Research of the influence of power engineering equipment accident rate on the indicators of adequacy and the value of operating reserve of electrical power system

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Abstract. Reliable source information is necessary for a correct adequacy assessment of electric power systems. Among a wide set of initial information, coefficients of accident rates of power engineering equipment are important. The analysis of methods for determining the coefficients of accident rates of power engineering equipment, which are used in the assessment of the adequacy of electric power systems, is presented in the article, also the features of accounting for coefficients of accident rates are elicited. The experimental part of the article is showed the influence of generating aggregates accident rate on the level of operating reserve on the example of the Unified Energy System of Russia.

1. Introduction

The accident rate of the power engineering equipment influences in the most direct way both the indicators of adequacy of electric power systems (EPS) and the level of operating reserve. The accident rate of the power engineering equipment depends on many factors. Factors or causes of failures for each type of power engineering equipment can be booth characteristic, for example, for overhead transmission line it can be weather conditions, the level of icing on the wires, and general for the whole complex of power engineering equipment, such as the culture of operational, the level of wear (ageing), etc. [1].

The notion of failure is fundamental in reliability theory. This notion is interpreted as an event that consists in the transition of an object from one functional ability level to another lower one. The analysis of equipment failures is carried out as part of the research of a single property of reliability – failure-free operation. There are existed a row of failure-free operation indicators that characterize the object of consideration from position of how often it fails, for what time, with what speed and probability.

The influence of failures of generating aggregates and power transmission lines that included in the connections between zones or controlled sections on the reliability of electrical and capacity supply to consumer is analyzed in the study of the adequacy of electric power systems (EPS). The criterion for system failure is the occurrence of capacity deficiency among consumers. The main reason for the appearance of capacity deficiency is the power engineering equipment failures. The values of the main reliability indicators, such as the probability of a fail-free operation and the mathematical expectation of

electricity sacrifice, on the basis of which the need for generating capacity reserves is assessed in further, depend on how often a capacity deficiency occurs and what is its magnitude.

Thus, the purpose of the article is to analyze the methods for determining the coefficients of accident rates of power engineering equipment and impact assessment of the values of the accident rates coefficients on the indicators of adequacy and on the level of generating capacity reservation using the example of the Unified Energy System (UES) of Russia.

2. Determination of the power engineering equipment coefficients accident rate

The most used method for assessment adequacy is based on the Monte-Carlo method [2,3]. One of the main steps of the methodology is the step of forming the calculated states of EPS. The calculated states is formed on the basis of simulation power engineering equipment failures that bases on coefficients of accident rate, also random deviations of capacity consumption are simulated during the assessment. Simulation of one accident event $K_i, i = 1, ..., I$, the probability of which is $p_i, i = 1, ..., I$, occurs when playing one random number $r_i, i = 1, ..., I$ from evenly distributed set R on the interval $[0,1]$. If at the same time r_i is in the interval $[0, k_i^{ав}]$, it is considered that the event has come if not, then it didn't come [4]:

$$K_i = \begin{cases} 1, if\ r_i \in [0, k_i^{ав}] \\ 0, if\ r_i \in (k_i^{ав}, 1] \end{cases}, i = 1, ..., I. \qquad (1)$$

In this case, it is of interest to determine the adequacy of the coefficient of accident rate $k_i^{ав}$ for the periods of the

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calculated interval, since it directly affects the indicators of adequacy.

The coefficient of accident rate of power grid or generating equipment k_i^{a6} characterizes the emergency repairs relative time of power equipment for a year or another period and can be determined by the following formula:

$$k_i^{a6} = \frac{t_i^{a6}}{t_{pac4}} , i = 1, ..., I, \qquad (2)$$

where: t_i^{a6}- down-time of power equipment in emergency repairs (issued by urgent and emergency dispatcher's request) during the retrospective period (h); t_{pac4}-the duration of the retrospective period (h); I- the amount of power equipment.

The retrospective period, of course, depends on the conditions of the assigned task and the available statistics on emergency downtime of power equipment. For example, if it is known, that power equipment failures have highly correlation with any climate that are characteristic of one or on other months of the year, then it is necessary to calculate the coefficient of accident rate with differentiation by months. An important condition for calculating the coefficient of accident rate is taking into account the dynamics of power equipment aging when pre-planning of the IPS development, what will influence the most directly the coefficient of accident rate. By default, the retrospective period in the formula, for example, for a year it will be equal to 8760 hours. According to [5], the coefficient of accident rate of a generating aggregate (electrical power unit) is determined by the following formula:

$$k_i^{a6} = \frac{t_i^{a6}}{t_I^{pa6} + t_i^{pe3}} , i = 1, ..., I, \qquad (3)$$

where: t_I^{pa6}- the duration of the generating aggregate operating time (h);t_i^{pe3}- the duration of the of generating aggregate in reserve (h).

Expression (3) can be generalized to the whole set of analyzed power equipment. If we analyze expression (3), that the denominator arises a question, namely t_i^{pe3}. Pertinently, during the period when the power facilities is in a state of cold reserve, it can't fail, therefore, at least it is necessary to exclude from the denominatort_i^{pe3}.

In fact, the power facility can be in the following states: in-service, emergency, scheduled repair, reserve. Two states have to consider when determining the coefficient of accident rate: in-service and emergency, therefore the most accurate assessment of the coefficient of accident rate can be obtained using the following expression:

$$k_i^{a6} = \frac{t_i^{a6}}{t_i^{pa6} + t_i^{a6}} , i = 1, ..., I, \qquad (4)$$

For example, in in modern conditions operation of generating aggregate the operating time can be only half the calculation period, i.e. 4380 hours, while the aggregate can be in emergency repair for 10 days or 240 hours and in scheduled repair for 8 days or 192 hours, the rest 3948 hours be in reserve. Let's calculate the coefficient of

accident rate by (2), (3) and (4): 0.0274; 0.0288; 0.0519 respectively. Thus, as can be seen from the presented example, which is very indicative, the coefficient of accident rate for different approaches to its definition can differ by 2 times.

3. Accident rate indicators of power equipment operated in the UPS of Russia

As already noted, obtaining actual coefficient of accident rate that reflect the modern state of power equipment [6,7] is important in assessing adequacy, but for some equipment, the differentiation of the coefficient of accident rate by the characteristic intervals of the calculation period is important. So, for overhead power transmission line the coefficient of accident rate depend on weather conditions in different periods of the year. Statistical processing of emergency downtime of power transmission lines for lines included in the controlled sections of the UPS of Russia was carried out. In fig.1 shows the results of there native values of the accident rate of power transmission lines for the IPS included in the UPS of Russia (the values are determined relative to the maximum).

Data on the accident rate of power transmission lines, presented in Fig. 1 were obtained after processing of retrospective data over a 10-year period. As can be seen from the presented dependences in fig.1, the relative accident rates of power transmission lines changes significantly depending on the months of the year and has different peaks and dips in different IPS. So the peak is in the spring months, and the dip is observed in the summer months in the IPS of the East. Peaks are observed in the summer months in the IPS of Siberia, which may be connected with forest fires, as well as the loading of many power transmission lines during the flood periods. Summer and autumn peaks are attended in the IPS of the Urals, spring and autumn peaks are in the IPS of the Middle Volga. Spring and summer peaks are observed in the IPS of the South, spring and autumn peaks are in IPS of the Center. Peaks are occurred at the end of summer and beginning of autumn in the IPS of the North-West.

The coefficients of accident rate for generating aggregates that exploited in the UPS of Russia were determined by dependencies (2), (3) and (4). Data of part on the IPS included in the UES of Russia is presented in table 1.The actual time during which the generating aggregates were in reserve was not known when calculating the coefficients of accident rate. We are talking about aggregates that exploited, first, at TPP, at NPP, as a rule, the operation of such aggregates is strictly regulated, but the loading of aggregates of HPP depends on the flood period. In modern operating conditions, the time of downtimes in the reserve for generating aggregates of TPP is significant and can be up to 50% of the estimated time, it was accepted, that the generating aggregates at TPP are in reserve from 30 to 50% from the estimated time during calculating the coefficient of accident rate. Also, the values of the coefficients of accident rate from [8] are presented in table 1.
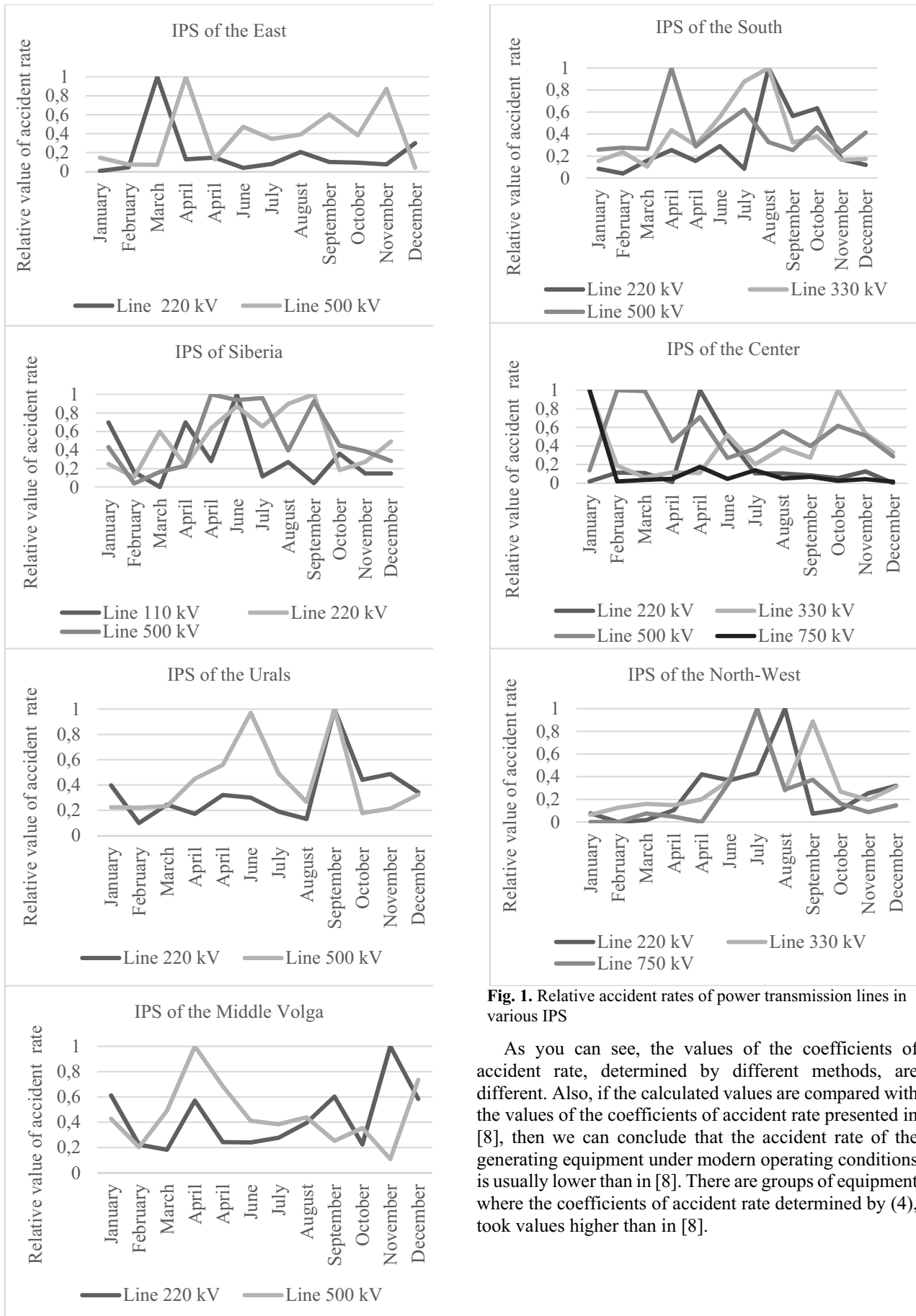
Fig. 1. Relative accident rates of power transmission lines in various IPS

As you can see, the values of the coefficients of accident rate, determined by different methods, are different. Also, if the calculated values are compared with the values of the coefficients of accident rate presented in [8], then we can conclude that the accident rate of the generating equipment under modern operating conditions is usually lower than in [8]. There are groups of equipment where the coefficients of accident rate determined by (4), took values higher than in [8].

Table 1. The coefficients of accident rate of generating aggregates of part in the UES of Russia, calculated using on different methods

Type of power plant	Amount of aggregates (pcs.)	Diapason of years of input	Diapason of installed capacity of aggregates, MW	Accident rates			
				(2)	(3)	(4)	[8]
IPS of the North-West							
NPP	16	2010 - 2010	151 - 451	0,0031	0,0036	0,0036	0,0650
HPP	62	1926 - 2016	0 -150	0,0106	0,0111	0,0110	0,0050
	49	1952 - 2014	26 - 70	0,0073	0,0077	0,0076	0,0050
	1	1984 - 1984	71 - 150	0,0127	0,0133	0,0131	0,0050
TPP	66	1945 - 2014	0 - 25	0,0254	0,0277	0,0526	0,0200
	67	1951 - 2016	26 - 70	0,0137	0,0145	0,0254	0,0200
	35	1976 - 2013	71 - 150	0,0138	0,0148	0,0266	0,0200
	20	2010 - 2012	151 - 250	0,0154	0,0174	0,0334	0,0450
	7	2010 - 2012	251 - 450	0,0029	0,0033	0,0050	0,0550
	5	2010 - 2010	451 and higher	0,0053	0,0053	0,0098	0,0550
IPS of the Center							
NPP	2	2010 - 2010	151 - 250	0,0016	0,0018	0,0018	0,0550
	22	2010 - 2016	451 and higher	0,0053	0,0071	0,0071	0,0750
HPP	8	2010 - 2010	26 - 70	0,0057	0,0061	0,0060	0,0050
TPP	86	1953 - 2011	0 - 25	0,0117	0,0124	0,0228	0,0200
	85	1953 - 2012	26 - 70	0,0113	0,0121	0,0187	0,0200
	84	1977 - 2014	71 - 150	0,0056	0,0060	0,0105	0,0200
	32	2010 - 2010	151 - 250	0,0152	0,0171	0,0316	0,0450
	30	2010 - 2010	251 - 450	0,0105	0,0118	0,0244	0,0550
	3	2010 - 2010	451 and higher	0,0138	0,0179	0,0423	0,0550
IPS of the South							
NPP	4	1986 - 2018	451 and higher	0,0098	0,0113	0,0112	0,0750
HPP	57	1934 - 2016	0 - 25	0,0165	0,0173	0,0170	0,0050
	18	1952 - 2015	26 - 70	0,0046	0,0047	0,0047	0,0050
	24	1985 - 2010	71 - 150	0,0092	0,0097	0,0096	0,0050
	8	1974 - 2010	151 - 250	0,0281	0,0300	0,0291	0,0050
TPP	49	1950 - 2015	0 - 25	0,0118	0,0123	0,0219	0,0200
	34	1958 - 2015	26 - 70	0,0195	0,0211	0,0394	0,0200
	27	1966 - 2013	71 - 150	0,0238	0,0260	0,0391	0,0200
	12	1970 - 2010	151 - 250	0,0146	0,0156	0,0253	0,0450
	18	1975 - 2016	251 - 450	0,0191	0,0218	0,0427	0,0550
IPS of the MiddleVolga							
NPP	4	1985 - 1993	451 and higher	0,0065	0,0074	0,0073	0,0750
HPP	1	2015 - 2015	0 - 25	0,0027	0,0028	0,0028	0,0050
	32	1967 - 2016	26 - 70	0,0018	0,0019	0,0019	0,0050
	52	1979 - 2010	71 - 150	0,0044	0,0046	0,0046	0,0050
TPP	35	1942 - 2010	0 - 25	0,0139	0,0149	0,0241	0,0200
	62	1952 - 2014	26 - 70	0,0098	0,0102	0,0170	0,0200
	83	1965 - 2015	71 - 150	0,0095	0,0101	0,0208	0,0200
	16	1963 - 2014	151 - 250	0,0049	0,0053	0,0079	0,0450

4. Experimental research

As a part of the experimental studies, the task was set to determine the difference in the value of the operating reserve for different standard values of the probability of fail-free operation taking into account the different coefficients of accident rate of generating equipment. The values obtained on (2) and from [8] were taken as the compared coefficients of accident rate. The researches were carried out on the scheme of the UPS of Russia (excluding the IPS of the East). The main characteristics (consumption, generation) were obtained on the basis of [9] for 2022. Fig.2 shows the separation of the UES of Russia scheme on reliability zones.

Table 2 provides information of the capacity balance of the UES of Russia (without IPS of the East) per hour of the coincident demand.

Table 2. Capacity balance in the UPS of Russia (without IPS of the East), original variant on level at 2022

Available capacity, MW	206259
Coincident demand, MW	158686
Generating reserve, MW	47573
Redundancy factor, %	30

Table 3 provides information on calculations to determine the generating capacity reserve corresponding to the standard values of the probability of fail-free operation at the level of 0.999; 0.996; 0.987. Fig.3 shows the dependence of the generating capacity reserve on the probability of fail-free operation in the reliability zones of the UPS of Russia.
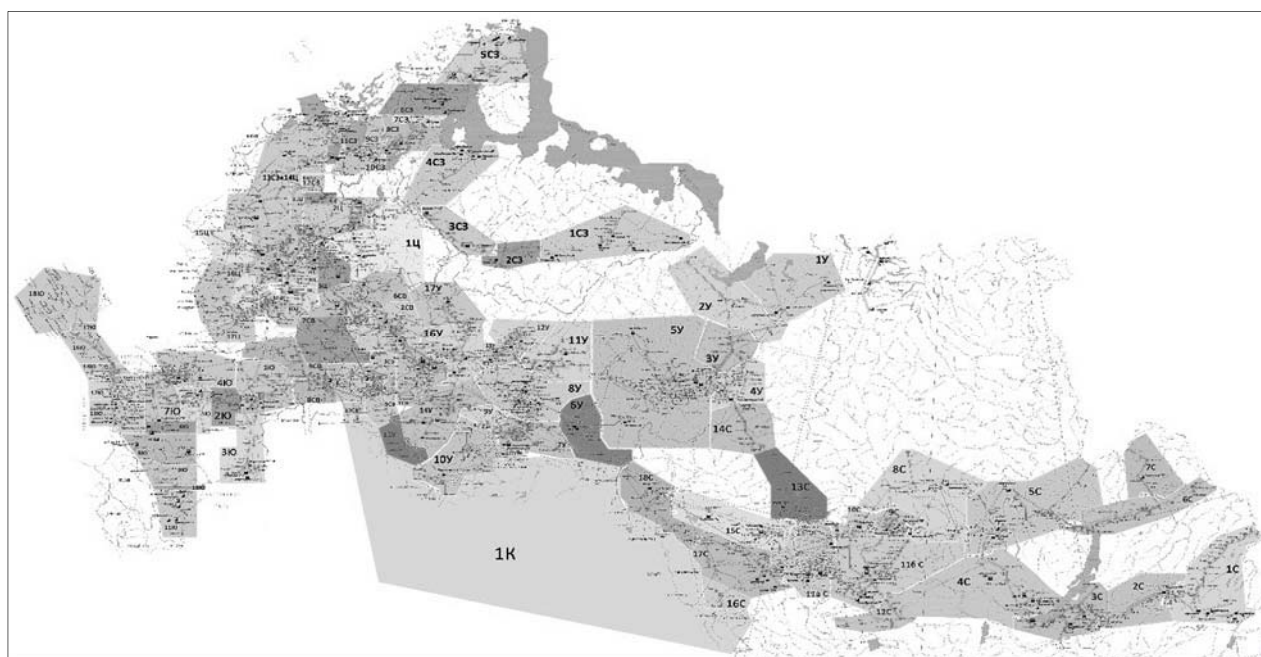

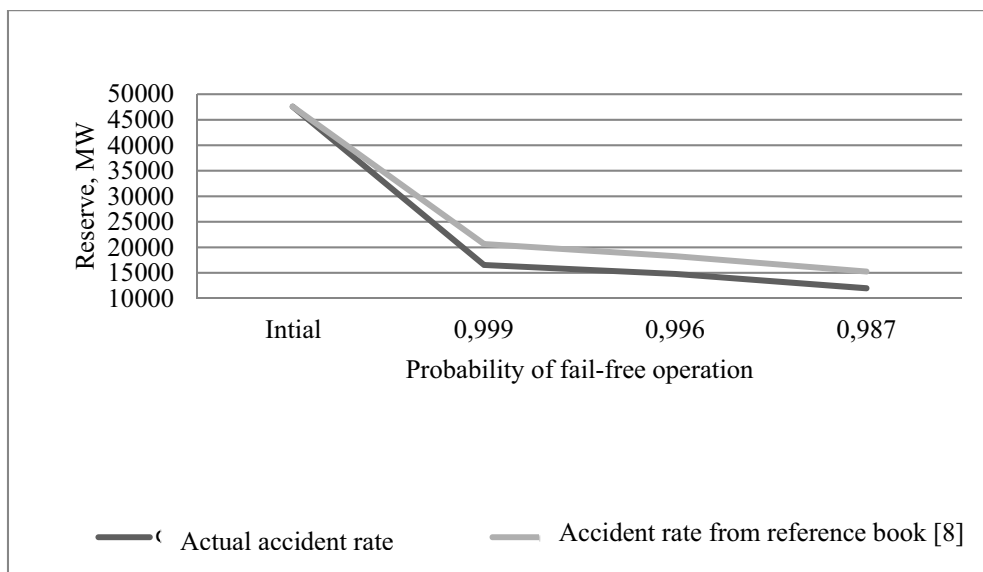**Fig.2.** Reliability zones of the UPS of Russia

Fig.3. Dependence of the generating capacity reserve on the probability of fail-free operation in the reliability zones of the UPS of Russia.

Table 3. Capacity balance in the UES of Russia for different standards of the probability of fail-free operation and with different coefficients of accident rates

Standard value of probability of fail-free operation	0,999		0,996		0,987	
	Actual accident rate	[8]	Actual accident rate	[8]	Actual accident rate	[8]
Required available capacity, MW	175206	179328,9	173454	176946,9	170659	173927,3
Over-generation, MW	31053	26930,1	32805	29312,1	35600	32331,7
Coincident demand, MW	158686	158686	158686	158686	158686	158686
Generating reserve , MW	16520	20642,9	14768	18260,9	11973	15241,3
Redundancy factor, %	10,4	13	9,3	11,5	7,5	9,6

As you can see from the table 3 the difference in the reserve of capacity for different values of the coefficients of accident rate is about 2%.

5. Conclusion

Justification of the rational level of reserving the generating capacity of the UES depends on many factors, among which maximally reliable information about the technical and reliability parameters of the power engineering equipment operated in the EPS. The coefficient of accident rate of the power engineering equipment is an important parameter that most directly affects the indicators of adequacy and the level of reservation of the EPS. The methods for determining the coefficient of accident rate of power equipment are analyzed in the article. Based on their analysis, it was concluded that in modern operating conditions of power equipment, when determining the accident rate for a unit of equipment, it is necessary to take into account the in-service time, the time in reserve, the time in scheduled repairs and the time in emergency downtimes.

When analyzing the accident rate of overhead transmission line of the basic network, operated in the UES of Russia, it was revealed that the accident rate of overhead transmission line is uneven during the year and this condition have to taken into account when assessing of the adequacy. When analyzing the accident rate of the generating aggregates, it was revealed that that for the same type of equipment in different IPS, the accident rate is different and also the coefficient of accident rate for modern operating conditions differs from those values that are presented in the reference books, what determines its constant relevance.

The experimental part of the article is showed the influence of different values of the coefficient of accident rate on the level of operating reserve of generating capacity using the example of the Unified Energy System (UES) of Russia.

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