DEVELOPMENT OF THE METHOD OF PREDICTION PARAMETER OF RELIABILITY CHEMICAL CURRENT SOURCES OPERATING IN A "SESSION" MODE

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Abstract

The paper describes the calculation method of reliability and conservability products class of chemical current sources (CCS) in the design to the specific conditions in the electronic means. The technical specification for the indicators of CCS reliability are for specific operation modes and their use in the calculation gives a large error. In the U.S. (MIL-HDBK-217F, Telcordia (Bellcore) SR 332), French (CNET RDF-2000), English (British Telecom HRD5) and Chinese (GJB/z 299B) references to the reliability of electronic devices there is no information for the calculation of reliability and conservability CCS, no calculation models.

The cumulative accounting model of physical factors affecting the calculated capacity of the chemical current sources, which is the main factor affecting the reliability is shown.

1. Introduction

Electronic devices (ED) for different purposes entered widely everyday life: ranging from cell-phones, laptops, medical devices, vehicles and ending spacecraft. Almost all of them can be used in stand-alone mode and uses as a power source chemical current sources (CCS). Most often CCS are divided by ability or inability to reuse: primary CCS (eg, nickel-cadmium batteries), secondary CCS (eg, lead-acid batteries) and electrochemical generators. Based on the harsh environment of the ED, such as a wide range of changes in ambient temperature (from -40 °C to +50 °C), to predict working capacity of ED, appears necessary to study the reliability of CCS for specific operating conditions (or a model of exploitation).

Therefore, there is the problem of assessing the reliability associated with the fact that the electronic part of the ED (resistors, capacitors, integrated circuits, etc.) that is responsible for the basic functions of the device can be determined by the methods described in the references [1, 5-9], and determine the reliability of the power supply CCS tied to specific conditions is not possible or is of great complexity. At present there is only one way - statistics on the reliability CCS in reference [1], but they do not allow us to estimate an accurate picture of the behavior of the element in accordance with the model of operation even in the later stages of design. No models for calculating CCS in references [5-9]. In this situation, the only solution is tests that cost developers in larger budgets.

Therefore, a fundamental solution to this problem is required: to create a method of forecasting performance of the reliability of CCS in the early stages of design.

In addition, according to tests of CCS various technological groups [4] were found that the greatest influence on the reliability is provided by:

- operating mode, i.e. during the discharge CCS, given to the load capacity at a given operating voltage is not less than the specified element to the load;
- The moment when a CCS on discharge;
- Storage mode (standby) mode, i.e. duration of storage.

For more details on the types of distributed denial of CCS class is shown in Fig. 1, where:

- Short circuit - 8%;
- Leaking electrolyte - 17%;
- Reduction of capacity – 43%;
- Swelling, depressurization - 17%;

- Assembly failures - 5%;
- Other - 10%.

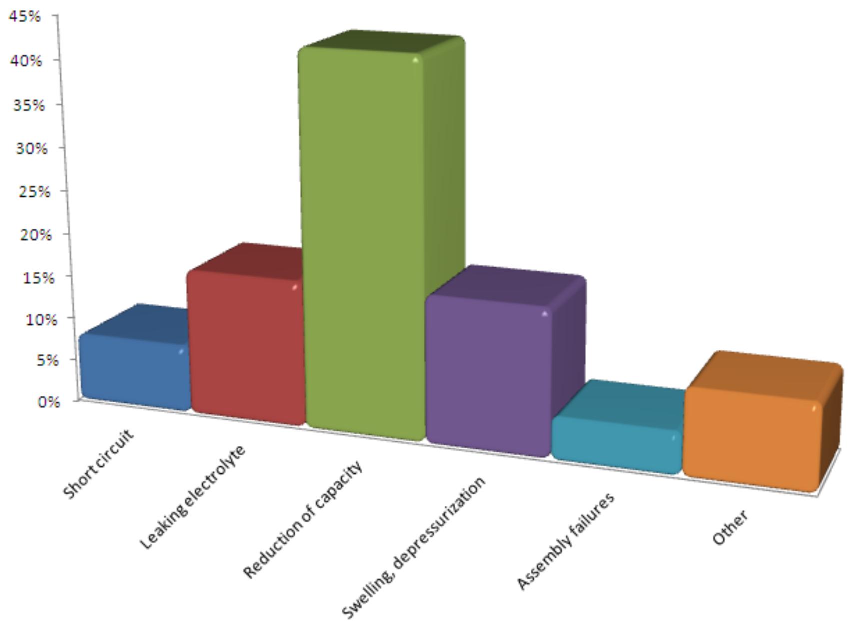


Figure 1. Percentage distribution by type of failure

2. The basic principles of construction of the calculation model of reliability and conservability for ED CCS

Indicators of reliability and conservability for the electronic part of ED is calculated by model, given in references [1, 5-9], depending on the country of origin of electrical product (EP).

Using as the basis mathematical models of EP [1, 5-9] for calculations reliability for CCS is not possible, because the elements are referred to as electro-chemical power products often combine both types of faults (sudden and gradual). And to a great extent, as the distribution by type of CCS failure (see Fig. 1), dominated by the gradual failure (degradation factors and aging). Actual sudden failure can happen, but in parallel is the "aging" of the element, which leads to phase out, if it has not had a sudden failure. Therefore, the mathematical model of reference [1, 5-9] can not be used as a basis for assessing CCS. Improvement the method of calculation of reliability and conservability is needed.

Based on the above analysis, these elements can be considered as consisting of two parts, one of which can only occur sudden failure, and in the other - only gradual. Elements work until the first of these failures. If $P_s(t)$ - the probability that sudden failure does not happen during time t, and $P_g(Z, t)$ - the probability that during time t the value of the safety factor for the centered container (key parameter CCS) will remain within the limits (set limits), i.e. does not happens gradual failure, the assumption that failures occur independently of each other, we find that the reliability function of CCS is:

$$P(Z,t) = P_s(t) \cdot P_g(Z,t) \qquad (1)$$

where:

$$P_s = \begin{cases} 0,999 \\ 0,9999 \end{cases}$$

- it is the probability of failure-free state at the time of CCS engagement from reference [1], which is determined by the results of tests;

$$P_g = \frac{1}{\sqrt{2\cdot\pi}}\int_{-\infty}^{Z} e^{\frac{-x^2}{2}}dx$$

- it is the probability of failure-free operation, defined by the normal distribution [3];
Z - normalized centered safety factor of capacity, a random variable.

To introduce the opportunities for a separate assessment of reliability and storage, put forward the following premise: "If the state probability at session mode λ_s spread out on two independent events - the probability of failure-free operation in the storage mode λ_{st} and the reliabilities in operation λ_{op}, and calculated using the following model with an exponential distribution [3]:

$$\begin{cases} \lambda_s = \dfrac{\lambda_{op}\cdot t_{op} + \lambda_{st}\cdot t_{st}}{t_{op}+t_{st}}; \\ \lambda_{tr} = \dfrac{\ln(P_s(t)\cdot P_g(Z,t_s))}{t_s}; \\ \lambda_s = \lambda_{tr},\ \text{provided that } t_{op}+t_{st}=t_s. \end{cases} \tag{2}$$

where: t_{op} – operating time, t_{st} – storing time; t_{op} + t_{st} = t_s – CCS operating time; λ_{tr} – traditional, calculated by reference [1].

When determining the indicators of reliability and conservability is necessary to divide the model into two operation mode to the power on the discharge, based on the extended postulate. Thus, we have the following general model of reliability:

$$P_g(Z,t) = \begin{cases} P_{op}(Z,t) = P_s\cdot P_{g.op}(Z,t); \\ P_{st}(Z,t) = P_s\cdot P_{g.st}(Z,t), \end{cases} \tag{3}$$

where: $P_{g.op}$ and $P_{g.st}$ – defined by the normal distribution, as in the model (1).

Thus, evaluating the reliability of a CCS, take into account the mode of operation, we are interested in a particular case: only storage, only operation; session mode, alternate storage and operation.

3. The calculation of the failure rate during operation and storage mode

CCS key parameter, as the statistical analysis shows in Fig. 1, is the average electrical capacity, determined by cumulative formula:

$$C = C_t - A_t\cdot\Delta_t + A_j\cdot\Delta J - A_{st}\cdot t'_{st} - A_c\cdot N_c, \tag{4}$$

where: A_t, A_j, A_{st}, A_c – table gradients of changes in capacitance of temperature, duration of storage, discharge current and best practices in the charge-discharge cycles; C_t - the average capacity of CCS; Δt=t_f - 20°C where t_f - functioning temperature; ΔJ=J_{req} - J_f, where: J_{req} - the required discharge current, J_f - actual critical value of the discharge current; t_{st} – storage time.

Empirical model (4) is to be divided according to the mode of operation to a simple model provided the independence of the two events. A simplified calculation model:

- Average electrical capacitance for the storage is a function of the storage time and the discharge current and is given by:

$$C(J_f, t_{st}) = C_t + A_j\cdot\Delta J - A_{st}\cdot t_{st} \tag{4.1}$$

where: t_{st} - the actual storage time.

- Average electrical capacity for the mode of operation is defined by the formula:

$$C(T, \Delta J, N_c) = C_t - A_t \cdot \Delta T + A_j \cdot \Delta J - A_c \cdot N_c, \tag{4.2}$$

Normalized centered safety factor for the capacitance is determined by the formula:

$$Z = \frac{(C - C_{req})}{\sigma}, \tag{5}$$

where: C - result from the formula (4.1) or (4.2), the capacitance value of CCS; C_{req} – the required level of capacity in the application of CCS, a reference value; σ – standard deviation value of CCS capacity, defined by the formula:

$$\sigma = \sigma_t \cdot \frac{(B_t \cdot B_j)}{(B_{st} \cdot B_c)},$$

where:

$$B_j = \frac{C_j}{C_t}$$

- coefficients, representing a ratio of capacity C_j, calculated by the formula (3) taking into account only the j-th factor to the specified value average capacity C_t.

σ_t - table value of standard deviation, for the type, reference value.

For storage conditions formula for the standard deviation value of CCS capacity looks as follows:

$$\sigma = \sigma_t \frac{B_j}{B_{st}}$$

Respectively for the operation:

$$\sigma = \sigma_t \frac{B_t \cdot B_j}{B_c}$$

Reliabilities estimated by the formula (3).

The problem of direct calculation of the model (1) and (3) is that the improper integral can not be solved by simple methods to get the recurrence formula, required for automation, so polynomial regression methods used to obtain the recursive formula for calculating the probability of failure-free operation CCS, depending on the parameter.

The failure rate is defined as:

$$\lambda(t) = \frac{P_s \dfrac{\partial P_{g.st}(Z,t))}{\partial t}}{P_{g.st}(t)} \tag{6}$$

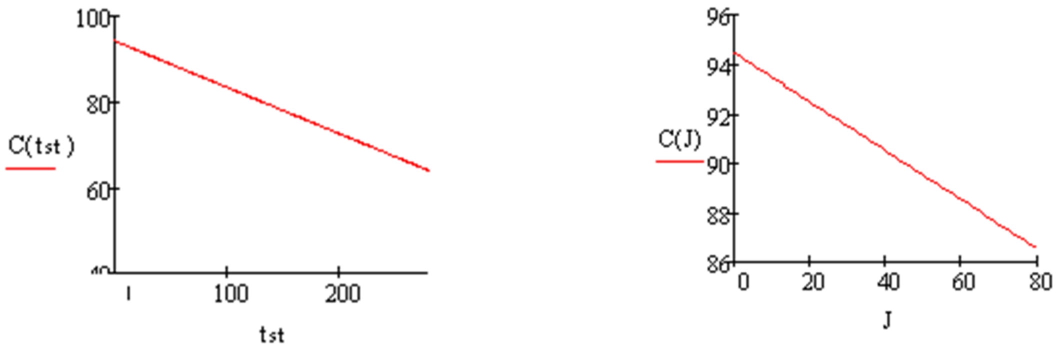
Or, by using the exponential distribution [3], we obtain the following relation to calculate the failure rate:

$$\lambda 1(t) = -\frac{\ln(P_s P_{g.st}(Z,t))}{t_{st}} \tag{7}$$

For example, we estimate the failure rate in the storage mode and operation of the battery related to the technological lead acid batteries group [10] - one of the groups most commonly used in vehicles [4].

As shown above, the reliability of the battery is affected by ambient temperature, discharge current, the number of charge-discharge cycles, the shelf life and storage conditions.

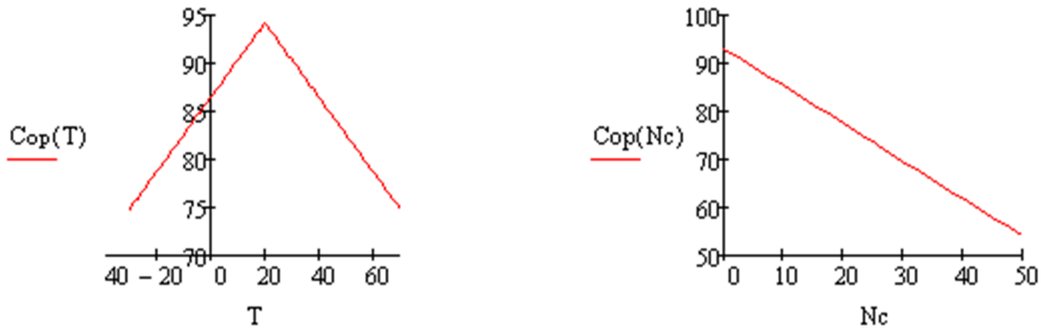
Plot the dependence $C(J_f, t_{st})$ of the model (4.1) (Fig. 2). Fig. 2a shows that with the increase of storage time, the average capacitance decreases linearly. With the increase of the discharge current, $C(J)$ also decreases linearly (Fig. 2b).



a) b)

Figure 2. Dependence of the average capacitance of storage time and discharge current: a) *C(tst)*; b) *C(J)*

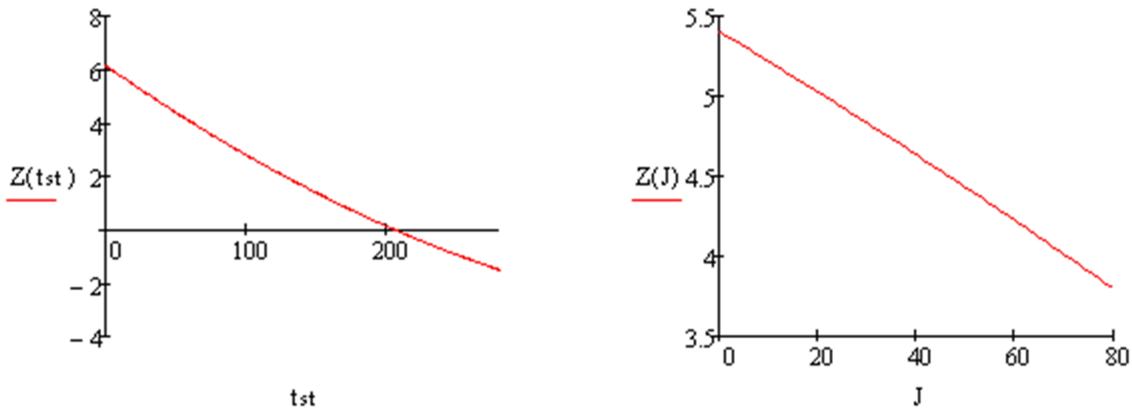
For operation (model (4.2)) plot the dependence of *Cop(T,Nc)*. Fig. 3a shows the dependence of *Cop(T)*. It is seen that up to *T*=+20ºC schedule capacity increases linearly (*T*=+20ºC corresponds to normal operating conditions), that is, at *T*=+20ºC average electrical capacity reaches its maximum value, and then begins to decline linearly.



a) b)

Figure 3. Dependence of the average capacitance of the temperature and the number of charge-discharge cycles in operation: a) *Cop(T)*; b) *Cp(Nc)*

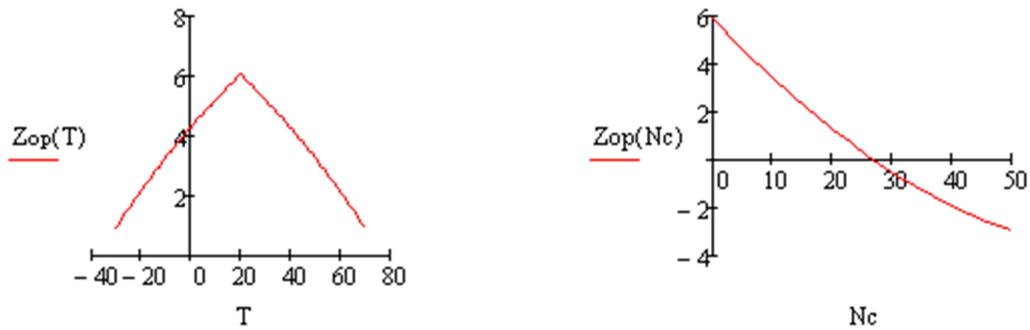
Using equation (5) plot the dependence of the normalized centered safety factor of the capacity for mode of storage and the mode of operation. Fig. 4 shows the dependence *Z(tst, J)* (storage mode). With the passage of time in storage mode normalized centered safety factor for the capacity drops almost linearly (Fig. 4a). The same can be said about the dependence of *Z(J)* (Fig. 4b).



a) б)

Figure 4. Dependence of the normalized centered safety factor in capacity Z(tst, J) in the storage mode: a) Z (tst); b) Z (J)

Fig. 7 shows the normalized centered safety factor for the capacity for the operation mode. Change in *Zop(T)* (Fig. 5a) corresponds to the variation *Cop(T)* (Fig. 3a). *Z(Nc)* (Fig. 5b) decreases with increasing number of cycles of charge discharge.



a) б)

Figure 5. Dependence of the normalized centered safety factor in capacity *Z(T, ΔJ, Nc)* in operation mode: a) *Zop(T)*; b) *Zop(Nc)*

Recursive formula for calculating the probability of failure-free operation of CCS during storage time t_{st}, obtained with the use of polynomial regression is:

$$P_{g.st}(t_{st}) = 0.999999 - 2.626\cdot10^{-3}\cdot t_{st} + 6.786\cdot10^{-5}\cdot t_{st}^{\ 2} - 4.76\cdot10^{-7}\cdot t_{st}^{\ 3} + 5.724\cdot10^{-10}\cdot t_{st}^{\ 4} + 7.959\cdot10^{-13}\cdot t_{st}^{\ 5} \quad (8)$$

Fig. 6 shows the dependence of the probability of failure in the storage mode *P(tst)* (solid line) and dependence $P_{g.st}(t_{st})$ (dashed line), built on the model (1). As we can see diagrams of dependence of the models (1) and (8) virtually identical.

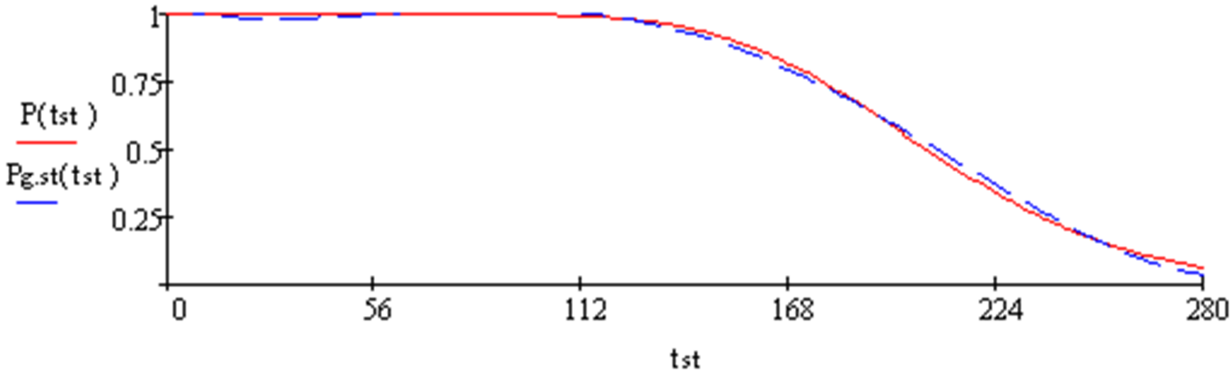


Figure 6. Dependence *P(tst)*, dependence *Pg.st(tst)*

Types of charts for the probability of failure-free operation of the discharge current, the number of charge-discharge cycles, and temperature are shown in Fig. 7-9.

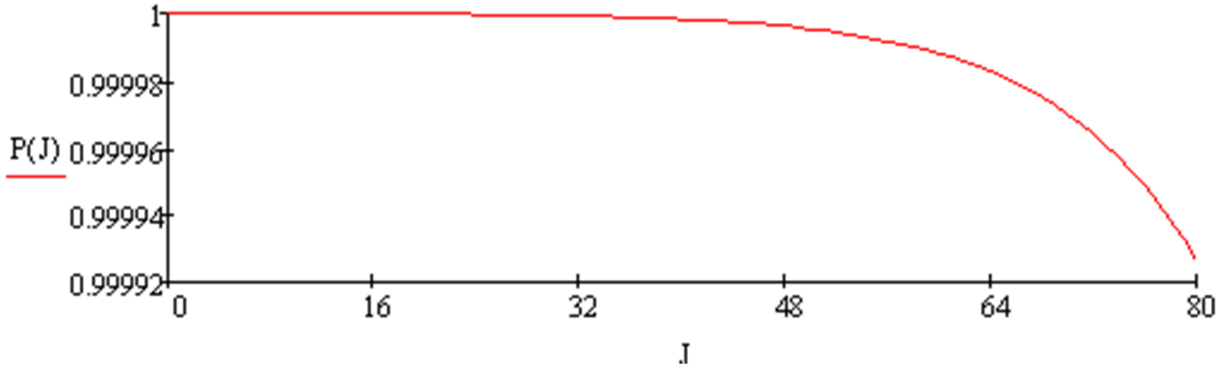


Figure 7. The dependence *P (J)*

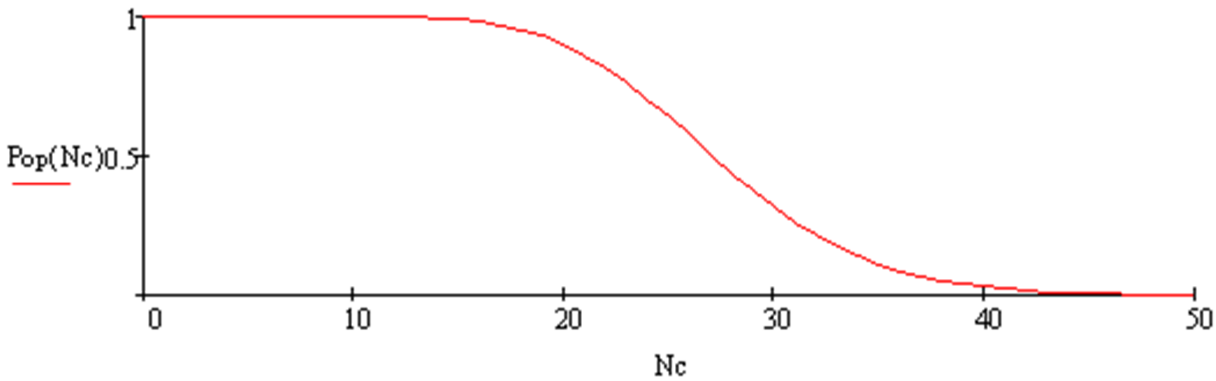


Figure 8. Dependence *Pop(Nc)*

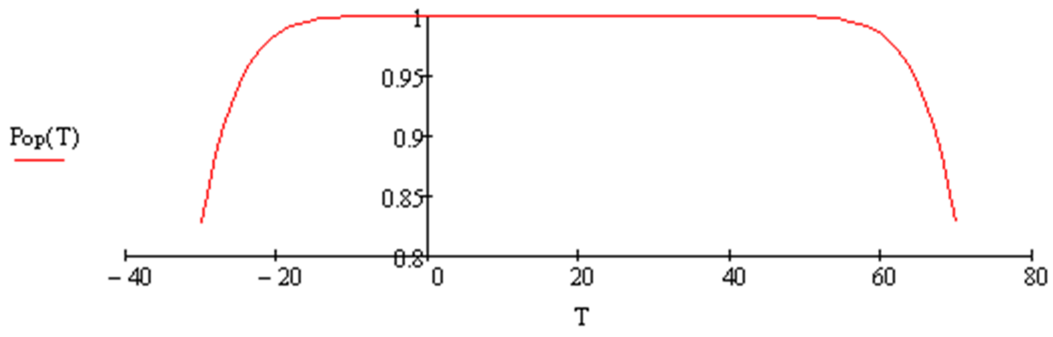


Figure 9. Dependence *Pop(T)*

Next, estimate the intensity to phase in the storage mode, depending on the storage time (see Fig. 10).

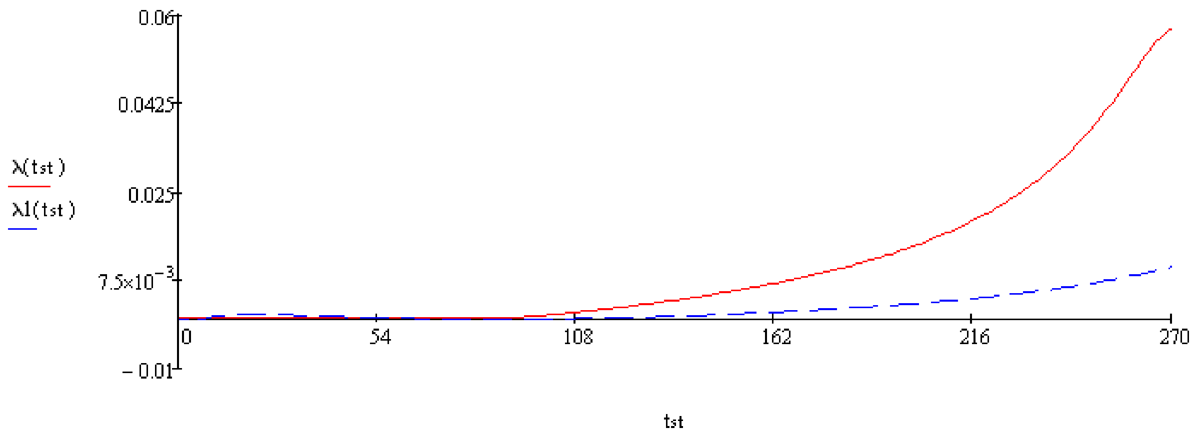


Figure 10. The dependence of the failure rate in the storage mode of storage time

Fig. 10 clearly shows that the warranty period for the estimated storage battery (≈ 100 months) plots of the failure rate of the storage time, constructed in two different models (models (6) and (7)) are practically the same, a sharp contrast to begin after the warranty period, when models already in use there is no need. This gives reason to believe that the assessment of the conservability of CCS can use the exponential distribution.

Types of dependence $\lambda(J)$, $\lambda op(T)$, $\lambda op(Nc)$ are shown in Fig. 11-13.

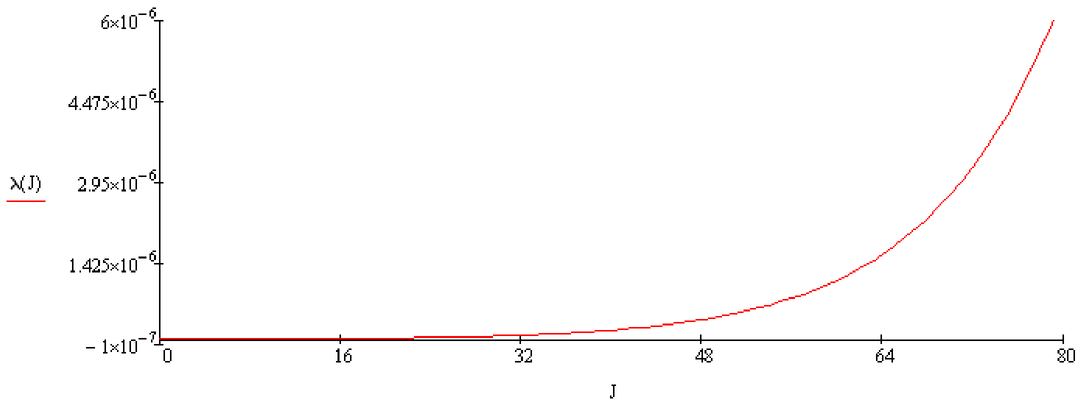


Figure 11. The dependence of the failure rate of the discharge current

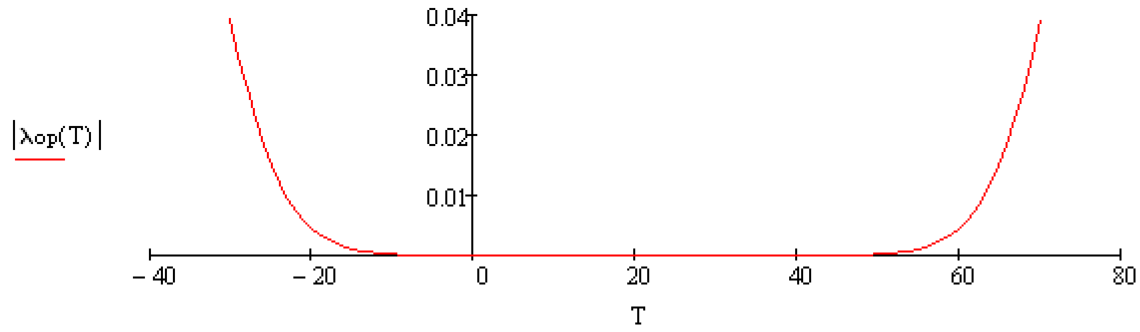


Figure 12. The dependence of the failure rate of the operating temperature

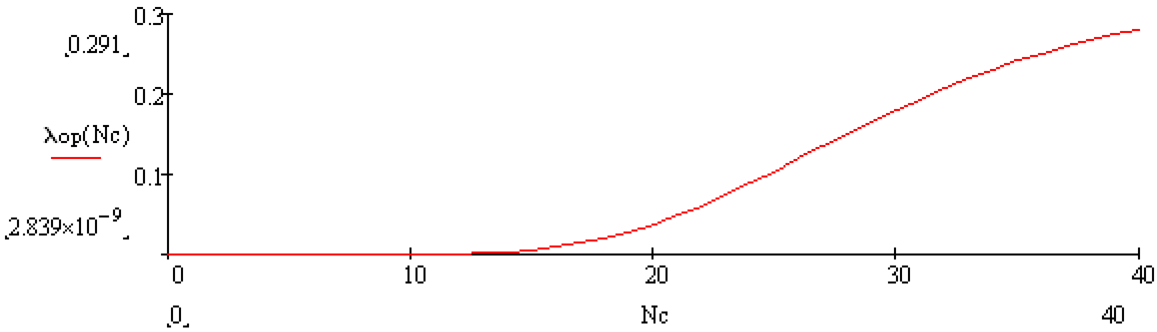


Figure 13. The dependence of the failure rate of the number of charge-discharge cycles

Now, to prove the postulate given in section 2, and the validity of the separation model (4), calculate the failure rate for the battery in the session mode in two ways and define the error.

1. Using the model (4) calculate λ. Storage time *tst* = 1 month, the number of cycles *Nc* = 1 .. 100. A dependence plot of λ of the number of cycles is shown in Fig. 14 (dashed line).
2. Calculate the *λs*, *λst* and *λop*, using the position of the postulate and of the models (4.1) and (4.2). Dependence *λs(Nc)* is shown in Fig.14 (solid line).

Taking *λ(Nc)* for the truth, we calculate the error:

$$\delta = \frac{\lambda(Nc) - \lambda_s(Nc)}{\lambda(Nc)} \cdot 100\%$$

The average error between the two methods in assessing the failure rate for the active lifetime is:

$$\delta_{ave} = \frac{\sum_{Nc=1}^{100} \delta}{100} \cdot 100\% = 9{,}3\%$$

The resulting value of the error is within acceptable engineering error (5-10%).

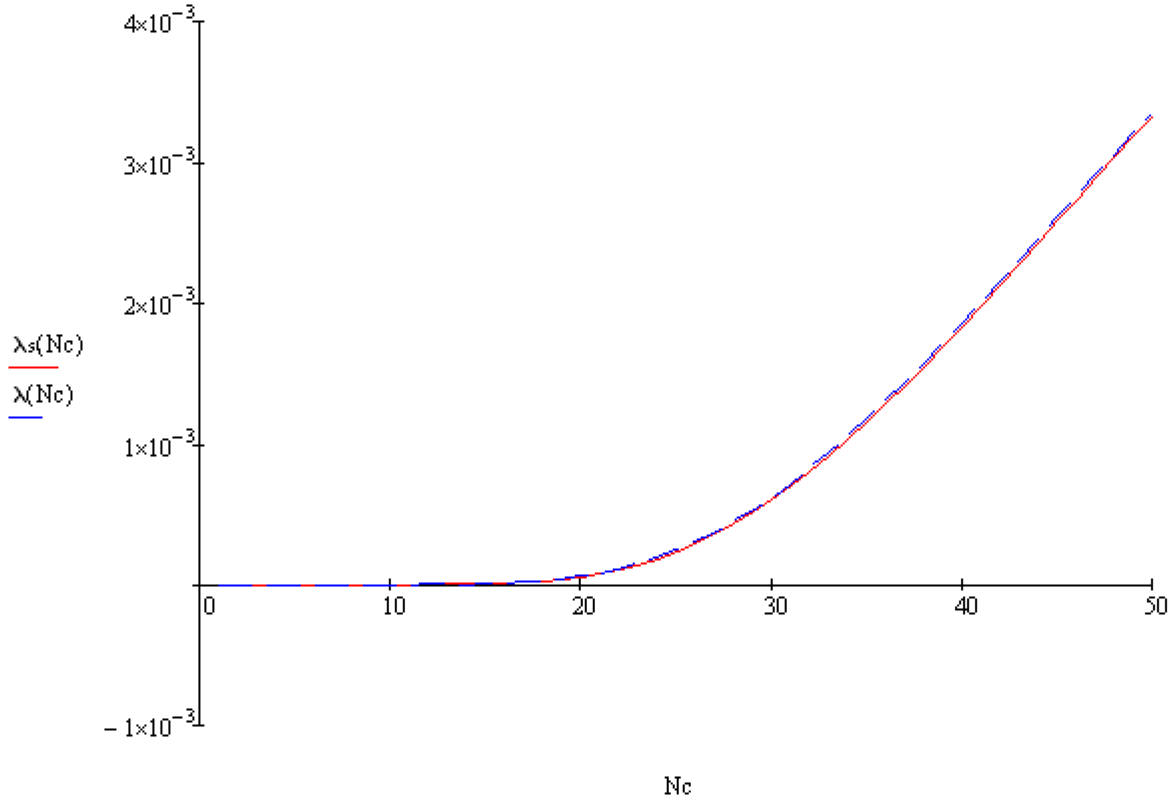


Figure 14. Dependence the failure rate *λtr(Nc)* - according to the traditional formula (1), *λs(Nc)* by (7)

4. The influence of parameters on the failure rate

The results of analysis of the influence of various parameters on the failure rate are presented in Fig. 15. As can be seen from the histogram, the strongest gradual failures depend on the number of charge-discharge cycles, which is consistent with the principle of battery life. Least contribution to gradual failure makes the discharge current.

To evaluate the accuracy of the proposed method construct on the same graph (Fig. 17) the calculated (solid line) failure rate, and reference (dotted line) as a function of time. Supplemental failure rate is constant, independent of any parameters, while, as in real-life conditions, each of the main parameters - temperature, time, discharge current and the number of charge-discharge cycles - will make its contribution to the gradual failure. The point of intersection of the graphs shows the guaranteed life of the product.

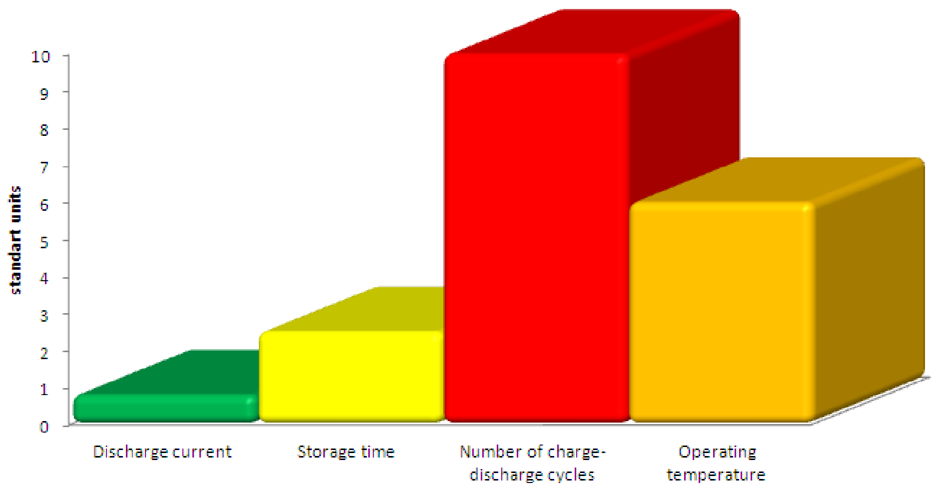


Figure 15. Histogram parameters influence on the value of the failure rate

5. Conclusions

Divide the graph into two parts: I - to the intersection graphs (short working time), II - after the intersection (life in excess of the guaranteed). On the section I the error, between the calculated and experimental values of the failure rate at time $t1 = 24$ will be:

$$\delta_1(under\ t_{st} = t_1 = 14) = \frac{\lambda 2 - \lambda(t=14)}{\lambda 2} = 1\%$$

On the section II error between the calculated and experimental values of the failure rate at time $t2 = 70$ will be:

$$\delta_2(under\ t_{st} = t_2 = 70) = \frac{\lambda(t=70) - \lambda 2}{\lambda 2} = 22\%$$

Thus, the error of this method ranges from 1% to 22% (this is the average score, with increasing time, the error will continue to grow). If the equipment is functioning a short time (or before the testing time before failure), the experimental failure rate gives even higher valuation. If it is required to assess reliability in a long period of time, perhaps even more than your initial period of service, the reference data, not taking into account the specific conditions of use, do not correspond to the real situation.

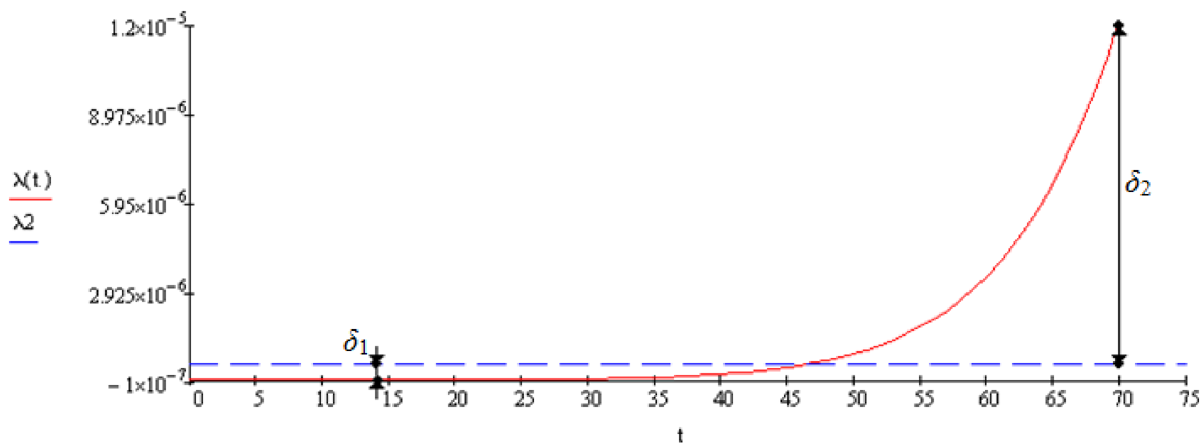


Figure 16. The failure rate obtained by the proposed model and the failure rate of reference

The error between the proposed method and the failure rate in terms of CCS technical conditions, an average of 1 - 22% for a given period of active existence. While the reference failure rate is constant, the value obtained by the proposed model in the article, is changing over time, which more accurately reflects the true picture of the reliability of any products, including CCS.

The substantiation of the possibility of separation failure rate in the session mode, the failure rate in the mode of operation and the failure rate in the storage mode is shown. The average error (at a hundred measurements) in this case is 9.3%, i.e. is within acceptable limits of engineering accuracy.

Proceeding from the premise that the main parameter is the average CCS capacitance model was developed predicting uptime hit, taking into account the main parameters that influence the capacity of: temperature exploitation, storage time, the number of charge-discharge cycles, the discharge current. Reduced reliability prediction CCS model allows more accurate assessment of the failure rate based on the model of operation (storage mode, operating mode, the session mode) in the specific electronic means. This model allows us to estimate the effect of various specifications of storage / work mode on the failure rate of CCS.

Given above mathematical model for predicting the reliability of CCS has been added to the base of mathematical models of «Automated system reliability and quality" [2].

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