UDC 621.311.019

SELECTION AND INSPECTION OF POWER PLANT ELEMENTS WITH APPLICATION OF PROBABILITY METHODS

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Probabilistic criteria of overload and destruction risks at substantiation of the chosen power components of electric installations under operating conditions and emergency influences are developed. The example of inspection of rigid modular trunks of the Surgut State District Power Station-1 is shown.

Designing and maintaining the developing electric installations, numerous problems of selection and substantiation of new or existing power components of power plants, electric power transmissions, district and distributing networks, power-supply systems occur.

These problems are usually introduced in the form of definition of design operating values of electric quantities under conditions of continuous steady state operations, short-time abnormal asynchronous modes, emergency electromagnetic processes of short circuits, loaded steady states and electromechanical transients (operating conditions). The enumerated design values at selection and substantiation, respectively, are matched with operating long-term-valid (LV) and short-term-valid (SV) parameters of reference data obtained at testing.

Both methods and conditions of defining the design values and LV and SV parameters are determined (calculated, accepted, assigned) by expert-testing method.

However, both when defining the extreme design values and when forming conditions of obtaining test values of the desired inspection parameter the questions which could not be solved by deterministic method occur. It is impossible both to determine maximum design value of randomly changing parameter in operating conditions and to predetermine random conditions of testing on observing LV and SV values. Although the existing expert references allow formally approaching theoretically and methodically to solution of the listed problems but practically, it could not be implemented and there is still no objective reason of these solutions in deterministic form.

The unique and objective determination of the design values of random quantities and conditions of obtaining concrete test values is possible on the basis of probability theory and mathematical statistics describing objectively the characteristics of random events, quantities and processes. Therefore, in [1, 2] the problem is set and the main mathematical model of selection and substantiation of power components (switch units, live parts and equipment) of electric installations with application of probabilistic technologies is developed. Practical picture of this approach is introduced in the Figure.

The feature of all probabilistic characteristics (PC) in the form of probability density function (PDF) given in the Figure are different conditions of their formation. PDF $c_{фэ}(п)$ and $c_{дд}(п)$ are constructed in operating conditions and PDF $c_{фа}(п)$ and $c_{кд}(п)$ in conditions of emergency perturbations.

The design values of the parameter П: $п_э^р$ – in operating conditions; $п_а^р$ – in conditions of emergency perturbations, $r_э$ is the overload risk owing to excess of the design operational value $п_э^р$ by the parameter П, $r_{дд}$ is the overload risk owing to decrease of LV values as a random quantity relative to the design operational value $п_э^р$, $r_а$ is the failure risk owing to exceed of the design emergency quantity $п_а^р$ by the parameter П, $r_{кд}$ is the failure risk owing to decreasing SV values as a random value relative to the design emergency quantity $п_а^р$, $п_{фэp_1}$ and $п_{фаp_1}$ are the quantiles of the orders $p_1=1-r_э$ and $p_1=1-r_а$ defining the design values $п_э^р$, $п_а^р$ with risks: $r_э$ and $r_а$ (overload quantile in operating conditions and failure in conditions of emergency perturbations).

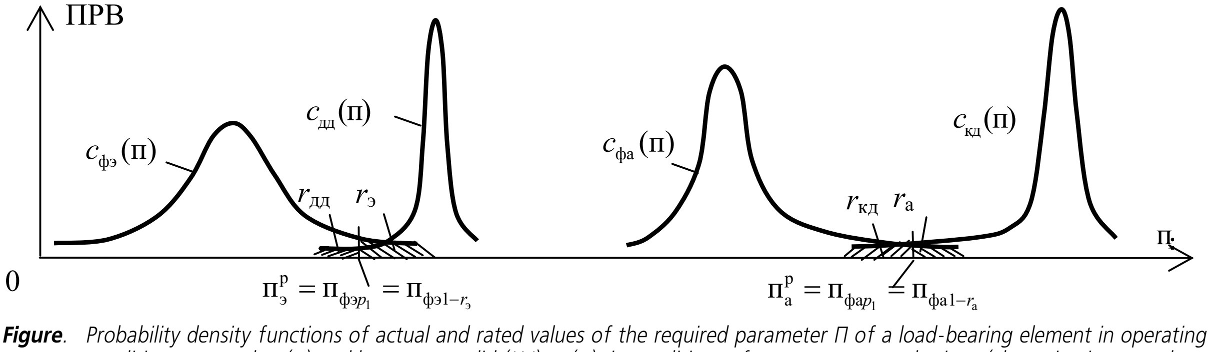

***Figure**. Probability density functions of actual and rated values of the required parameter П of a load-bearing element in operating conditions – actual $c_{фэ}(п)$ and long-term-valid (LV) $c_{дд}(п)$, in conditions of emergency perturbations (short circuits, asynchronous modes) – actual $c_{фа}(п)$ and short-term-valid (SV) $c_{кд}(п)$*

Another feature is a randomized representation of LV and SV of the test parameters. The latter, as it is given in [2], is conditioned by random fluctuations of medium parameters as well as change of actual voltages in modes which influences the derivative parameters (power, resistance). A substantial randomized factors of parameter test values is the transients in test conditions (dielectric media polarization, dynamic and thermal actions of flowing currents in conductor junctions and joints, time of transient existence), the free components of which change randomly from zero to peak values. In the whole the randomized factors may condition the 30...40 % change of the required parameter value from its extreme value. An average value or mathematical expectation (ME) of the parameter is determined at testing and scatter, for example, in the form of mean-square deviation (MSD) in Gaussian law hypothesis may be taken as 5...7 % from the tested range or its maximum (initial) value on the basis of above-named test change.

Different conditions of PC, Figure, are caused by the necessity of their definition by the method of selection of data interval boundaries [1], which allows in the specified observation conditions determining the total PC of the output data by the initial ones. Different conditions of forming total PC of the initial data in the form of PDF, probability density functions condition different factors of obtaining the output data PC that does not allow joining risks, indices, probabilities at different conditions for obtaining the generalized criteria.

The analysis shows that the probability distribution laws of the studied parameters in the form of PDF for operating conditions [PDF $c_{фэ}(п)$, $c_{дд}(п)$] in emergency conditions [$c_{фа}(п)$, $c_{кд}(п)$] as well as various indices (for example, overload risks $r_э$, $r_{дд}$ and failure $r_а$, $r_{кд}$) in the mentioned vapors have no significant differences in their examination conditions. Therefore, the risks of overload $r_э$, $r_{дд}$ and failure $r_а$, $r_{кд}$ may be pairwise summed up with the same specific weight, i.e. $r_п=r_э+r_{дд}$, $r_р=r_а+r_{кд}$, that allows carrying out the validation of parameters of the selected power components by the generalized risks of overload $r_п$ and failure $r_р$ and therefore, implementing local optimization respectively in operating and emergency perturbations conditions.

The analysis of the Figure allows stating the practically realized variants of selection and check of power element design parameters which consist in:

- variation of the design values of calculated parameter П in operating $п_э^р$ and emergency $п_а^р$ conditions;
- determination of overload $r_э$ and failure $r_а$ risks owing to exceed of the design values $п_э^р$ and $п_а^р$ respectively;
- determination of overload $r_{дд}$ and failure $r_{кд}$ risks owing to decreased LV and SV values relative to the design values $п_э^р$ and $п_а^р$;
- determination of total overload $r_п=r_э+r_{дд}$ and failure $r_р=r_а+r_{кд}$ risks;
- minimization of the results of selecting the design values $п_э^р$ and $п_а^р$ by the quantity of total risks $r_п$ and $r_р$ respectively.

The procedure of selecting and validating the power element parameters may be stated in the following way:

- the parameters of conditional PDF of the design parameter in operating $c_э(п)$ and emergency $c_а(п)$ conditions are determined by the method of selection of data interval boundaries,
- the parameters of conditional PDF of LV $c_{дд}(п)$ and SV $c_{кд}(п)$ of the design parameter П may be determined by the same method if the dependence of LV and SV parameters on the initial data is known otherwise, the problem is solved in another way,
- on the basis of the obtained results the design operating and emergency electric quantities are accepted.

Nominal values are appropriate to be accepted as the initial design operating values and a halfsum of mathematical expectations of normal PDL of actual emergency and short-term valid quantities – as the similar emergency values. Owing to this fact the risks of:

1) overload in operating conditions:

$$r_п = 0,5 - \Phi\left[\frac{i_{рр} - m(I^э)}{\sigma(I^э)}\right] + 0,5 + \Phi\left[\frac{i_{рр} - m(I^{дд})}{\sigma(I^{дд})}\right],$$

where $i_{рр}=i_н$ is the design operating current,

2) failure in emergency conditions:

$$r_р = 0,5 - \Phi\left[\frac{i_{рао} - m(I^а)}{\sigma(I^а)}\right] + 0,5 + \Phi\left[\frac{i_{рао} - m(I^{кд})}{\sigma(I^{кд})}\right],$$

where $i_{рао} = \dfrac{m(I^а) + m(I^{кд})}{2}$ is the design current of emergency outage may be respectively defined.

The example of validation of rigid bus bars of auxiliary section in Surgut GRES-1 power unit

Bus bars of Surgut GRES-1 of a complete switchgear feed from bus of lower (6 kV) voltage of auxiliary transformers with power 16 MVA by the lines made by rigid bars. Owing to short current leads from working auxiliary transformers to bus bars the section of line current leads and bus bars is selected by current capacity. Two-band buses with section 80×8 mm and current capacity 2,04 kA were used.

Current check in operating conditions

Peak current of current lead and busbars is determined by nominal capacity of the auxiliary transformer, i.e.

$$i_{p1} = 1,2 i_{нТСН} = 1,2\frac{S_{нт}}{\sqrt{3}U_{нн}\cos\varphi_{ср}} =$$

$$= 1,2\frac{16}{\sqrt{3}\cdot 6,3\cdot 0,85} = 2,07 \text{ кА}.$$

Minimum current of operating mode

$$i_{p2} = \frac{e_{p2}}{e_{p1}} i_{p1} = \frac{1}{1,9}\cdot 2,07 = 1,09 \text{ кА}.$$

Parameters of normal PDL current in operating conditions:

$$\text{ME } m(I_э) = \frac{i_{p1} + i_{p2}}{2} = \frac{2,07 + 1,09}{2} = 1,58 \text{ кА},$$

$$\text{MSD } \sigma(I_э) = \frac{i_{p1} - i_{p2}}{6} = \frac{2,07 - 1,09}{6} = 0,163 \text{ кА}.$$

Parameters of normal PDL LV current for rigid buses are determined by the design values minimally or maximally observed by the formulas:

$$i^{\theta}_{\text{дди}} = i^{\text{дд}}_{p2} = 0,$$

$$i^{\theta}_{\text{дда}} = i^{\text{дд}}_{p1} = i^{\text{к}}_{\text{дд}} \sqrt{\frac{\theta_{\text{доп}} - (-40)}{\theta_{\text{доп}} - \theta_{0\text{ном}}}} =$$

$$= 2040 \sqrt{\frac{70 + 40}{70 - 25}} = 3189,5 \text{ A}.$$

where $i_{\text{дд}}^{\text{к}}$=2040 A is the catalogue value of the current capacity, $\theta_{\text{доп}}$=70 °C is the permissible bus temperature in operating conditions, $\theta_{0\text{ном}}$=25 °C is the accepted air temperature.

Parameters of normal PDL LV current:

$$\text{ME } m(I_{\text{дд}}) = \frac{i^{\text{дд}}_{p1} + i^{\text{дд}}_{p1}}{2} = \frac{3189,5 + 0}{2} = 1594,75 \text{ A},$$

$$\text{MSD } \sigma(I_{\text{дд}}) = \frac{i^{\text{дд}}_{p1} - i^{\text{дд}}_{p1}}{6} = \frac{3189,5 - 0}{6} = 531,6 \text{ A}.$$

Overload risk at specified design working current $i_{\text{рр}}$=2000 A is determined by the expression

$$r_{\text{п}} = 1 - \Phi\left[\frac{i_{\text{рр}} - m(I_э)}{\sigma(I_э)}\right] + \Phi\left[\frac{i_{\text{рр}} - m(I_{\text{дд}})}{\sigma(I_{\text{дд}})}\right],$$

that gives in numbers:

$$r_{\text{п}} = 1 - \Phi\left[\frac{2000 - 1580}{163}\right] + \Phi\left[\frac{2000 - 1594,75}{531,6}\right] =$$

$$= 1 - 0,49506 + 0,27637 = 0,78.$$

The risk is possible to be decreased by increasing rectangular bus section or accepting buses of another embodiment.

Conclusion

The probabilistic approach of selection and validation of equipment, conductive parts and switching devices of electric installations was proposed for quantitative estimation and guaranteed validation selecting equipment, conductive parts and switching devices as well as their optimal parameters.

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Received on 22.11.2006