IOP Conf. Series: Materials Science and Engineering 1019 (2021) 012090 doi:10.1088/1757-899X/1019/1/012090

Application of the probabilistic technologies to power plant design

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Abstract. In the report the developed approach for choice and substantiation of power equipment, current-carrying parts and switching devices using existing and proposed probabilistic method of borders selection of input and output data (SBID) is presented. SBID method allows to receive complete probabilistic characteristics or probability distribution laws (PDL) of output data as functional dependence from the arguments (input data) by probabilistic characteristics of arguments. Any task, including electrical values in operating modes and transient conditions in power system can be exposed as dependence on input or output data. Due to SBID method, the PDL of input data processing results of these dependencies may be received. PDL allows to calculate risks of overload of the power components in the operating modes and destruction, also power equipment parameters, current-carrying parts and switching devices are going to be selected on the basis of the minimum specified risks.

1. Introduction

Questions of reliability, efficiency, safety, maintenance, other functional specifications for the design and operation of any objects are always relevant. These issues even more updated in the case of electrical plants - large and complex facilities in the power sector, such as substations, power plants, or the whole power grid. The importance of these issues constantly accompanies all stages of development, design and operation of electric power systems.

According to this, the aim to assess the functional reliability of the main parts of power system as power plants and substations is stated. Thus, the probabilistic approaches applied to equipment choice for power plant with renewable resources and power system stability assessment are presented in [1–7].

Reliability is a property of an object (element, a component of the system) to perform specified functions under specified conditions.

Structural reliability – reliability designs and schemes without taking into account their operational modes (downloads).

Functional reliability is filling sensitive component properties and their aggregates included in designs and schemes of objects that are not included in the structural indices of reliability.

The structural and functional reliability of systems are the tasks of determining the reliability of interesting elements, objects, and whole systems on indices of reliability of all system components.

2. The proposed methodology

Performance of objects and components of the systems can be different and similar. Depending on different methods for determination of reliability parameters of objects, systems and their components can be formed. Experience shows that rational methods of reliability calculation are the methods that allow to estimate the reliability of any units (individual items, different sets of them) and other objects with similar indices.

At the Department of Power Stations, Tomsk Polytechnic University the method of evaluating of functional reliability indices in the form of probabilities or risks of overload and destruction of the switching devices, current-carrying parts and equipment that are included in the above mentioned objects was developed [8, 9]. Risks are defined, respectively, in the operational and emergency modes according to the probability distribution laws (PDL) of electrical quantities (currents and capacity in the branches and voltage at nodes) in the choice and substantiation of the power components. Methods and indices of functional reliability are important and necessary, in addition to choice and substantiation of power objects in power supply systems and for many other engineering tasks: definition of imbalances and deficits of active power at switchgear, power plants, substations, and, more generally, power systems, determine the settings and the effectiveness of relay protection and automatics, etc.

Feature of the proposed methodology application for assessment of functional reliability in contrast to expert guidance methods for recommending solutions, is that it allows not only to implement an objective choice of interesting parameters based on certain criteria, but also to assess the effectiveness of this choice, and therefore, to adjust the choice, to achieve the relevant maximum efficiency. These methods can be realized only when known complete probabilistic characteristics of interesting parameters, i.e. the way to obtain these characteristics have to be known.

3. SBID method

Discussed methodology of functional reliability is based on the method of boundaries selection of input and output data (SBID), also developed at the Department of Power Stations, Tomsk Polytechnic University. SBID method allows for complete probabilistic characteristics (probability distribution function (PDF) or probability distribution density) of arguments of any deterministic (non-random) or random function to determine almost exactly or inexactly the PDF of function results. Knowing the same complete probabilistic characteristics of interesting parameters or values, simple and objective solutions to many practical problems can be easily found.

The essence of the method is based on the following SBID:

1. Any task can be represented as an ordinary nonrandom or random function. With nonrandom functions the arguments or the original (input) data are arbitrarily (randomly) change, functions remain the same and the results or output are formed by transformation of input data by using nonrandom functions (NF). Therefore, the output data are also random, but dependent on the input data through a rigid (deterministic) conversion of the NF. In case of random functions (RF) arguments are arbitrarily (randomly) change, and transformation of random functions and results or output when will be formed by a random transformation of random input data.

2. Integral probability characteristic – the function of probability distribution (PDF) or the probability that each random variable will not exceed the given values has such great properties as taking their own measure in the range from zero to unity throughout the range of the specified arguments from the minimum possible to the maximum possible, and at any interval is not declined. In other words, PDF is the no decreasing function.

These properties of PDF may it possible to decline that if all arguments of NF (the input data) accept as the values corresponding to the same value of their PDF, in case of increasing NF, the result of NF transformation or output data should match the same value PDF of nonrandom function.

PDF value corresponding to the value of its argument, called quantiles of given order to be determined by the value of the NT. In other words, the transformation of input data, quantiles of the same order of increasing SF gives the result as a quantile of the same order (as the order of the quantiles of the input data). In case if input data are transformed by decreasing NF, quantiles of the same order of decreasing NF gives the result as quantile of order equal to the difference between the unity and the order of the quantiles of the input data. sign of increasing or decreasing NF is that if the difference between the previous and subsequent orders of input data, have the same polarity, the NF is increasing, otherwise the NF is decreasing. Thus, starting with the second version of the input data as quantiles of

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the same order, based on the results of each NF it is possible to specify increasing or decreasing character of the NF and, consequently, to identify specific orders of output data (results) as the quantiles of the same order as the order of the input data quantiles, or about equal to the difference between the unity and the order of the input data quantiles.

In this paper materials on the development and application of algorithms, sequences, calculations and procedures for the choice and substantiation of the different components of the power stations and substations are presented, some of them tested for specific components by using named methods and procedures.

4. Example of SBID method application

For illustration of SBID method the CAG - 24 - 30 / 30000UZ circuit breaker in the output circuit of the generator 200 MW at Surgut GRES – 1 was chosen. In case of retrofitting the power plant equipment the methodology may be also applied for choice and substantiation of SF6 and vacuum circuit breakers.

The electrical quantities in the calculated operating and emergency modes are determined for specified areas of the Tyumen energy system, the databases of which are formed in the computing complexes (CC) of the TKZ-3000 (forced sinusoidal electrical quantities with short-circuits and other disturbances), Dakar (operating modes).

Since the circuit breaker switches the generator of the G-T unit, the maximum observed value of the current in operating modes should be taken equal to the maximum operating current of the generator.

The minimum observable current of the operating mode is determined by the switching state of the area of the network where the G-T unit is located and the minimum mode of the generators. The minimum observed operating current is determined by the minimum mode of the generator itself.

By means of computer program TKZ - 3000 it is possible to find the maximum and minimum observed values of the fault current flowing through the circuit breaker. The maximum observed value is the periodic component of the super-transient short-circuit current from the generator and the power system when short-circuit takes place on the periphery of the circuit breaker and the mode of the sources providing the maximum values.

The minimum observable value in accordance with the prescribed recommendations will be found in two stages. First, the minimum observable value due to the switching state of the network and the type of short circuit damage is determined at the same periphery of the circuit breaker.
Then the minimum observable value is determined taking into account 30% of power source load and type of short circuit, which is considered as a quantile of order p_2=0.0013.

Next, the ME and MSD of the normal PDL of the short circuit current through the circuit breaker are determined:

$$m(I_f) = \frac{i''_{p1} + i''_{p2}}{2} = \frac{65.492 + 35.254}{2} = 83.119 \quad \text{kA}$$

$$\sigma(I_f) = \frac{i''_{p1} - i''_{p2}}{6} = \frac{65.492 - 35.254}{6} = 5.033 \quad \text{кA}$$

Similarly, in emergency conditions, quantiles of orders and thermal effects are calculated:

$$b_{kp_1 main} = i''^2_{p_1 main}(t_{ter} + \tau) = 65.492^2(3 + 0.15) = 13511 \quad \text{kA}^2 \cdot \text{c}$$

$$b_{kp_2 main} = i''^2_{p_2 main}(t_{ter} + \tau) = 35.254^2(3 + 0.15) = 3915 \quad \text{kA}^2 \cdot \text{c}$$

$$m(B_{k\ main}) = \frac{b_{kp_1\ main} + b_{kp_2\ main}}{2} = \frac{13511 + 3915}{2} = 8713 \quad \text{kA}^2 \cdot \text{c}$$

$$\sigma(B_{k\ main}) = \frac{b_{kp_1\ main} - b_{kp_2\ main}}{6} = \frac{13511 - 3915}{6} = 1935.3 \quad \text{kA}^2 \cdot \text{c}$$

In a static state, the load circuit breaker must withstand the emergency short circuit currents arising from disturbances in the power plant and in the power grid. In this regard, for this device, the amplitude and effective values of the limiting test short circuit current for the main circuit and grounding conductor are set. Assuming a possible random change of these values is similar to other short-term allowable test values, we define the parameters of the normal PDL specified random changes of the short circuit current $I_{s\ main}$ given in catalogue for main circuit. For grounding circuit, the named values are found according to similar equations.

Similarly, a previously possible predetermined random change in the test current of thermal withstanding allows forming the parameters for a normal PDL in main circuit.

Based on the results of the calculations, the calculated operating (i_{co}) and emergency electrical quantities are accepted. It is advisable to take nominal values as initial calculated operating quantities, and as similar emergency values can be recommended as a half-sum of mathematical expectations of normal PDL actual emergency (I_e) and short-term acceptable (I^{sa}) values. It is possible to determine the risks accordingly:

1) r_{ol} overload in operating conditions:

$$r_{ol} = 0.5 - \Phi\left[\frac{i_{co} - m(I_e)}{\sigma(I_e)}\right] + 0.5 + \Phi\left[\frac{i_{co} - m(I^{la})}{\sigma(I^{la})}\right],$$

where $i_{co} = i_r$

i_r - rated current,

I^{la}- long-term allowable current.

2) damage under emergency conditions:

$$r_d = 0.5 - \Phi\left[\frac{i_{dem} - m(I_{max})}{\sigma(I_{max})}\right] + 0.5 + \Phi\left[\frac{i_{dem} - m(I^{sa})}{\sigma(I^{sa})}\right] \text{ where } i_{dem} = \frac{m(I_{max}) + m(I^{sa}_{s\ main})}{2}$$

where Φ - Laplace's function.

Finally, may be found:

1) the risk of overload in operating conditions:

$$r_{ol} = r_o + r_{la} = 0{,}5 - \Phi\left[\frac{8.625 - 6.911}{0.715}\right] + 0.5 + \Phi\left[\frac{8.625 - 30}{0.6}\right] = 0.5 - 0.490613 + \frac{x_{-\infty} + x_{п} - x_{\Phi_2}}{-100} 0.000000000000032 =$$

$$= 0.009387 + \frac{-100 - 7.5 - (-35.625)}{-100} 3.2 \cdot 10^{-14} = 0.009387000000023$$

i_{pp}=8.625 kA,

x_{tL}– table values of Laplace's function,

x_{pL} – positive values of Laplace's function,

x_{nL} – negative values of Laplace's function.

Calculating of extremely small values of Laplace's function is presented in [9].

2) the risk of destruction in emergency conditions:

$$r_d = 0.5 - \Phi\left[\frac{218.36 - 50.318}{5.033}\right] + 0.5 + \Phi\left[\frac{218.36 - 353.6}{7.07}\right] = \frac{x_{\infty} + x_{п} - x_{\Phi_1}}{100} 3.2 \cdot 10^{-14} +$$

$$+ \frac{x_{-\infty} + x_{п} - x_{\Phi_2}}{-100} 3.2 \cdot 10^{-14} = \frac{100 + 7.5 - 33.388}{100} 3.2 \cdot 10^{-14} + \frac{-100 + (-7.5) - (-19.129)}{-100} 3.2 \cdot 10^{-14} = 5.2 \cdot 10^{-14},$$

$$i_{dem} = \frac{83.119 + 353.6}{2} = 218.36 \text{ kA}.$$

Further, it is possible to optimize the calculated values by changing their magnitudes and based on the minimum risks of overload and destruction respectively.

5. Conclusions

The specified positive and unique opportunity to substantiate the power equipment, switching devices and current-carrying parts by means of the probabilistic technology allows not only selecting interesting parameters and electrical quantities characterizing these objects, but immediately and objectively assessing the total technical losses - risks of overload and accidental destruction. This substantiation can be implemented if risks of overload and destruction due to exceeding the selected values of the parameter, respectively, in operating and abnormal conditions, other risks of overload and destruction due to the reduction of the permissible limits long respectively and short time limits on selected values for the specified parameter or parameters can be adjusted to the same observation conditions. The criterion of synergies can be considered and used as a tool to optimize the choice of values of the specified parameter or parameters of the power components. Finding the optimal values of selected parameters is the subject of a task or group of tasks that are not finally solved, but it is possible.

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