About the Planned Reliability of Electric Power Systems

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Abstract. The article discusses the issue of expanding the methodological foundations of system reliability of electric power systems as part of the development of a new type of system reliability - planned reliability. Planned reliability is a type of system reliability intended for the analysis of electric power systems when planning their operation for a period of up to 1-2 years. Planned reliability includes some signs of security and adequacy. The need for the development of methodological foundations for this type of system reliability is associated with the need to solve a number of important problems in electric power systems, such as planning repairs of power equipment, long-term planning of power system modes, etc.

1 Introduction

Reliability is a complex property of objects to perform specified functions to a given extent under certain operating conditions [1]. Projecting this definition onto the electric power system (EPS), we can conclude that the reliability of the electric power system is its property, which consists in the generation, transmission and distribution of electricity in the required volume and standardized quality, taking into account failures of power equipment, which are of a probabilistic nature, planned repairs of power equipment, probabilistic the nature of electricity consumption, disruption of the supply of primary energy resources to stations.

In the theory and practice of ensuring the reliability of EPS, such a concept as system reliability is used. System reliability is the reliability of a system as a complex technical or production facility (system reliability includes adequacy and security) [1]. Adequacy is the property of an object to satisfy consumer requirements within specified values and restrictions on the supply of energy resources, taking into account planned and unplanned interruptions in the operation of its elements and operational restrictions. If we make a composition of individual properties that form adequacy, then the subject of consideration can include reliability and maintainability (recoverability) [2]. Security is the property of an object to maintain specified operating states when conditions change, element failures and sudden disturbances. The composition of individual properties that make up operational reliability consists of reliability, stability, survivability, and controllability.

Both adequacy and security are used to solve specific problems at various stages of EPS control. Conventionally, the stages of management can be divided into the following: long-term design, work planning and operation. In terms of duration, the operation stage includes direct online control, planning of EPS operation is carried out for up to one year, long-term design is carried out for a period of up to 10-15 years.

The main goal of the security analysis is to assess the impact of possible failures of power equipment and other adverse phenomena in the EPS on its ability to maintain operating parameters within the required limits and uninterruptedly supply consumers with electricity and power in full. The stability of the EPS power system is the basis of security and, by analogy with static and dynamic stability, there are two subtypes of security: static security and dynamic security [3]. Various methods are used to analyze security [4-6], the main requirement for these methods is speed while maintaining the required accuracy. Indicators of operational reliability are indicators showing the probability of deviation of operational parameters from nominal values, the lack of resources in different places of the system in a specific operating state of the EPS. As part of the assessment of operational reliability, problems of online control of EPS are solved, and security is also assessed when solving some design problems. With online control of EPS, the main task of security is to determine the optimal composition of control actions to ensure reliability of power supply.

Adequacy is assessed when planning work and designing the development of EPS. The main goal of assessing adequacy is similar to the purpose of assessing operational reliability and is to analyse the ability of the system to supply consumers with electricity and power, taking into account random and non-random events: failures and repairs of power equipment, load fluctuations, etc. To analyse adequacy, a technique based on the method is mainly used Monte Carlo [2,7,8]. When assessing adequacy, only the balance of the active power of the EPS and the ability of the EPS elements to withstand active power loads...
are taken into account; accordingly, operating parameters such as voltages in nodes and reactive power are not analysed and not taken into account. Not taking into account operating parameters is an assumption that affects the final result of determining reliability indicators. The main indicators obtained as a result of assessing adequacy are: probability of deficit-free operation, mathematical expectation undersupply of electricity, energy reliability characteristics. Based on these indicators, the problems of synthesizing adequacy are solved, mainly to justify the level of redundancy of generating capacity, the structure and capacity of electrical networks in the long-term design of development.

Among the many problems solved at all stages of the design and operation of EPS, there are a number of problems that do not correspond well to the use of the methodological apparatus of security and adequacy for their solution. First of all, this refers to the tasks that arise when planning the operation of an EPS. The main limitation, in methodological terms, on the part of security is the time limitation of reliability assessment, since in essence the reliability of a certain EPS state is assessed. As for adequacy, the main limitation here is the assumptions made in the assessment, which are fully justified in long-term development design, when there is objective high uncertainty in consumption forecasts and operating conditions of EPS and fairly rough estimates of EPS states are required. Thus, in order to correctly solve problems that arise when planning the operation of EPS, it is necessary to develop a methodological basis for assessing system reliability. To do this, it is proposed to introduce a third type of system reliability – planned reliability. As a result, system reliability will consist of three components: security, planned reliability, adequacy (Fig. 1).

![Fig. 1. Types of system reliability of EPS.](image)

As part of the assessment of planned reliability, it is necessary to comply with the requirements for the dynamics of changes in random processes in the EPS over the required period of time and at the same time model the EPS states quite accurately. In essence, the problem of assessing the planned reliability of an EPS can be formulated as follows: for a given forecast of power consumption for a period of up to 1-2 years, a known structure and composition of EPS equipment (including taking into account plans for the input/output of equipment), it is necessary to determine reliability indicators characterizing the provision of electricity and the power of consumers, reflecting the “weaknesses” of the EPS and allowing rational decisions to be made when solving subsequent problems of synthesizing planned reliability, taking into account random processes in the behaviour of power equipment, the random nature of fuel supplies to power plants, random fluctuations in electricity consumption, as well as the most correct power flow distribution.

### 2 Problems solved based on the planned reliability of EPS

When planning the operation of EPS, a set of problems is solved that directly or indirectly affect their reliability. This may mean that to effectively solve such problems it is necessary to develop methods and approaches that will correctly take into account the factors affecting reliability. Based on the content of the problems, it is possible to formulate requirements for analyzing and determining the planned reliability of the EPS. By planned reliability we understand the property of an EPS, which consists in the ability to perform the required functions of supplying consumers with electricity and power in the required volume and standard quality and quickly respond to changes in electricity consumption and generation, taking into account random processes in the behavior of power equipment, the random nature of fuel supplies to power plants, random fluctuations in electricity consumption, as well as correct power flow distribution. The main idea of developing a methodological apparatus for analyzing planned reliability is a comprehensive analysis of existing probabilistic events and processes occurring in the EPS and determining their impact on the reliability of the supply of electricity and power to consumers. The composition of individual properties of the planned reliability of an EPS will combine reliability, maintainability (recoverability), stability, survivability and controllability.

The question of developing a methodological apparatus for planned reliability has arisen in recent decades in connection with the transformations taking place in the global electric power industry. Along with the existing problems of ensuring the reliability of the EPS, transformations in the electric power industry, contributing to changes in the structure of production and consumption of electricity, contribute to ensuring the reliability of the EPS. The ongoing changes make both a positive and negative contribution, but in any case it is necessary to be able to adequately model these changes in order to assess the reliability of the power supply. Thus, on the electricity production side, uncertainty in its production has increased due to the development of renewable energy sources (RES), which are characterized by a highly probabilistic nature of work. One can also note the development of distributed generation, which introduces additional specifics when ensuring the reliability of EPS [9]. Significant volumes of RES in the balance of power and electricity can lead to undersupplies of electricity and power to consumers and the development of system accidents [10-12]. On the electricity consumption side, a demand management mechanism can be identified, with the help of which it is possible
to “smooth out” the power consumption schedule and thereby increase the reliability of the system. Undoubtedly, as part of the analysis of planned reliability, special attention must be paid to the modeling of energy storage systems (ESS). In modern energy systems, various types of energy storage systems are being developed, each with its own specific operation.

As noted above, modern trends in the electric power industry create requirements for expanding the methodological apparatus for assessing and ensuring system reliability. The following main problems can be identified that can be solved at a higher quality level when using planned reliability analysis:

1. Formation of schedules for repairs of power equipment during long-term planning of EPS operation.

Planning for repairs of EPS equipment depends on two main components. Firstly, the need for scheduled repairs, which can be determined based on operating hours and calendar time. Secondly, the ability of the EPS to bring power equipment into scheduled repairs with maximum efficiency and without increasing the risk of system accidents is above critical assessment.

2. Analysis of planned reliability for the period of planning the operation of the EPS.

A similar analysis of adequacy is carried out in various power systems [13,14]. A numerical assessment of planned reliability will make this analysis more in-depth. When identifying bottlenecks in the EPS, it is necessary to adjust control actions to ensure reliability of power supply and eliminate bottlenecks. In addition, in the process of assessing planned reliability, it becomes possible to take into account at a fairly detailed level the specifics and operating modes of power plants, including the risks of extreme water availability for hydroelectric power plants.

3. Assessment of EPS capabilities and efficiency in the integration of renewable energy sources (RES).

One of the main problems in the electric power industry in recent decades is assessing the effectiveness of RES integration. Such integration, due to the uneven nature of electricity and power generation from renewable energy sources, can lead to problems in ensuring the system reliability of EPS and the reliability of power supply. Assessing the planned reliability of EPS with adequate modeling of RES will make it possible to reflect the most critical random processes for EPS that characterize the operation of RES. The main issue in the problem under consideration is the ability of the EPS to compensate for the imbalance of power and electricity caused by the lack of a renewable source (sun, wind). Ultimately, the amount of generating capacity reserves, as well as the structure and capacity of the electrical network, will depend on the accuracy of RES modeling.

4. Analysis of the effectiveness of integration of energy saving systems (ESS) into electric power systems.

There are various types of ESS, which are characterized by such parameters as capacity, charge/discharge rate, operating principle. These parameters must be correctly reflected when assessing the reliability of the EPS. The specificity of the ESS operation lies in the continuity of the charge/discharge process. This process depends on the capabilities of the solar energy system and on the operating modes of the EPS, so it is important to reflect all influencing and limiting factors when modeling the solar energy system. In addition, the methodology for assessing the planned reliability of EPS is based on the analysis of random processes, which is important when modeling the operation of ESS.

5. Analysis of the need to attract electricity consumers to ensure the required level of planned reliability.

The main idea of this task, first of all, comes down to the selection of electricity and power consumers to manage demand. Demand management is one of the mechanisms for managing the reliability of the power system. In the process of selecting consumers, it is important to know which consumers can make the maximum contribution to ensuring the reliability of the EPS.

3 Methodology for assessing the planned reliability of EPS (content characteristics)

As noted above, the planned reliability of an EPS essentially integrates some aspects of assessing both security and adequacy, and also has a number of specific features. The most effective (in different positions) method for assessing system reliability is the Monte Carlo method [8]. It is on this basis that the methodology for assessing planned reliability is based.

The functioning of an EPS is a multidimensional random process in which many numerical parameters that characterize the operation of the power system change over time. By a random process of functioning of the EPS $X^n(t)$ we will understand a process whose value for any fixed $t = t_0$ is a random state of the system $X^n(t_0)$ [15,16]. During the operation of an EPS, various events $\omega$ occur: equipment failures, changes in consumer load, changes in the parameters of elements, which are analyzed when assessing reliability. Taking the latter into account, the random process of EPS functioning can be written as a function of two arguments:

$$X^n(t) = \varphi(t, \omega), \omega \in \Omega, t \in T, X^n \in \Xi,$$

where: $\omega$ – events occurring in the EPS; $\Omega$ – event space; $T$ – time period of EPS reliability analysis; $\Xi$ – set of possible values of the random process of functioning of the EPS $X^n(t)$.

The EPS consists of various elements with different operating features. The random process of ESS functioning is a process with continuous time and with continuous states (in fact, the states are mixed, since there are both continuous and discrete ones; in the theory of random processes, such states are also called continuous). Continuous time is explained by the fact that for EPS, system transitions from states to other states can occur at any moment $t$ of the observed period $T$. In the process of assessing the reliability of EPS
based on the Monte Carlo method, the periods under consideration are discrete and equal to 1 hour. As for random states, as already noted, various states are considered, both discrete and continuous, for example, failures of power equipment form discrete states, and the random behavior of an EPS parameter, for example, voltage and a parameter that affects the reliability of the EPS, for example, speed winds or solar insolation form continuous conditions.

The flow of events for an electric power plant is extraordinary, since more than one event can occur at any given time, for example, the failure of a generating unit, the failure of a power transmission line, a change in wind speed, which affects the power output of a wind farm. If we consider the flow of events for a specific element of the EPS, then it can be accepted as ordinary, since events, in the case under consideration - failures and restorations, appear one by one. The flow of events for an EPS is a flow with consequences, since for any non-overlapping time periods the number of events (for example, failures) falling on one of them can depend on how many events fell on the previous one, for example, the failure of some elements of an EPS can lead to subsequent periods of time lead to overload of other elements, their failure and the occurrence of power shortages and undersupply of electricity. At the same time, the flow of events for a specific element will appear without consequences, since the events that form the flow appear at successive moments in time independently of each other, for example, failures and restorations. As for the stationarity of the flow of events in the EPS, in fact it is non-stationary, since the probability of the analyzed events can change over time depending on various factors.

4 Conclusion

Ensuring the reliability of electric power systems is the most important problem when managing them at different time stages. In the theory and practice of managing electrical power systems, the concept of system reliability is used. System reliability includes two components: security and adequacy. These components cover a number of problems solved when managing operations and designing development. However, these components do not fully cover a number of problems that arise when planning the operation of electric power systems. To solve problems that arise when planning the operation of electric power systems, it is proposed to use a new type of system reliability, which is called planned reliability. Based on planned reliability indicators, it becomes possible to solve a number of pressing problems in the electric power industry at a qualitatively new level.

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References

10. 9 August 2019 power outage report, 50 (2020)