Preventive Risk-Management of Power System for Its Reliability Increasing

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Abstract: - In article is considered the problem of effective Electrical Power System management in the conditions of incomplete information about regimes and technical stuff of equipment and in the conditions of financial restrictions. Fault probability and accident risk are proposed as the criteria for the effective Electrical Power System management. Using these criteria allows increasing reliability of Electrical Power System and its elements. For the decreasing accident risk and increasing Electrical Power System reliability Pareto optimal method is used. Developed approaches, methods and algorithms are checked on IEEE test scheme.

Key-Words: - fault, risk, probability, Electrical Power System, technical stuff, Pareto method.

1 Introduction

At present time, the Electrical Power Systems (EPS) of Eastern European countries operate in very tight conditions. These conditions are the consequences of next factors:

- large part of power, commutation, secondary and auxiliary equipment fully spent its resource (for example, in Ukraine this part is approx 75 % of total equipment) [1];
- rates of replacement and modernization of existent equipment much lag from the rates of the equipment aging;
- market relations in power engineering cause the maximal tight exploitation regime of equipment to its complete degradation;
- increasing of the adverse weather conditions (storms, rains, ice glaze, etc).

These factors are significantly decreasing the EPS operation reliability. Reliability decrease leads to the growing the number of faults, the consequences of which may be overloads of EPS elements, transient or dynamical stability loss. In such conditions is very important to choose the optimal strategy of EPS management. This strategy must include:

- control of EPS regime taking into account real technical stuff of electrical equipment;
- equipment modernization taking into account structural, regime and technical reliability of objects;
- optimal distribution of financial resources between EPS subsystems;
- maintenance planning in the financial restrictions conditions should be taking into account the accessory of electrical equipment to a certain sets according to its importance and technical stuff;
- planning development of EPS as multicriteria problem of taking decision.

Listed strategic problems are the problems of EPS preventive management, which has the aims to decrease the number of faults in EPS and to increase its reliability. For its adequate solution is necessary criterion, that would give correct estimation of EPS reliability.

Analysis of modern world trends has shown the efficiency and great perspectives of risk-based asset management, which has the risk as main quantity characteristic. In [2] is proposed the approach to the complex using of risk-management in distribution networks and shown the results of equipment performance estimation for the forecasting of EPS reliability. In [3, 4] special attention is paid to assessing the reliability of distribution system components and presented the models for estimation. Effective risk-management is oriented to the minimization of total costs on the electrical networks exploitation. Models of such management are proposed in [5] and allowed to take into account the influence of equipment life on the fault probability of each type of equipment. In [6] is shown the model risk as a characteristic, which includes probability of fault and the resulting losses in the fault case. So, the fault risk in EPS consists of the fault probability, accident development probability on a particular scenario and technical, economical or ecological losses.

2 Determined and Probabilistic Approaches to the Risk Estimation

Very important is to choose the correct approach to the risk component estimation. Determined approach to the fault risk estimation requires taking the probability is equal to one. In this case the adverse scenario of the accident will be obtained [7]. The advantages of determined approach are the relative simplicity of its application and the high level finality of decision tasks. At the same time, determined approach has next disadvantages: neglecting the effect of the object fault probability, not a definition of the events and conditions of the object fault. As a result, solutions, obtained by determined approach, can determine significantly under- or overestimate value of risk. Such results lead to the intuitive decisions.

Probabilistic approach, for a difference to determined approach, allows taking into account the probabilistic character of the processes, which taking place in EPS. Probabilistic approach allows obtaining the quantity description of accident too. These advantages are providing more deep approach to the EPS reliability estimation [1, 6, 7].

For the object fault probability estimation at the time interval it's necessary to consider its technical stuff (TS). Object TS determination is the complicated problem solution of which lies in the conditions of restricted information about diagnostic parameters, which could be obtained without the equipment switch off. Mathematical dependences between some of these parameters are missing too.

On the basis of these conditions, in [8] is proposed using the fuzzy methods and models for the EPS objects TS estimation. Object fault probability at the time interval with taking into account the TS is determined by to the Bayes theorem according to the method, proposed in [1, 7]. The using of expert estimations, fuzzy-models and Zadeh rule for the fault probability at the time interval estimation due to the lack of adequate mathematical models for electrical equipment TS estimation [7, 9].

3 Risk Estimation Algorithm

For the object fault probability estimation at the time interval $p(H_1/B)$ (when H_1 – is the event, that means object fault and B – is the event, that means the corresponding TS of object) it's necessary to know the fault probability distribution function for each element of equipment, taking into consideration its TS. For the obtaining of this function are used:

- statistical fault probability distribution function for such type of equipment $F(t)$;
- fuzzy model for the EPS objects TS estimation S, which using information, obtained without the equipment switch off;
- fuzzy relations matrixes between the object TS S and conditional probabilities $p(B/H_1)$ (hypothesis about the object with TS S fault at the time interval) and $p(B/H_2)$ (hypothesis about the object with TS S not fault at the time interval).

EPS accident risk estimation in the case of electrical equipment fault is performed according to the next algorithm:

1. The set N of whole EPS elements (generators, transformers, lines, circuit breakers, etc) is formed.
2. The set M of possible accidents is formed.
3. For each element from the set N is performed the determined analysis of EPS regime in the case of this element fault. Parameters of EPS regime must as hard as possible (minimal voltages and maximal loads in EPS bundles).
4. From the elements of set N is formed the subset N_1, including elements, faults of which lead to the accident from the set M.
5. For the elements of subset N_1 are determined the fault probabilities at the time interval $\Delta t = t_2 - t_1$ with taking into account its TS:

$$p(H_{1i}/B_i) = \frac{p(H_{1i}) \cdot p(B_i/H_{1i})}{p(H_{1i}) \cdot p(B_i/H_{1i}) + p(H_{2i}) \cdot p(B_i/H_{2i})}, \quad (1)$$

$$p(H_{1i}) = \frac{F_i(t_2) - F_i(t_1)}{1 - F_i(t_1)}, \quad (2)$$

$$p(H_{2i}) = 1 - p(H_{1i}), \quad (3)$$

$$p(B_i/H_{1i}) = \zeta_i(S_i), \quad (4)$$

$$p(B_i / H_{2i}) = \xi_i(S_i)\,, \qquad (5)$$

$$S_i = G_i(\phi_i(P_i), R_i(W_i), M_i, D_i)\,, \qquad (6)$$

$$i \in N_1,$$

when $p(H_{1i} / B_i)$ - is the object fault probability at the time interval Δt with taking into account its TS; $p(H_{1i})$ - apriority object fault probability at the time interval Δt; $p(H_{2i})$ - apriority non-fault operation probability of object at the time interval Δt; $F_i(t_1)$, $F_i(t_2)$ - values of statistical fault probability distribution function for such type of equipment in the time moments t_1 and t_2; S_i - object TS, obtained by fuzzy-model G_i; ζ_i, ξ_i - causal relations, according to which conditional probabilities $p(B_i / H_{1i})$ and $p(B_i / H_{2i})$ are determined.

6. Using the random number generator (RNG) at the fault moment time are defined next EPS regime parameters:
   - load active and reactive powers in EPS bundles (on the intervals [P_{MIN}; P_{MAX}] and [Q_{MIN}; Q_{MAX}] accordingly);
   - generator active and reactive powers in EPS bundles (on the intervals [P_{MIN}; P_{MAX}] and [Q_{MIN}; Q_{MAX}] accordingly);
   - voltage at the infinite bus (on the interval [U_{MIN}; U_{MAX}]).
7. Using the RNG are defined the values of function $p_i(t)$, $i \in N_1$ at the fault moment time (on the interval [0;1]).
8. From the subset N_1 is stood out the subset N_2 elements of which faulted at the time interval $\Delta t \in [t_1; t_2]$. If no fault elements at the time interval Δt, then $N_2 \in Ø$.
9. From the subset N_2 is elected the element, which has the maximal value of fault probability $p = \max\{p_i(t)\}$, $i \in N_2$.
10. At the EPS scheme is simulated the established regime and transient condition, which will take place after the elected element fault.
11. Algorithm steps 6-10 are performed k once.
12. From the obtained regime set K is performed the subset K_1 in which has taken place any accident from the set M.
13. Accident probability is determined as $P = k_1/k$.
14. Total losses costs from the all simulated accidents are determined, Y_M.
15. Accident risk is calculated as $R = P \cdot Y_M$.

Obtained value of risk is a quantity characteristic of EPS reliability. Analyzing this value, expert or makes a decision about its admissibility on the considered time interval or about the feasibility of it's reduce. For the EPS accident risk reduces it's necessary to use certain preventive actions. Effective and optimal choosing of preventive actions is the important problem of EPS risk management.

4 Risk Decreasing Method

The statement of the optimal choosing of preventive actions problem is as follows. Let consider the set $Z = \{z_1, z_2, ..., z_m\}$ of possible preventive actions for the accident risk decreasing. There are several criteria of preventive actions efficiency. For the selecting the optimal action is performed the subset of Pareto-optimal solutions. Optimal solution, which selected according to the multicriteria approach, must lays in the area of effective compromises. Subset of Pareto-optimal solutions $Z^{opt} \in Z$ includes all Pareto-optimal solutions. Subset image Z^{opt} in the space of optimization criteria L referred as $L^{opt} = f(D^{opt})$. This area called the Pareto set in the criteria space.

In general case, optimization criteria have different dimensions. For the solving of this problem, normal comparison is used. Defining a subset of Pareto-optimal solutions is based on the principle of dominance. For this purpose two types of convolution are formed: minimization convolution $Q_1 = R_1 \cap .. R_j .. \cap R_n$ and linear convolution $Q_2 = \sum_{j=1}^{n} R_j \cdot \omega_j$ [10].

That solution will be best, which has maximal power of non-dominance by the both convolutions. There is algorithm of convolutions definition:

1) formed the membership function of relations benefits:

$$\mu_{Rj}(x, y) = \begin{cases} 1, & if\ x \succ y\ or\ x \sim y; \\ 0, & if\ x \prec y. \end{cases} \qquad (7)$$

2) formed the first convolution Q_1:

$$\mu_{Q_1}(x, y) = \min\{\mu_{R1}(x, y) .. \mu_{Rj}(x, y) .. \mu_{Rn}(x, y)\}. \qquad (8)$$

3) determined the strict preference by the first convolution:

$$\mu_{Q_1^S}(x, y) = \min\{\mu_{Q_1}(x, y) - \mu_{Q_1}(y, x); 0\}. \qquad (9)$$

4) determined the set of non-dominance alternatives by the first convolution $Q_1^{\text{нд}}(x)$:

$$\mu_{Q_1^{\text{нд}}}(x) = 1 - \max \mu_{Q_1^S}(y,x). \qquad (10)$$

5) formed the second convolution Q_2:

$$\mu_{Q_2}(x,y) = \sum_{j=1}^{n} \mu_{Rj}(x,y)\cdot\omega_j . \qquad (11)$$

6) determined the strict preference by the second convolution and formed the membership function:

$$\mu_{Q_2^S}(x,y) = \max\{\mu_{Q_2}(x,y) - \mu_{Q_2}(y,x);0\}. \qquad (12)$$

7) determined the set of non-dominance alternatives by the second convolution $Q_2^{\text{нд}}(x)$:

$$\mu_{Q_2^{\text{нд}}}(x) = 1 - \max \mu_{Q_2^S}(y,x). \qquad (13)$$

8) determined the set of non-dominance alternatives by the both convolutions:

$$Q_{\text{нд}}(x) = Q_1^{\text{нд}}(x) \cap Q_2^{\text{нд}}(x), \qquad (14)$$

$$\mu_{Q\text{нд}}(x) = \min\{\mu_{Q_1^{\text{нд}}}(x), \mu_{Q_2^{\text{нд}}}(x)\}. \qquad (15)$$

9) found the best solution:

$$\mu_Q(x) = \max\{\mu_{Q\text{нд}}(x_1)..\mu_{Q\text{нд}}(x_m)\}. \qquad (16)$$

5 Example

By the proposed fuzzy-statistical approach performed the risk of dynamical stability loss in 14-bundles test scheme IEEE (fig.1). Voltage change interval in bundle 101 is [0,95;1,05]. Load change intervals in load bundles are next: №4: $P\in[860;1060]$ MW, $Q\in[450;550]$ MVAr; №6: $P\in[540;660]$ MW, $Q\in[180;220]$ MVAr; №100: $P\in[585;715]$ MW, $Q\in[380;470]$ MVAr; №202: $P\in[900;1100]$ MW, $Q\in[585;715]$ MVAr.

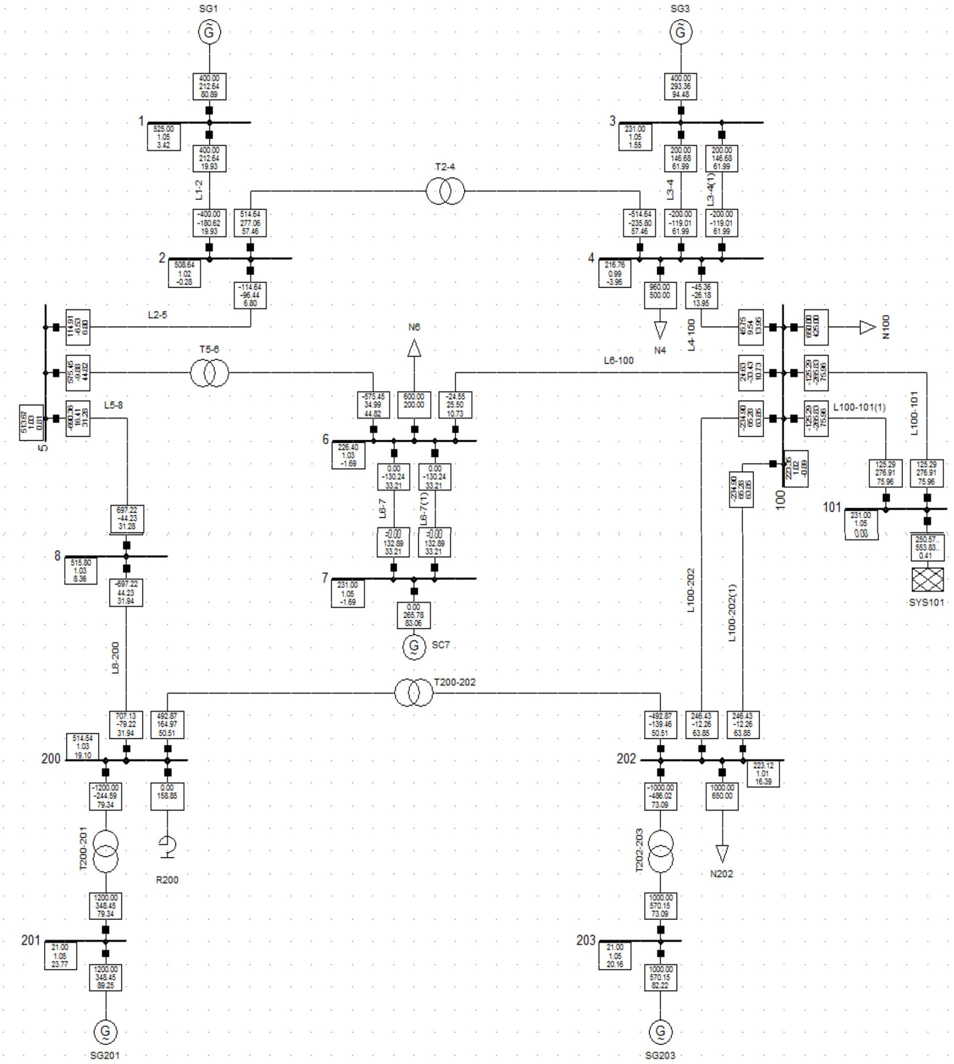


Fig.1 14-bundles test scheme IEEE

According to the above proposed algorithm has performed the fuzzy-statistical modeling of test scheme IEEE. Power equipment set N consists of 24 elements (14 lines, 5 transformers and 5 generators). Set M consists of one event – dynamical stability loss.

For the regime of minimal voltage in bundle 101 and maximal loads in bundles №№ 4, 6, 100 and 202 are defined elements, fault of which leads to the dynamical stability loss. Dynamical stability loss has taken place by the fault of next elements: transformer T5-6, line L5-8, line L8-200, parallel lines L100-202 (simultaneous fault), transformer T200-202, transformer T202-203 and generator G203. As example, at the fig.2 are shown dynamical dependence of generators rotors angles by the line L6-100 fault without dynamical stability loss.

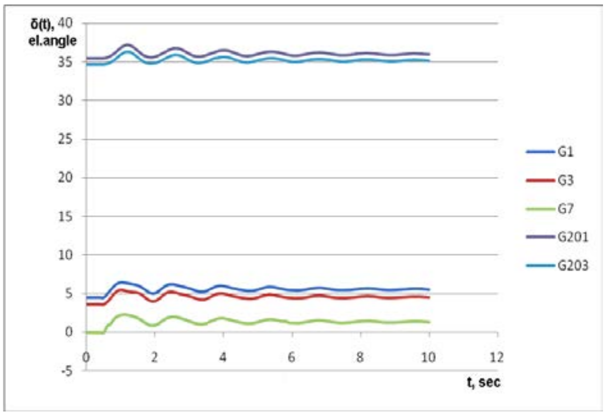
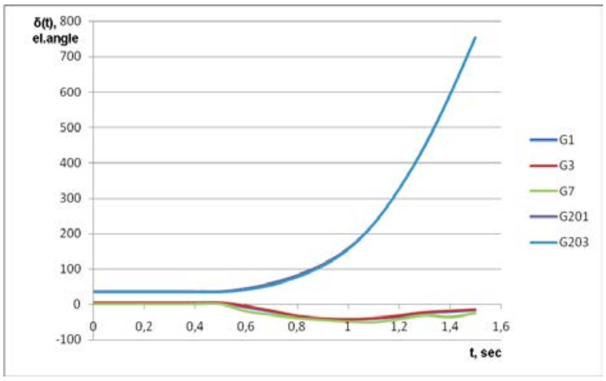


Fig.2 Dependences *δ(t)* of generators G1, G3, G7, G201, G203 without dynamical stability loss

At the fig.3 are shown dynamical dependence of generators rotors angles by the line L6-100 fault with dynamical stability loss.

Thus, subsystem N_1 includes 7 elements. For the subset N_1 elements are determined fault probabilities at the time interval $\Delta t = 1$ month. Obtained results are shown at the table 1.



b)

Fig.3 Dependences *δ(t)* of generators G1, G3, G7, G201, G203 with dynamical stability loss

Table 1 Fault probabilities of the subset N_1 elements

Element	Fault probability at the Δt = 1 month
T5-6	0,002
L5-8	0,041
L8-200	0,057
L100-202 (parallel lines)	0,012
T200-202	0,002
T202-203	0,002
G203	0,010

Using the RNG are determined regime parameters of IEEE test scheme at the fault moment and chose element, which will fault the first at the time interval Δt = 1 month. After that was analyzed the dynamical processes in IEEE test scheme. As a result, was formed the set *K*, which consists of *k=200* elements. Results are shown in the table 2.

Table 2 Fuzzy-statistical modeling of IEEE test scheme (fragment)

№	Voltage in bundle №101, p.u.	Load at the EPS bundles								Fault element	Dynamical stability loss
		№4		№6		№100		№202			
		P, MW	Q, MVAr	P, MW	Q, MVAr	P, MW	Q, MVAr	P, MW	Q, MVAr		
1	0,97	973	479	576	215	700	457	1011	616	-	no
2	0,98	919	477	633	188	702	446	1016	699	-	no
3	0,96	983	528	649	185	615	454	1011	688	-	no
4	0,95	1037	481	565	183	611	449	998	623	T5-6	yes
5	0,98	860	530	544	211	657	387	1089	619	-	no
6	1,03	1008	488	658	206	678	406	1023	693	-	no
7	0,98	870	499	621	205	681	408	1037	626	L5-8	yes
8	0,97	899	543	578	191	678	469	960	683	-	no
9	0,97	970	459	650	209	702	457	916	598	-	no
………………………………………											
200	0,98	1018	546	647	218	614	440	1032	618	-	no

Regime subset K_1, in which dynamical stability lost, includes 31 regimes. In this case, probability of dynamical stability loss, which is equal to technical risk without the accident cost, is determined as:

$$R = \frac{k_1}{k} = \frac{31}{200} = 0{,}155 . \qquad (17)$$

By the result of fuzzy-statistical modeling was analyzed the fault and risk distribution by test scheme elements. Risk distribution histogram is shown at the fig.4.

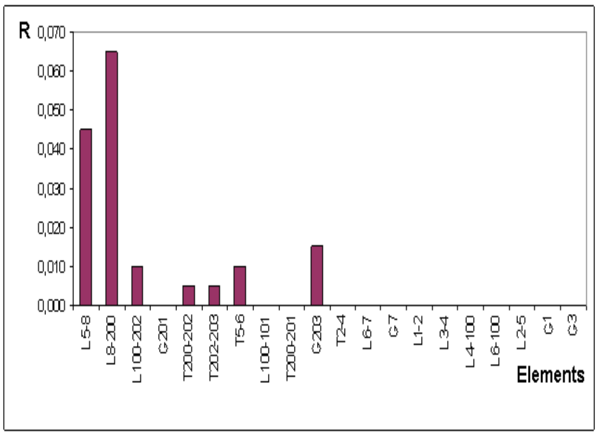


Fig.4 Histogram of risk distribution by its probabilistic estimation

For the comparison: in the case of the risk estimation by determined approach, were obtained values equal either one or zero (fig.5).

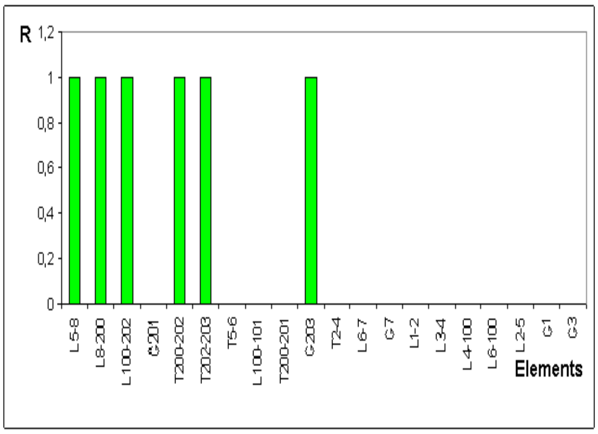


Fig.5 Histogram of risk distribution by its determined estimation

Comparison of two histograms shows, that by the determined approach risk estimation would given more high value of risk for the L5-8, L8-200, L100-202, T200-202, T202-203, G203 and more low value of risk for the T5-6.

In considering example fuzzy-statistical modeling is the non-continuous method of monitoring a mass phenomenon [11]. By such method of monitoring is very important the question about sufficiency the number of fuzzy-statistical algorithm implementations for the valid risk estimation. If to consider set K, which includes k regimes, as the general population, it is possible to set the number of sampling populations and to determine the part of elements, which has the certain sign (dynamical stability loss). For example, in this case $k=200$. Given next sampling populations k_i: $k_1=25$, $k_2=50$, $k_3=75$, $k_4=100$, $k_5=125$, $k_6=150$, $k_7=175$, $k_8=200$ and define for each population k_i the number of elements m_i with dynamical stability loss. Results are shown in the table 3.

Table 3 Sampling populations for the appreciating sufficiency of set K

i	k_i	m_i	$R_i = m_i/k_i$
1	25	7	0,28
2	50	8	0,16
3	75	13	0,173
4	100	17	0,17
5	125	19	0,152
6	150	23	0,153
7	175	27	0,154
8	200	31	0,155

According to the obtained populations was built the function $R_i(k_i)$ (fig.6). From the obtained graphic clearly, that for the valid risk appreciation its necessary at least 150 implementations of fuzzy-statistical algorithm. So, formed set K with 200 elements is sufficient for the valid quantity dynamical stability loss risk estimation.

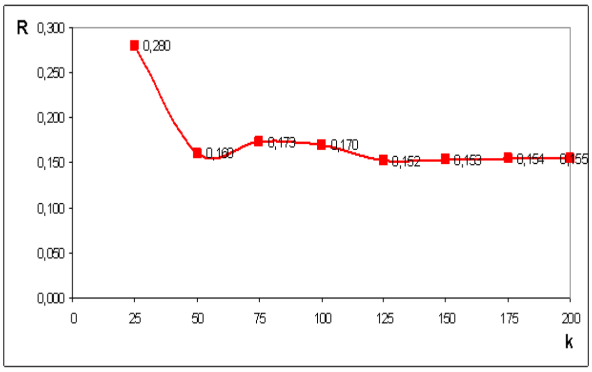


Fig.6 Function $R_i(k_i)$

For the decreasing of obtained risk value its necessary to form the set of possible preventive actions Z. Preventive action set is formed based on the risk distribution by its probabilistic estimation.

According to the risk distribution, the most often fault element in IEEE test scheme is line L8-200. To increase the test scheme reliability could to build a parallel line L8-200(1). Alternative ways of dynamical stability increasing are install the generator load decrease automation (GLDA) at the generator G201 in the case of L8-200 fault or install the generator electric braking automation (GEBA) at the generators G1, G3, G201 and G203 in the case of L8-200 fault. So, for this IEEE test scheme set *Z* consists of 3 elements:

- z_1 – building a parallel line L8-200(1);
- z_2 – install the GLDA at the generator G201;
- z_3 – install the GEBA at the generators G1, G3, G201 and G203.

In the case of realization preventive action z_1, the number of regimes with dynamical stability fault is $k_1=17$ (regime set *K* includes $k=200$ elements). So, technical risk of dynamical stability loss is equal:

$$R(z_1)=\frac{k_1}{k}=\frac{17}{200}=0{,}085. \qquad (18)$$

In the case of realization preventive action z_2, the number of regimes with dynamical stability fault is $k_2=20$ (regime set *K* includes $k=200$ elements). So, risk of dynamical stability loss is equal:

$$R(z_2)=\frac{k_2}{k}=\frac{20}{200}=0{,}1. \qquad (19)$$

In the case of realization preventive action z_3, the number of regimes with dynamical stability fault is $k_3=24$ (regime set *K* includes $k=200$ elements). So, risk of dynamical stability loss is equal:

$$R(z_3)=\frac{k_3}{k}=\frac{24}{200}=0{,}12. \qquad (20)$$

For the finding the optimal solution from set *Z*, efficiency criteria are determined:

- l_1 – risk decreasing;
- l_2 – investment;
- l_3 – implementation deadline.

Defined criteria is forming the set L. For the definition the Pareto-optimal solution from *Z* at the criteria from set L minimization and linear convolutions are formed. Resulting minimization convolution is following:

$$\mu_{Q1}(Z)=\{0 \quad 1 \quad 0\}. \qquad (21)$$

For the forming the line convolution it is necessary to define the criteria importance weights. For this purpose Saaty scale is used [10], according to which obtained next results:

- criterion R_1 has *weak* advantage before the criterion R_2 => $a_{12}=3$;

- criterion R_2 has *significant* advantage before the criterion R_3 => $a_{23}=5$;

- criterion R_3 has *very weak* advantage before the criterion R_1 => $a_{31}=2$.

On the basis of obtained estimations by Saaty method [10, 12] are defined the criteria importance weights: $\omega_1=0{,}241$; $\omega_2=0{,}386$; $\omega_3=0{,}373$. Obtained by this weights linear convolution is next:

$$\mu_{Q2}(Z)=\{0 \quad 0{,}627 \quad 0{,}518\}. \qquad (22)$$

Best solution is that, which has maximal non-domination power by both convolutions:

$$\mu_{\text{Qнд}}(z_1)=\max\{0;\ 0\}=0; \qquad (23)$$

$$\mu_{\text{Qнд}}(z_2)=\max\{1;\ 0{,}627\}=1; \qquad (24)$$

$$\mu_{\text{Qнд}}(z_3)=\min\{0;\ 0{,}518\}=0{,}518. \qquad (25)$$

Because $\mu_{\text{Qнд}}(z_2)>\mu_{\text{Qнд}}(z_3)>\mu_{\text{Qнд}}(z_1)$, the most effective preventive action is z_2 - install the GLDA at the generator G201.

6 Conclusions

1. In article defined fuzzy-statistical approach to the EPS accident risk estimation. This approach allows to make the valid estimation of fault probability, its development by the particular scenario (or by several scenarios) and its consequences. This is advantage of probabilistic approach before determined approach which determines significantly under- or overestimates value of risk.
2. Pareto-optimal method is proposed for the optimal action definition for the accident risk decreasing. This method let the most efficient action from the set of possible at the multicriteria conditions, which have not clearly structured mathematical relationships.
3. Conducted probabilistic-statistical modeling of IEEE test scheme has shown the efficiency of used methods, approaches and algorithms for the realization the risk-oriented management in fuzzy-information and stochastic character of regime conditions. Proposed in article methods and approaches allow to define the correct strategy of EPS management at present market relations conditions in power engineering.

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