Ensuring balance reliability in managing the development of electric power systems with renewable energy sources

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Abstract. The issues of substantiating balance reliability - reserves of the generating power of the EPS in the presence of renewal power in the standpoint of achieving the required normative indicators of balance reliability and the execution planned volumes of electricity generation at the wind power plants (WPP) and solar power plants (SPP) in the balance sheet. The results of substantiation reservation tools are given for various scenarios for the development of SPP and WPP both in power and the production of electricity.

1 Introduction

Planning for the development of electric power systems in modern conditions requires the accounting features of the work renewable power sources (RPS), mainly wind (WPP) and solar (SPP) power plants. The process of commissioning these types of stations is at a higher rate in countries with limited traditional energy resources. In Russia, the development of environmentally friendly generation touched a lesser extent, which is quite understandable. Nevertheless, the development of the industry under the program CPP RPS in the power balance of the South union power system (UPS) by 2025 provides for increasing such capacities up to 3.5 GW.

It is clear that the installations RPS do not radically solve the problems of reliability, due to the features of their work, depending on random natural factors associated with their energy supply, especially for the period of passing maximum loads. An analysis of the current RPS shows that the share of the SPP in the coating of maximum loads is insignificant small (less than 10%), the WPP share can fluctuate from several percent of the percent to tens. Nevertheless, when justifying the operational capacity power reserve of power systems for a promising period, it is necessary to take into account the features operation of these types power plants.

The article discusses the methodological problems of evaluating the indicators of balance reliability and justifying the value of the operational power reserve in the management development of electric power systems if there is a receipt WPP and SPP in the structure of the power balance. At the same time, the approach is considered to be an unquestioned that only those whose solution is associated with the need to take into account the specified restrictions on the supply of energy resources and the expected unplanned breaks in the operation of its elements - failures of the system due to emergency damage is considered to be an indisputable reliability. This aspect provides algorithms for embedding the SPP and WPP, taking into account the emergency failures of their attitudes and power restrictions caused by the insufficiency of energy resources (sun, wind).

2 Methodological approaches to assessing the balance reliability of the EPS

When developing mathematical models for evaluating the balance reliability of multi-zone EPS, approaches that are based on the use of analytical methods, statistical modeling methods or their combined are used. The last two approaches were most widely used due to the large opportunities for taking into account various kinds of restrictions [1, 2]. The methodology for solving the problem of evaluating balance reliability indicators when using these approaches, regardless of the control principles in electroenergy industry, is based on the solution of two interconnected stages:

- the formation load levels and random states of generating power caused by unscheduled conclusions in emergency repair of power plants;
- assessments the formed conditions for ensuring the load of territorial zones.

In the developed methodology [1, 2], as in the methods proposed in [3, 4] determination the indicators of balance reliability is carried out sequentially for all time intervals T_t, during which the structure of generating capacities and load remain unchanged. The formation of random states is carried out by methods of statistical modeling on the analytically obtained probabilities of reducing the generating capacities in

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individual zones of the EPS due to an unscheduled output of equipment into emergency repairs (regardless of the type of equipment). To evaluate the formed accidental condition of the system, approaches based on the use of methods for permanent current idealization are used [1, 4]. In this case, either a linear or nonlinear setting of the problem can be used. Summing up of balance reliability in the form of power deficits or probability of their existence in all the allocated time intervals allows you to determine their integral values. The most widespread in our country was a probabilistic indicator of balance reliability in the form of an integral probability of power deficiency ($J_д$) [2, 5].

From the point of view of evaluating the indicators of balance reliability from the entire multitude of states of generating power and load formed by randomly, only those conditions in which power deficiency are observed are of interest. There are extremely few such conditions, less than one percent at the largest steps in the steps of discrete daily load (usually not more than 8 out of 24) and their practical absence on other steps. As a matter of fact, this is not caused by the accounting for evaluating the indicators of balance reliability EPS the specification by types of generating equipment involved in consumer coating. Crimeless states do not affect the indicators of balance reliability and in existing models, the generation power can be redistributed between the different types of generating equipment (HPP, TPPs, NPPs, RPS). This moment was somewhat accompanied by the development of a methodology for evaluating balance reliability indicators taking into account the limited resource for the production of electricity at HPP [6]. This approach can be extended to the WPP and SPP.

The methodological principles of substantiating the operational power reserve value remain unchanged since the distant 60s of the last century. In modern conditions, a regulatory indicator of balance reliability for territorial zones ($J_д^н$= 0.004) is used to make decisions on the justification of reservation [5, 7], approved by order of the Russian Federation Ministry of Energy (№321 30.04.2021). The accepted value of the normative indicator of balance reliability has been used for more than 40 years (since the 80s of the last century). In the countries of Western Europe, the normative indicator of balance reliability $LOLH^н$ = 3-8 hours/day, in North America - $LOLE^н$ = 0.1 times a year.

All of the listed regulatory indicators of balance reliability is characterized by approximately the same methodological basis for their receipt with different information component, especially according to the regimes of electrical consumption [1]. The European standard for the indicators of balance reliability is focused on hourly electricity consumption schedules for all 8760 hours of the year, the North American provides for accounting for the load only the maximum hour of the day (365 values). The domestic regulatory indicator of balance reliability is focused on only one medium - hour daily schedule of December the month in the assumption of its action within 250 working days of the year.

3 The possibilities of accounting for the WPP and SPP when evaluating the indicators of balance reliability EPS

The use of statistical information on the climatic features of the region. The easiest way to take into account the WPP and SPP in model support the task of evaluating the indicators of balance reliability is to obtain probabilistic functions of reducing the generating power of these stations types caused on the one hand by their unreliable, on the other - the unsecured by their energy carriers (sun, wind). To implement this approach, it is necessary to have statistical information about the power of wind or solar activity by the hour of the year for a sufficiently large temporary segment (10 or more years). Having these two probabilistic rows, it is possible to build a resulting series of reducing the generating power for these types of stations [8]. A significant disadvantage of this approach is the loss of temporary and territorial dependencies of wind loads and activity of the sun when constructing the resulting rows of power reduction.

The problem can be solved by constructing the probabilistic series of reducing the generating capacity for all time periods (at the limit of 8760 hours) and special correlation matrices taking into account the change in probabilities in the territorial section of the power system. It should be noted that this is a very difficult procedure in the aspect of the information filling of the task. They encountered such a problem when assessing the effect of changes in temperature on the load power in different territorial zones EPS of Russia. The decision was the creation of a correlation matrix at the level of Russia UPS [9].

Using the planned electricity production at SPP and WPP. Recall that information about the values of electricity planned during the year at all types of power plants is given in the annual work scheme and development program of Russia UPS for the seven year period. Focusing on these indicators, which in such documents are considered a high degree of probability of reliable, it is possible to determine the distribution of electricity production by hours of the estimated period. At the same time, the corresponding shares of the clock period can be obtained in reporting documents on the work of current WPP and SPP.

As noted, a feature WPP and SPP is the unequal of their production of electricity caused by natural factors. This feature is proposed to take this feature by randomly setting the values of electricity production at WPP and SPP for the same periods of time T_t, according to which the indicators of balance reliability are evaluated. In a model for evaluating the balance reliability indicators, taking into account the participation of these types of stations in the coverage of consumers in defective states, it is possible to carry out by separate for them and all other types of power plants for the formation of capacities reducing the equipment caused by the conclusions of the equipment into emergency repairs [6]. At the same time, of course, mathematical models of assessment of each random state formed by power should be transformed.

4 Transformation the problem of assessing a random condition when taking into account the production of electricity at SPP and WPP

The task of streaming in the models of evaluating the indicators of balance reliability is called the task of distributing power deficiency. There are many productions of this task [2, 3]. Consider the simplest linear production, as the target function of which uses the functionality of maximizing the load or minimize power deficiency in the EPS, consisting of *n* territorial zones [1, 2]:

$$\sum_{j=1}^{n} c_j^{\text{н}} (\overline{P}_j^{\text{н}} - P_j^{\text{н}}) \rightarrow \min, \qquad (1)$$

The restrictions in these expressions are compliance with capacity balance, as well as restrictions on the power of loads and generating capacities in relation to all J-M territorial zones [1]. Accounting for the energy supply of WPP and SPP somewhat changes this target function, due to the introduction of two additional terms into it, characterizing the loading of these $c_j^{\text{в}}(\overline{P}_j^{\text{в}} - P_j^{\text{в}})$ and all other types of stations $c_j^{\text{пр}}(\overline{P}_j^{\text{пр}} - P_j^{\text{пр}})$. In the introduced additional terms in expression (1) $c_j^{\text{н}}$- the loading coefficients are taken equal to one; $c_j^{\text{пр}}, c_j^{\text{в}}$- coefficients reflecting the need for loading in defective states of other stations types ($P_j^{\text{пр}}$) and renewable ($P_j^{\text{в}}$); $P_j^{\text{н}}, \overline{P}_j^{\text{н}}, P_j^{\text{пр}}, \overline{P}_j^{\text{пр}}, P_j^{\text{в}}, \overline{P}_j^{\text{в}}$-accordingly covered with the need and power of the load demand, used and existing powerful power of other types of stations and RPS *j* - th territorial zone.

In order to exclude the influence of the introduced components of power in the deficit states of the EPS, the values of the coefficients of the target function with component generating power ($c_j^{\text{в}}$ and $c_j^{\text{пр}}$) are accepted much less (100 or more times) of the coefficient with the mainly plain of optimized functionality (1).

5 Principles of determining the production of electricity

For specified in the model of evaluating indicators balance reliability of time periods T_t, random values of electricity production at WPP and SPP are formed. The amount of electricity production for all the allocated periods of time should be equal to the specified planned value, for example, the SDP UPS. When solving the problem of assessing defective states, this requirement is carried out by the use of a special approach based on dynamic variation of the coefficients with additional terms of the target function (1).

The time period T_t for which the production of electricity is divided into many equal parts (up to 100). It is known [1-3] that obtaining reliable results of assessing the indicators of balance reliability requires the formation of at least 25,000 random conditions at each time interval T_t. Thus, for each of the 100 broken areas, 250 states are played. For each selected section (up to 100), the methods of statistical modeling are formed by the states of the generating power. At the same time, the coefficients $c_j^{\text{в}}$ and $c_j^{\text{пр}}$ additional terms for expression (1) in the allocated areas are unstable. Their values depend on how it is necessary to redistribute the generating power between all types of power plants and RPS. So that at the time under consideration, to approach the given volume of electricity production as close as possible.

For the ratio of the target function specified in the first section, the production of electric power is determined by the generation electric power on them and is compared with the one that should be on the site. If the production of electricity is lower than the planned, the coefficients are additional for the target function (1) of the terms for generating renewables $c_j^{\text{в}}$ are increased, and for other types of stations $c_j^{\text{пр}}$ they decrease. Thus, when playing the next group of states (for example, 250 states) in the 2nd section there is an increase in the production of electricity at the WPP and SPP. When considering the last section, the estimated value of electricity production is approached the value specified for the period T_t.

The most characteristic case was discussed above when the modest value production of electricity on WPP and SPP reaches the given value using all the allocated sections of the time period T_t. When an accidentally specified electricity production on WPP and SPP is characterized by a low value, the effect is slightly different. The achievement given volume of electricity production at WPP and SPP is achieved in a smaller number the selected areas. This leads to the exclusion power of WPP and SPP when considering all subsequent sections. This condition is possible when in UPS power balance is insufficiency the generating power other types of plants and prevails WPP and SPP. This generally leads to an increase in balance reliability in the form of integral probability of power deficiency $J_{\text{д}}$. And, of course, to increase the operational reserve of power.

6 Experimental calculations

The influence of WPP and SPP on balance reliability indicators and value of power operational reserve was considered on the example South UPS. Information on promising capacity and electricity balance sheets for 2025 was taken from the SDP UPS for 2021-2027. Important characteristics South UPS, from the standpoint the issues of evaluating balance reliability, are the established capacities of all stations types (28687 MW) and WPP with SPP (3645 MW), as well as the production of electricity for them (112317 and 7700 million kWh). WPP and SPP used 2112 hours. The maximum load combined with Russia UPS is 16995 MW. The calculated scheme Russia UPS (Fig. 1) and information content the task of assessing the balance reliability indicators were obtained when performing joint research with the «SO UPS» JSC. From the same work in Fig. 1 shows the values the maximum

Table 1. Comparison the values of operational power reserve for various parameters of electricity production at WPP and SPP

№	Power WPP and SPP, MW	Power used in balance, MW		Electricity production of WPP and SPP, million kW · h		Operational power reserve	
		WPP and SPP	other	Plan, million kW · h., %	Calculation	MW	%
1	2	3	4	5	6	7	8
Without restrictions on electricity production at WPP and SPP						1725	10,15
1.	910	506	18229	1925 / 1,72	1786,8	1740	10,24
2.	1820	956	17893	3850 / 3,43	3583,0	1854	10,91
3.	3645	1685	17453	7700 / 6,86	7099,7	2143	12,61
4.	5465	2672	17106	11550 / 10,28	11374,3	2783	16,37
5.	7290	3812	17181	15400 / 13,71	14250,9	3998	23,52
Without restrictions on electricity production at WPP and SPP						790	4,65
6.	910	604	16476	1925 / 1,72	1792,8	795	4,68
7.	1820	866	16239	3850 / 3,43	3588,6	830	4,88
8.	3645	1682	15498	7700 / 6,86	7254,8	950	5,59
9.	5465	2510	14966	11550 / 10,28	11224,3	1210	7,12
10.	7290	3290	14667	15400 / 13,71	14852,1	1648	9,70

permissible power with neighboring UPS: 1572 MW (issuance), 2610 MW (receipt).

When using the balance reliability indicators annual load in model with 8760 clock changes, you can play the volume of electricity production for each hour estimated period. The formation of only one random parameter of electricity production for an hour is not entirely correct (not representative). Therefore, it is proposed for each stage of the annual load graphics, at least 4-multiple repetition of calculations during the recruitment of other randomly obtained electricity production values.

When applying the indicators of the balance reliability of the average daily graph load on December [5], implemented in the model [1, 2], the effects probabilistic nature of electricity production on WPP with SPP for 250 working days of the year is applied. Here, representativeness is fulfilled, and this approach is implemented in software "Orion-M" [2].

Research was carried out for isolated work South UPS and when it was part of the Russia UPS (Fig. 1). Due to the lack of information on the distribution electricity production at WPP and SPP on the calculation hours in the calculations below, the assumption of its uniform distribution was made. This made it possible to determine the volume of electricity produced at each selected time interval T_t. At this stage, an uniform law of distribution of electricity production at a time interval T_t was applied. It is clear that both the first and second assumptions are not entirely correct and used only to show the performance of the proposed methodological approach. The receipt of more reliable information on

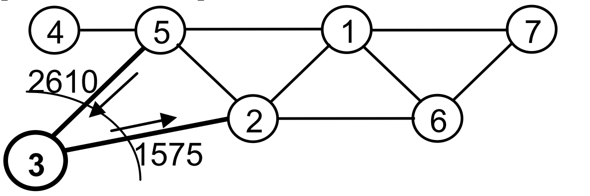

Fig. 1. South UPS and Russia UPS:
1 – Ural UPS; 2 – Middle VolgaUPS; 3 – South UPS;
4 – North-West UPS; 5 – Centre UPS; 6 – Kazakhstan;
7 – Siberia UPS.

the distribution of electricity production at WPP and SPP, as well as the laws of their changes problems in modern conditions, cannot cause them.

The scenarios of electricity production at WPP and SPP South UPS at 2025 were subject to consideration the planned value of 7700 million kWh, its decrease of 2 and 4 and an increase of 1.5 and 2 times with the corresponding change in the installed capacity. In table 1 for these scenarios, results optimization the value of operational power reserve in South UPS are provided, subject to compliance the probabilistic normative indicator of balance reliability is $J_д$ =0.004. For a more visible presentation of the proposed algorithm for accounting the work WPP and SPP, the work of South UPS was considered in isolated mode and as part of Russia UPS. For the 5 considered scenarios changes the power WPP and SPP (column 2 in the table), according to the ratio of hours use, the planned values production of electricity on them (column 5) are determined. The producer of the column 5 shows the percentage electricity production at WPP and SPP to the planned values. The approximate equality values the production of electricity at WPP and SPP and their values planned for a year (columns 5 and 6) for all considered scenariors.

The task in the model of an additional condition for

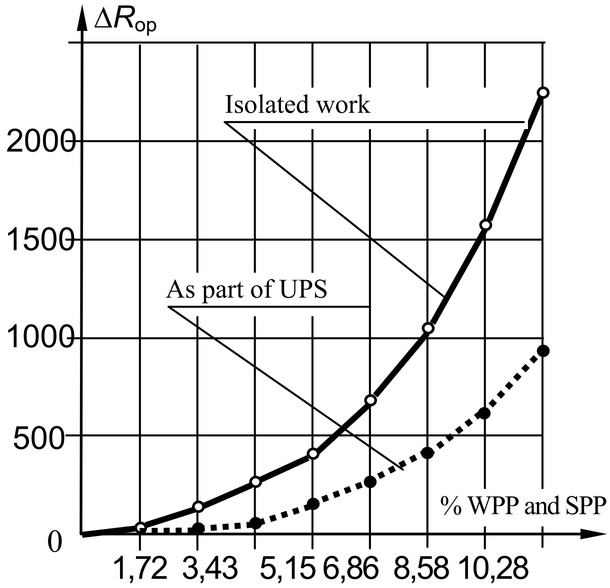

Fig. 2. Change value operational power reserve from the share (%) of electricity production at WPP and SPP.

redistribution of capacities between renewables and other types of stations leads to the fact that at some time intervals allocated randomly, the WPP and SPP are ready to provide a systemic power deficit, but cannot do this due to restrictions on the electricity produced on them. This leads to an increase in the calculation indicator of balance reliability in the form of an integral probability of the appearance of a power $J_д$ deficiency at this time interval. This can be explained that for the conditions of isolated operation South UPS, the power used in the balance sheet for all types of stations exceeds the maximum load (16995 MW) according to all scenarios of electricity production at WPP and SPP (column 4, Table 1). During the operation of South UPS, this principle is violated as part of Russia UPS. The reason for this is quite simple - the lack of its own generating power to cover the deficiency is covered with excessive Russia UPS. The capacity of 2610 MW (Fig. 1) allows this to be done.

The principles of redistribution generating capacity between the immediately personal types of power plants in defective states (section 4) and the probabilistic random task of the electricity production at WPP and SPP in different periods of time (section 5) made it possible to evaluate the influence values of electricity on the operational power reserve (column 7 and 8). In Fig. 2 shows the characteristics of a change in the operational power reserve in relation to its value, obtained without taking into account any restrictions, for various shares of electricity production at WPP and SPP. It can be seen that with a small proportion of electricity production at WPP and SPP (up to 3.5 %), which is characteristic of current state of the Russian electric power industry, an increase in the operational reserve of power is slightly (about 125 MW / 0.7 %). It is clear that taking into account the peculiarities of the work WPP and SPP in the task of substantiating the operational power reserve when working as part of Russian UPS in this case is not required.

Calculations showed that with the value of 7700 million kW h (6.86 %) and assumed assumptions planned by 2025, an increase in the operational capacity reserve by 160 MW (0.94 %) when working in Russia UPS and 420 MW (420 MWs (2.47 %) with isolated work. This already requires the preparation of more detailed information about the work WPP and SPP and the development of software that allows you to determine the necessary additives to the value of operational capacity reserve at the development stage of Russia UPS. These ratios on the influence of WPP and SPP on the reliability of energy systems are quite well consistent with the results presented in the work [10] by reviewing foreign sources, in relation to operating conditions.

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