CURRENT APPROACHES TO ANALYSIS OF THE PROJECT RELIABILITY OF ELECTRONIC DEVICES OF CYCLIC USE

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ABSTRACT

Many electronic devices operate in a cyclic mode. This should be considered when forecasting reliability indicators at the design stage. The accuracy of the prediction and the planning for the event to ensure reliability depends on correctness of valuation and accounting greatest possible number of factors. That in turn will affect the overall progress of the design and, in the end, result in the quality and competitiveness of products.
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1. Introduction

As stated in [1] for the calculation of reliability, it is necessary to make an accurate identification of the object, its operating conditions and other factors determining the reliability and reproducibility of the most important results of the real model of functioning calculations. There are many methods to estimate the parameters of reliability of electronic devices, among which the main groups are analytical, numerical and statistics.

Standard [2] recommends using of several methods of reliability prediction, which are shown in Table 1.

Table 1. Comparison of reliability calculating methods

№	Method	Distribution reliability requirements /goals	Qualitative analysis	Quantitative analysis	Recommen dations
1	Predicting failure rate	Applicable for sequential systems without redundancy	Can be used to analyze the maintenance strategy	The calculation of the failure rate and MTTF* for electronic components and equipment	Support
2	Fault tree analysis	Applicable if the behavior of the system depends on the time and sequence of events	An analysis of the combination of faults	Calculation of indicators of dependability and efficiency and of the relative contribution of the subsystems in the system	Applicable
3	Event Tree Analysis	Possible	Sequence analysis of failures	The calculation of failure rates	Applicable
4	Analysis of structural reliability schemes	Applicable for systems which can distinguish independent blocks	Analysis of ways of working capacity	Calculation of performance and dependability of systems complex reliability indices	Applicable

№	Method	Distribution reliability requirements /goals	Qualitative analysis	Quantitative analysis	Recommendations
5	A Markov analysis	Applicable	Analysis of failures Sequence	Calculation of reliability indices and of complex systems dependability indices	Applicable
6	Analysis of Petri nets	Applicable	Analysis of failures Sequence	Preparing the description of the system for a Markov analysis	Applicable
7	Mode and Effect Analysis (critical) of failure FME (C) A	Applicable for systems which have dominated the single failure	Analysis of the impact of failures	The calculation of failure rates (and their criticality) for the system	Applicable
8	The truth table (the analysis of the functional structure)	Not applicable	Possible	Calculation of reliability indices and of complex systems dependability indices	Support
9	Statistical methods for reliability	Possible	Analysis of the impact of faults	Determination of quantitative estimates of reliability indicators with the uncertainty	Support

Note: Word-notation of the table: "Applicable"- the method is recommended for the solution of the problem; "Possible" - the method may be used for solving the problem, given that it has some disadvantages compared with other methods; "Support" -method is applicable to apart of the problem and can be used to solve the whole problem only in combination with other methods; "Not applicable" - the method must not be used to solve the problem.

Table 1 shows that, for calculating the reliability of electronic devices received widespread methods № 1-5, 8 and 9. At the same time models, built on them, allow the assessment of the reliability for the components in continuous use with a constant failure rate. But in the electronic devices operating in "session" mode there is a lot more difficulties in calculating. One of them is the use of models to predict reliability for redundant group, that is, how to take into account the group redundant periodic cycles of work/storage.

2. The basic principles of the calculation model of reliability for electronic devices

Consider this issue on an example of calculation of reliability of the electronic module, which has a series connection of elements working in the "session" mode.

In this case, the element failure rate function, $\lambda(t)$, is periodic (see. Fig.1).

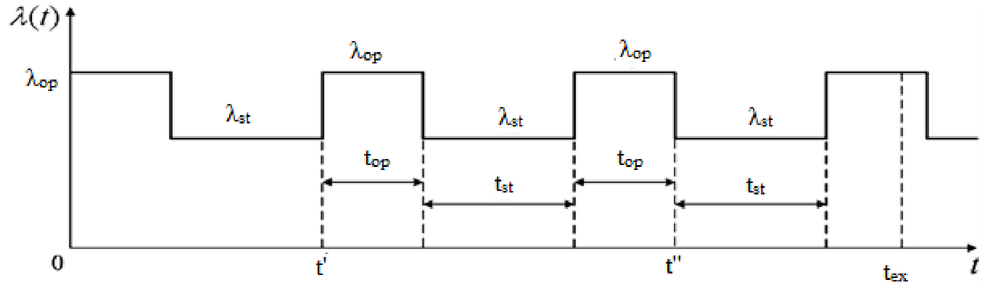

Figure1. Cyclogram of component operation.

In accordance with the general equation for determining the probability of failure-free operation of the component:

$$P(t) = e^{-\int_0^t \lambda(\tau) d\tau}, \quad (1)$$

where:

$$\lambda(\tau) = \begin{cases} \lambda_{op}, for\ t' < t < t' + t_{op} \\ \lambda_{st}, for\ t'' < t < t'' + t_{st} \end{cases}.$$

t=t_{ex} = the set time of existence.

If the calculation is performed on integer work and storage plots, the ratio of the estimated probability of failure-free operation of the component is:

$$P(t) = e^{-(\lambda_{op} \cdot T_{op} + \lambda_{st} \cdot T_{st})}, \quad (2)$$

where: $T_{op} = m \cdot t_{op}$ = cumulative operating time (for the time t_{ex}) for all m working areas;
$T_{st} = m' \cdot t_{st}$ = cumulative storage time (for the time t_{ex}) for all m' working areas;

$$m' = \begin{cases} m \\ m-1 \\ m+1 \end{cases}$$

- number of areas depending on whether the area (work or storage) starts and ends the time interval t_{ex}.

The reliability graph constructed by the equation (1) is continuous, but have breaks at the points of the t' and t'' in which the failure rate function has a jump.

In cases where calculation is to be made on a predetermined number m of work areas and storage areas obtain:

$$P[m(t_{op} + t_{st})] = e^{-m(\lambda_{op} \cdot t_{op} + \lambda_{st} \cdot t_{st})}, \quad (3)$$

where: $t_{ex} = m\ (t_{op} + t_{st})$.

The calculations then resorted to the determination of the average (per period of work and storage) component failure rate, which is obtained from the following equation:

$$\lambda_{av} = \frac{\lambda_{op} \cdot t_{op} + \lambda_{st} \cdot t_{st}}{t_{op} + t_{st}}, \quad (4)$$

where:
$\lambda_{op} \cdot t_{op}$ = the proportion of the influence of the failure rate in operation mode for the period;
$\lambda_{st} \cdot t_{st}$ = the proportion of the influence of the failure rate in the storage mode for the period;
$t_{per} = t_{op} + t_{st}$ = the period.

Probability of failure-free operating is calculated by the model 2.

As an example, consider the assembly of electronic device, which has a single unloaded reserve (see Fig.2) having the following inputs:

1. Assembly is working in sessions on the amount of in work mode for 32,000 hours and in the storage mode for 55600 hours. The two components are the same and have the following parameters:
   - The failure rate during work mode (λ_{op}) $1.232992 \cdot 0^{-6}$1/h.;
   - The failure rate in the storage mode (λ_{st}) $2{,}194 \cdot 10^{-8}$ 1/h.

2. The failure criterion is the following:

- In the work mode the main element 1 is working, a reserve element 2 is switched off; in case of failure the second element switches on;

- In storage mode, both elements are disconnected from the power supply and it is necessary to consider whether the first element will work after turning on or not. If not, a second element will turn on (both elements together are in loaded reserve with failure rate parameter for storage mode).

Consider a few ways to calculate:

1. Using a model for calculating the probability of failure-free operation for redundant groups from [2], [3] or the scientific literature, and the parameter of the failure rate is determined by the model (4), periods of work and storage are known. According to [2] - a method №4;

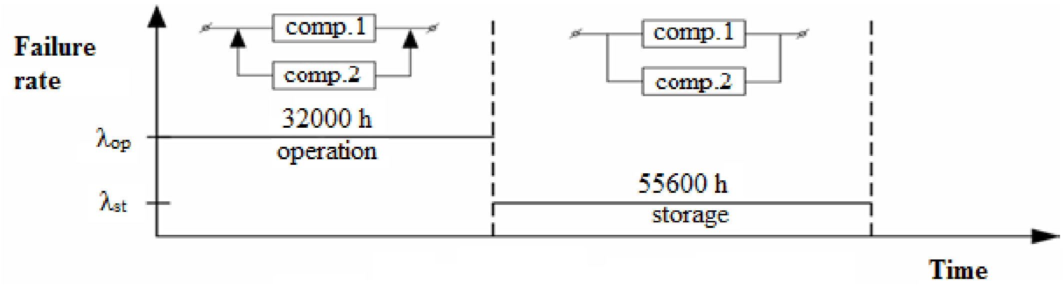

Figure 2. The block diagram of the reliability of the product

2. Construction of a model for calculating the probability of failure-free operation by a method of search of hypotheses based on the total probability formula [4] in accordance with the time schedule specified in [1], where the main parameters will be the failure rate in session mode and storage mode and time intervals. According to [2] - a method №5;

3. The method of decomposition of the time is used – a partition model for calculating the probability of failure-free operation in accordance with a predetermined schedule of operation for the work mode and storage mode. For each of the segments is selected model to calculate the probability of failure-free operation from a standard set or other sources provided that the probability of failure-free operation of a storage mode is determined basing on failure criterion at the time of switching. According to [2] - a methods №1 and 4;

4. Building a model for calculating the probability of failure-free operation using the Monte Carlo method, where the main parameters are the failure rate in the "session" mode, in work mode and in the mode of storage, storage and work periods. According to [2] – a method №9.

Now consider each method in more detail.

When using the first method, choose model for calculating the probability of failure-free operation, based on the criteria of failure for the entire service life of 87600 hours:

$$P_1(t) = \frac{\prod_{j=0}^{m}(n+j\alpha)}{\alpha^m m!} \sum_{i=0}^{m} (-1)^i \frac{C_m^i}{n+i\alpha} e^{-(n+i\alpha)\lambda_{av} t}, \quad (5)$$

where: n = the number of basic components (in this case 1) and m = redundant components (in this case 1);
$\alpha = \frac{\lambda_{st}}{\lambda_{op}}$ - coefficient of proportionality;
λ_{op}, λ_{st} = the failure rate of components in the work and storage modes.

The result of the calculation is following value of the probability of failure-free operation over the lifetime (87600 hours): 0.999180711554146.

The second method involves the output probabilities of all scenarios that lead to the operation at the end of the period of exploitation on the basis of the above criteria of a failure of the electronic assembly, of temporary work schedule (see. Fig. 2), the list of incompatible successful hypothesis [1]. As a result, get the following model:

$$P_2(t) = e^{-\lambda_{av} t_\gamma} + \int_0^{t_\gamma} \lambda_{av} \cdot e^{-\lambda_{av} \cdot t} \cdot e^{-\lambda_{st} \cdot t} \cdot e^{-\lambda_{av}(t_\gamma - t)} dt \quad (6)$$

As seen from the mathematical model (6), it takes into account all aspects of the assembly, including the time schedule, failure criteria and a transition of component 2 from storage mode to work mode dependent on status of the first component. Thus, this model will be considered as "Pareto standard" for evaluating the error.

As a result of the calculation get the following value of the probability of failure-free operation over the lifetime: 0.999157335573541.

The third method is analytical calculation by using method of temporal decomposition, it means to estimate separately the probability of failure-free operation of the electronic device for the time of work and time of storage, considering the event of failure at any stage of exploitation independent. In this case, the calculation is divided into three stages:

- The first phase is calculated probability of failure-free operation for the structural scheme of electronic device in work mode for a single period of work;
- The second phase describes the structure of the electronic device in storage mode and similarly the probability of failure-free operation on a single period of storage is estimated;
- At the final stage estimates the probability of failure-free operation for electronic device for the entire exploitation period, taking into account the amount of work and storage periods.

In general, the design equation for determining the probability of failure-free operation over the exploitation period is as follows:

$$P_{gen} = \prod_{i=1}^{m} P_{st}(\tau_{sti}) \cdot \prod_{j=1}^{n} P_{op}(\tau_{opj}) \, , \tag{7}$$

where: P_{gen} = general probability of failure-free operation for system; P_{st} = function of the probability of failure-free operation of the system in storage mode;τ_{sti} = the *i*-th storage interval, h.; P_{op} = function of the probability of failure-free operation of the system in work mode; τ_{opj} = *j*-th interval of work, h.

Using equation (7) in practice quite inconvenient, especially when there is redundancy in the system, which implies a fairly complex function defining the probability of failure of the system in either storage mode or in work mode. In addition, the design phase is usually not know the exact schedule of the electronic device (in general, it may be the case), it is known only to the expected ratio of time of work and time of storage, in this case suggest that the duration of sessions is constant. Based on this and on the use of mathematical models with time-constant failure rates equation (7) is transformed to the following form:

$$P_{gen} = (P_{st}(\tau_{st}))^{n} \cdot (P_{op}(\tau_{op}))^{m} \tag{8}$$

Also, based on the use of the exponential model for failure of electronic devices, intervals of work and storage can be combined:

$$P_{gen} = (P_{st}(\sum \tau_{st})) \cdot (P_{op}(\sum \tau_{op})) = P_{st}(t_{st}) \cdot P_{op}(t_{op}) \tag{9}$$

where: t_{st} = cumulative time of storage, h.; t_{op} = cumulative work time, h.

Equation (9) is valid for a strictly exponential mathematical models of failures of investigated electronic devices. However, in practice (9) is used to estimate the probability of failure-free operation of redundant systems, which failure model no longer corresponds to an exponential form.

Consider the application of (9) at the example of the investigated electronic assembly. It is possible to determine that during storage the failure rates of the main and the reserve component groups are same as both chains are identical and are stored under identical conditions. Thus, during storage, the electronic assembly is a loaded reserve, which probability of failure-free operation is described by the following expression [2]:

$$P_{st} = 1 - (1 - e^{-\lambda_{st} t_{st}})^2 \tag{10}$$

In mode of work the components of the redundant group are located in different conditions, main chain performs its functions and is under load, while the backup continues to be stored unloaded. In case of failure in the main chain, the backup chain will be loaded. In this case, the system works on the scheme of facilitated reserve, probability of failure-free operation of which is determined by the equation [2]:

$$P_{op} = e^{-\lambda_{op} t_{op}} (1 + (1 - e^{-\lambda_{st} t_{st}}) \cdot \frac{\lambda_{op}}{\lambda_{st}}) \tag{11}$$

Thus, substituting (10) and (11) into (9) we can determine the overall probability of failure on the entire period of operation. The result of calculation is the following value: 0.99922699998305.

One of the sources of error in this method is that the failures in the storage mode and operation mode considered to be independent, that is only true to a simple linear structural reliability schemes where a failure of any component in any mode is the failure of all electronic devices. In (9, 10, 11) are considered two groups of two parallel elements as independent, that is, order to system is considered not failed enough that to the end of the period of work to keep working capacity of any one component of the two examined groups. This statement is incorrect, since the event of failures of system components in the first and second group are dependent.

Consider the specific of inaccuracy of the assumption of independence of groups of components on an example: the mathematical model (9) finds a workable system in which the first group declined 2 component, the second - 1, while it is physically the same components, and such a situation will lead to failure. That is, in such a calculation deliberately introduced an error, leading to an overestimation of the result, which is unacceptable in assessing of the reliability.

3. The simulation method

An alternative for analytical method is a simulation method, in theory it allows to take into account any correlation between failures. Using the simulation method for calculating the reliability parameters involves the construction of a model describing the operation of the device and the process of its failure over time. To build such a model can be used any programming or simulation language, but the most convenient to use specialized simulation languages already containing the blank for simulation of the systems studied. With regard to this problem is advantageous to use specialized software ASONIKA-K-RES containing a standard model to describe the electronic devices with a complex structure [5].

The tool implements a simulation method for the problem of determining parameters of reliability of electronic equipment with a complex structure and the presence of reconfiguration during operation. To perform simulation formal model that describes all the components of the electronic devices of distribution, failure criteria and possible events in the operation is build. Proceedings of the construction of a simulation model, consider on an example of the investigated system. It represents only 2 components, and has a fairly simple the algorithm performance for descriptive tools of the source language.

Primarily for model announces the laws of the distribution of component failure, in this case, can be declared two laws, each of which is characterized by its failure rate - work and storage. Fig. 3 shows an example of syntax classified exponential distribution laws.

```
distribution  Dis_Save (2,194e-8);
distribution  Dis_Work (1,232992e-6);
```

Figure 3. Announcement of the laws of distribution of failures.

After the announcement of the distribution laws can describe the working components, their formal model builds on the basis of possible states of the components and the laws of distribution of time spent in each state. Moreover component transfer from storage mode to work mode is not considered, as it will be implemented separately. Description of the first component shown in Fig. 4, it has two states corresponding to the storage and work and one operation mode.

```
knot K1
{
state: Fail, Work;
mode: Save,Normal;
startState: Work;
startMode: Normal;

cntrlMode: unDistribution;

tableDistribution:
       | Save       |     Normal    |
Work   |  Dis_Save |     Dis_Work  ;

tableStateChange:
           Normal   | Save
Work     |Fail     |Fail ;

};
```

Figure 4. A formal model of component part 1.

Description of the second component part is somewhat more complicated: it has two modes, one corresponds with the proper operation of the K1 (or component part 1), the second with the failure. Accordingly, in a serviceable K1 during the operation of the K2 (or component part 2) continue to be stored under the same crashed into operation instead, which is reflected in the table of distribution laws (see Fig. 5). In more detail the principles of construction of formal models of components are covered in [6].

```
knot K2
{
state: Fail, Work, Rezerv;
mode: Save,Normal;
startState: Rezerv;
startMode: Normal;

cntrlMode: unDistribution;

tableDistribution:
       | Save            | Normal    |
Work   |  Dis_Save      |  Dis_Work |
Rezerv |  Dis_Save      |  Dis_Save ;

tableStateChange:
              Normal   | Save
Work        |Fail     |Fail    |
Rezerv      |Fail     |Fail    ;
};
```

Figure 5. A formal model of K2.

Further, into the model introduces a conditional component simulating assembly of electronic tools in general and the failure criterion for it, which is the simultaneous failure of K1 and K2, in the framework of a formal model of the operators can be described as a very simple logical expression (see Fig. 6). This expression represents that the assembly is running if any of the components K1 and K2 are serviceable.

```
function FunctREA
{
return K1|K2;
};
```

Figure 6. The criterion of failure of the electronic equipment.

Now to the model of assembly is necessary to add an event associated with the failure of K1, which should lead to the switching the component K2 to the work mode, if it is serviceable at this time. For these tasks, it provides a formal model of a specialized tool «switch_event», which consists of conditions and reconfiguration actions. In this case, the condition is simple: failure of K1, and the action is only one - to change the mode of operation of K2. In the case of an earlier failure of a component K2 change mode operator just will not have any effect. A formal record of this action is shown in Fig. 7.

```
switch_Event EL_1_fail
( ->K1:Fail & K2:Rezerv )
{

set_state ( K2:Work );

} ;
```

Figure 7. A formal description of the switching of K2.

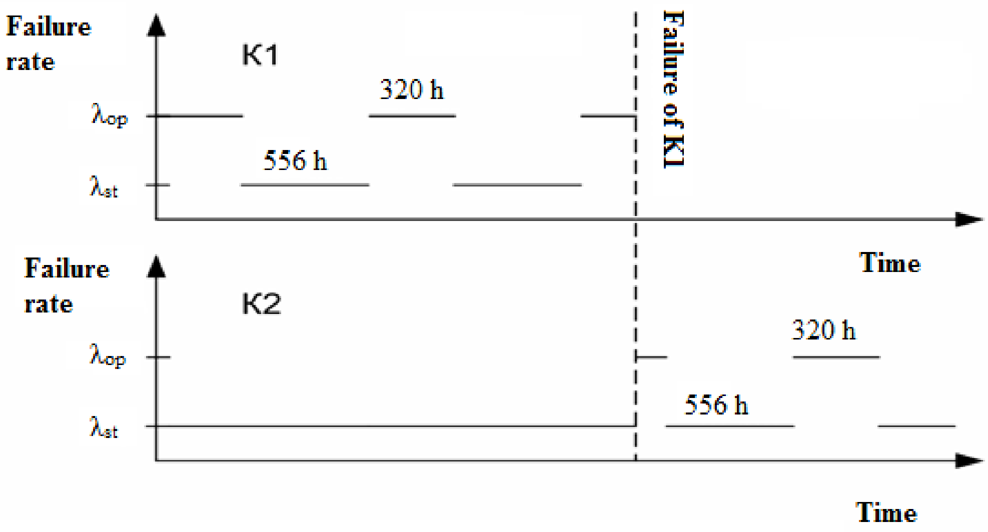

Figure 8. The timing diagram for changes of failure rates of components in the simulation.

After direct describing the structure of electronic assembly it is necessary to start modeling session mode, that is carried out through the introduction into a model additional conditional component of the periodic switching of the components of the state stored in the state of work. Since it is not known the exact real time distribution of work and storage of assembly, but only their ratio, the period of turning on and off are selected on the base that they are much smaller (by at least two orders of magnitude) than the operation period and maintaining overall ratio and time of storage and work. Based on these conditions, we assume that the duration of the work period is 320 hours and 556 hours of storage period. Thus we obtain a uniformly distributed the storage and work areas over the period of operation (see. Fig. 8).

Call the switch component SK, and announce its corresponding distributions (see Fig. 9). In this formal model it turns out that SK is fixated between the two states, while in each of which a constant. This technique is a standard for modeling periodic events by means of software ASONIKA-K-RES and it allows you to simulate not only the hard-coded time of work/storage, but unlikely individual impact on the analyzed assembly, the main requirement is the availability of information on the distribution law, corresponding to the impact.

```
distribution  Dis_per_Work (const 320);
distribution  Dis_per_Save (const 556);

knot Switcher
{
state: Fail, StW, StS;
mode: Normal;
startState: StW;
startMode: Normal;

cntrlMode: unDistribution;

tableDistribution:
       | Normal       |
StW    | Dis_per_Work |
StS    | Dis_per_Save ;

tableStateChange:
       | Normal      |
StW    | StS         |
StS    | StW         ;

};
```

Figure 9. Model optional assembly SK.

Declaring assembly SK, which is a timer of transition from one state to another, it can be associated with it changes in the functioning of the electronic equipment. This is done as well as regime change of component K2, through operator switch_event, formal description of these events is shown in Fig. 10.

```
switch_Event SwitchOn
( ->Switcher:StW )
{

set_mode ( KR2:Normal );
set_mode ( K1:Normal );
} ;

switch_Event SwitchOn
( ->Switcher:StS )
{

set_mode ( K2:Save );
set_mode ( K1:Save );
} ;
```

Figure 10. Simulation session mode of electric assembly.

The resulting formal model introduced in the software tool ASONIKA-K-RES is compiled and checked for compliance with the functioning of the algorithm. Since the model consists of only a few components, the verification process is not difficult and can easily be formed directly by the developer of formal model. Then one can start modeling. Programming model can be subjected to several types of tests - a test on the probability of failure-free operation (for a specific period of operation), and the MTBF. And in the second version obtained statistical data can be used to plot the probability of failure-free operation and of the failure rate of the investigated electronic devices.

The results of calculation of the fourth procedure get the following value is the probability of failure-free operation over the lifetime: 0.9991667.

4. Conclusions

Fig. 11 is a summary histogram of the probability of failure-free operation over the lifetime calculated by 4 ways, which shows that the smallest values provide methods 2 and 4, i.e., they may be used as a lower limit estimation of probability of failure-free operation that is acceptable in terms of calculations [3].

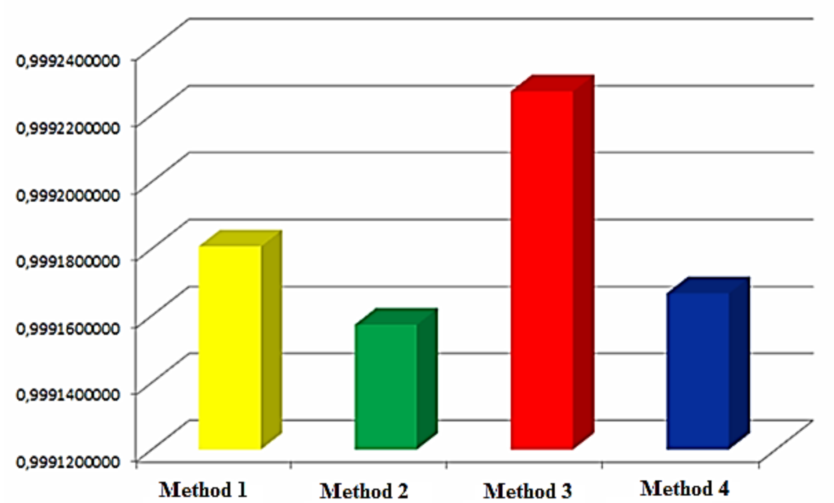

Figure 11. Summary histogram of probabilities of failure-free operation over the lifetime (87600 hours).

As a result, obtain the following values of the probability of failure-free operation over the lifetime (see Table 2). A second method is taken as a reference to calculate the relative error (method of constructing a model based on the equation for the total probability) for reasons which have been described above.

Table 2. Results of calculating the probability of failure-free operation and the relative error

№	Name of the calculation method	A value of probability of failure-free operation for the lifetime for scheme №1: one primary and one reserve	A value of probability of failure-free operation for uptime for the lifetime for the schema №2: 1 main and 2 reserve	The value of the relative error of the probability of failure-free operation		The value of the relative error of probability of failure	
				The scheme №1	**The scheme №2**	**The scheme №1**	**The scheme №2**
1	Method 1 (method of standard structural reliability schemes)	0,999180711554146	0,999988538873878	2,339569532504992·10^{-5}	8,709636600984844·10^{-5}	0,027741	0,883701
2	Method 2 (by sorting hypotheses)	**0,999157335573541**	**0,99990145109112**	**0**	**0**	0	0
3	Method 3 (temporal decomposition method)	0,99922699998305	0,999990059235791	6,972316273800213·10^{-5}	8,861687776787736·10^{-5}	0,082672	0,899129
4	Method 4 (simulation method)	0,9991667	0,9999876	9,72e-6	8,7057e-5	0,011113	0,883307

As can be seen from Table 2 coincidence between the results obtained by simulation (method 4) and by exact analytical calculation (Method 2) with a very small error (relative accuracy of probability of failure from 0.011113 to 0.883307). But the probability of failure when building a simulation model is minimized (as well as for a simple model) due to special means of verification model, while the probability of failure in the construction of a mathematical model (9) (Method 3) starts to grow because of its complexity and difficulty of verification. Thus, it becomes evident that the simulation can be regarded as an alternative to accurate analytical methods (method of sorting hypotheses) [2] in predicting the reliability of complex electronic devices in terms of types of redundancy and get a more accurate estimate of reliability parameters.

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