership functions affects the overall result.

The "result" for our case can be considered the degree of integration of RES into the power supply system. It can be viewed at different values of physical parameters of the network in the case of RES connection. For example, at relative values of *Ku* = 0.95, Δ*U* = 0.96, cos*φ* = 0.92, the integration rate is 0.786, and at *Ku* = 0.92, Δ*U* = 0.9, cos*φ* = 0.85 – it decreases to 0.5. That is, there is a mechanism for making a generalized decision when integrating RES by using the described method of fuzzy logic. We also obtained the output surface of our system by using the functionality of the selected software (Fig. 4). It shows the entire possible range of the integration index based on the range of the input set of risk factors.

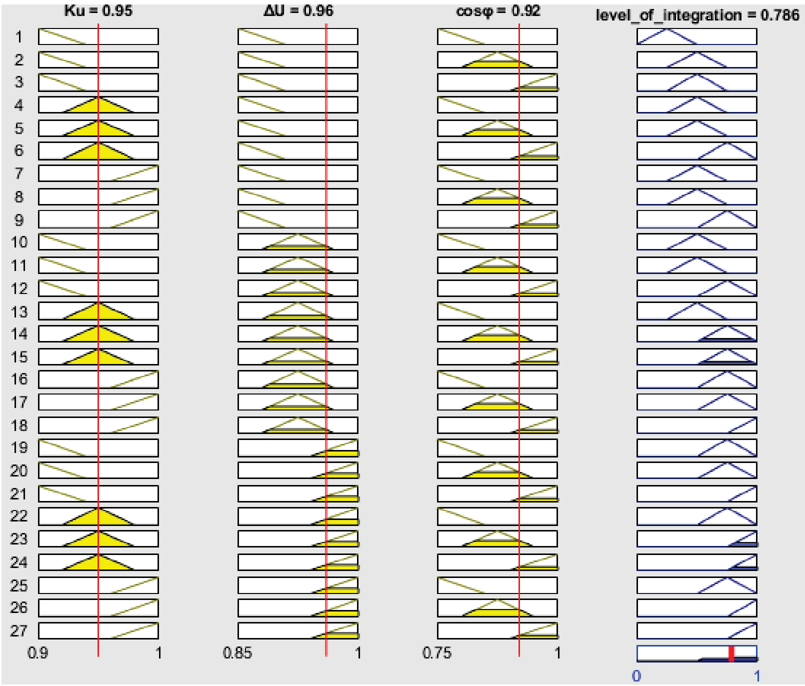
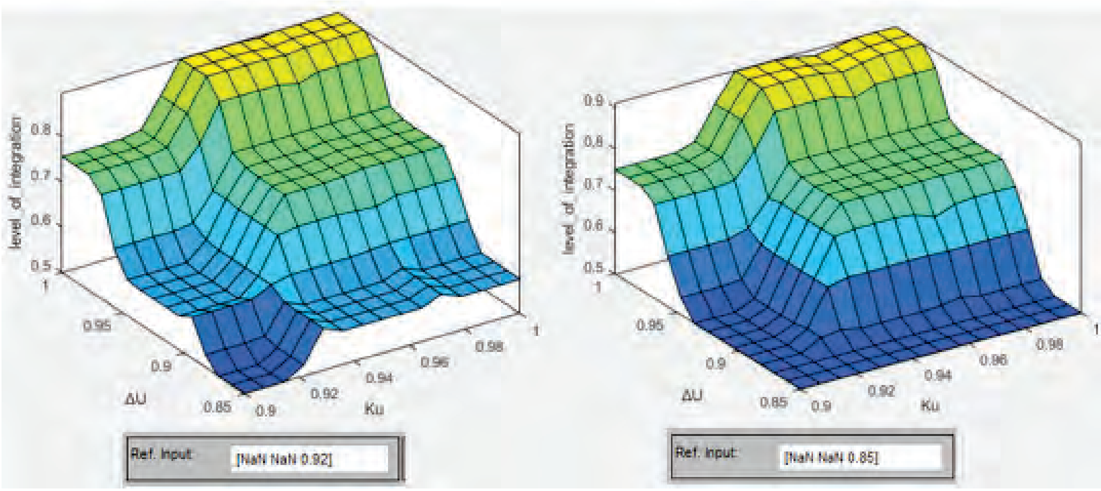


FIGURE 3. *Results of fuzzy logic for given parameters of the power supply system*



(a) (b)

FIGURE 4. *The surface of the fuzzy conclusion at the input parameters ΔU, Ku at cos φ = 0.92 (a) and cos φ = 0.85 (b)*

The resulting model makes it possible to visually assess the probabilities of the situation that may result from the connection of the RES installation. It is necessary to adhere to the parameters of the yellow and green zones of the profile to obtain the highest efficiency of RES. The blue zone, on the contrary, is characterized by the greatest risks for the normal functioning of the system. It shows a categorically unacceptable integration under the given parameters of the system and RES. Getting into the blue zone is also not recommended, as there is low efficiency from RES and a higher probability of risk consequences.

Thus, we have developed a fuzzy inference of risk in the integration of RES into the grid by such factors as higher harmonics, voltage deviation from *Un* and reactive power flow. The resulting model makes it possible to visually assess the probabilities of the situation that may result from the connection of a RES installation to the grid. In this method, the quality of decision-making is determined by the base of fuzzy rules. Supplementing the model with other factors, overcoming possible contradictions of the rules and increasing the intellectual level of the fuzzy logic system will allow making a generalized decision on the integration of RES into the power supply system. The obtained results will be used to develop a methodology for controlled and efficient development of renewable energy. This methodology will be carrying out a feasibility study of the choice of location and technical scheme for connecting RES to the power supply system. It will also allow determining the relevant requirements for the parameters of the electrical installation at the stage of issuing technical specifications to the customer.

Conclusions

Further increase in the share of RES in the total generation of the power system poses a significant challenge for the effective management of the distribution network and creates problems for its normal functioning. Therefore, decision-making on the integration of RES into the power supply system should be based on the analysis of the modes and processes that arise under different options for connecting RES. There is a need to put forward requirements for the main equipment or to install additional equipment for flexible and dynamic regulation of RES operation at the stage of forming technical specifications.

In the process of the research, the concept of "risk profile of RES integration into the power supply system" was defined. An algorithm for making a generalized decision on the connection of distributed generation to the power supply system was proposed. The basic principles of profile formation were also proposed for further consolidation of the RES integration risk profile at the regulatory level. However, the absence of a complete description of the system at the point of connection, the lack of accurate statistical estimates of risk factors and the presence of factors in qualitative or interval form objectively require the use of the mathematical apparatus of fuzzy logic theory.

The Mamdani algorithm is used to assess the risks of integrating RES into the power supply system. The fuzzy system rule base is formed and the membership functions of input parameters for the algorithm implementation are determined. The application of the Mamdani method allows to qualitatively describe the possible causes of the connection problem. It also provides a mechanism for assessing risk avoidance and planning possible solutions for RES integration.

The work will continue on further development of the methodology for making a generalized decision on the connection of RES. Because a properly proposed methodology to reduce risks will greatly facilitate the rapid integration of these sources into the energy system of Ukraine. Controlling the development of renewable energy at the stage of issuing technical conditions will ensure the combination of electricity production from renewable sources with other energy facilities of the Ukrainian system.

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