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Use of the Control Graph for Pursuing the Reliability of an Electric Power Station

Reliability — a measurable expression of products durability; reliability in operating is expressed in time units.

Underlining the necessity of intensifying in all the branches of economy the action of systematic improvement of the quality of products and services, the Directives of the Tenth Congress of the Romanian Communist Party point out that the improvement of the quality of products on which depends, to a great extent, the ensurance of our efficiency and competitiveness on the market, must be a main preocupation of economic activity in all sectors.

The problem of the reliability of industrial products has ever more acutely been raised of late, a fact determined by the rapid increase of the volume and, especially, of the complexity of the industrial aggregates, a cause which leads to increasing possibilities of defects and to render the re-establishing operations difficult.

If the "quality" of a product can be considered as "a statiscal virtue", that is the consumer is satisfied upon accepting the product, "reliability" is a "dynamic virtue", it is the permanent maintenance of the performance of products, for the entire period of their utilization [1].

The terminology and definitions in this field (of reliability) must be used very carefully, because their different interpretations are still continuously changing, to the extent to which its basic principles are ever more cleared up.

The aspects of reliability in the field of energetics are today key problems through the consequences implied on the scale of the national economy as a whole. Both in the reports presented at the Seventh session of the World Power Conference — Moscow, 1968 and at the session of reports of the same

organism, held in Bucharest, important steps were made in defining the concept of reliability and in the methodology of determining the reliability indicators for the power systems [2]. The problems of the quantitative estimation of reliability are dealt with by several authors, the problem being still in the stage of seekings [3].

Taking this situation into consideration, we shall present an efficient working method of graph control of reliability in case of an electric power station.

First, we shall consider a definition of reliability recommended by the International Commission of Electronics, a definition which is rather widely adopted [4]: "Reliability is a characteristic of a device expressed by the probability with which it fulfils a necessary function in the conditions given, for a period of time given."

Being particularized in the case of electric power station, reliability is expressed by a functioning probability without falls *). It is well known that the appearance of falls has an aleatory character and, consequently, the moments of their appearance cannot be envisaged. Yet, the statistical-mathematical methods allow the determination of intervals in which falls will almost certainly occur. One can thus affirm with certain probability that, for example, in a certain period of exploitation, the power station will produce 0, 1, 2 or 3 falls. Thus, in this domain, reliability represents a calculated and measurable size, defining, apart from other indicators, the qualitative performances of an installation.

Summing up, one can say that reliability is defined by the following four terms:

— probability;
— performance to achieve
— working conditions;
— time

Very frequently, reliability is expressed by the functioning probability without falls in a certain period of time, thus by the probability that the time T of functioning without faults of the power station should surpass or be at least equal with the prescribed time t [5], [6], [9].

An analogy can be made between the control of reception of the lots of products and the control of reliability. Thus, in case of the former, the control and conclusions on the quality of the entire production are drawn by checking some tests extracted from the lot and the conclusions on the reliability of the systems are drawn by studying several time selections. What practically interests in the study of reliability is the number of falls produced in a certain time interval T and if this number can be accepted or not.

Before passing on to the effective calculations, it is necessary to know the law on the distribution of the studied variable (the phenomenon of the appearance of falls). From previous studies on the phenomenon of the appear-

*) the fall represents the fault hindering the proper functioning of the system (power station) in the next period of time; in other words, it is the event consisting in the transition from the functioning state to the fault state.

ance of falls in the power station, the hypothesis was made that this phenomenon follows the law on the distribution of the rare events [10], [11]. For checking this hypothesis, an analytic method, namely the criterion χ^2 [12] was used for testing.

For checking this character, the falls were registered in a system in the last 40 months of functioning, the results being presented in the form of a statistical distribution in columns 1, 2 of table 1.

Table 1

No. of falls x	No. of months in which x falls have appeared n_i	$F(x)$	p_i	np_i	$n_i - np_i$	$(n_i - np_i)^2$	$\frac{(n_i - np_i)^2}{np_i}$
1	2	3	4	5	6	7	8
0	18	0.387	0.387	15.480	2.52	6.3504	0.410
1	11	0.754	0.367	14.680	−3.68	13.5424	0.922
2	7	0.929	0.175	7.000	0.00	0.0000	0.000
3	3	0.984	0.055	2.200	0.80	0.6400	0.291
4	1	0.997	0.013	0.520	0.48	0.2304	0.443
5	0	1.000	0.003	0.120	−0.120	0.1440	1.200
Total	$n = 40$	—	1.000	$\Sigma np_i = 40.000$	—	—	$\chi^2 = 3.266$

The values of the distribution function $F(x) = \sum_{k=0}^{x} \frac{\lambda^k}{k!} e^{-\lambda}$ are tabulated [11], [12] in keeping with the values of variable x and the parameter λ of the law (the arithmetical mean of the characteristic). The mean value was determined as follows:

$$\lambda = \frac{\Sigma x_i n_i}{\Sigma n_i} = 0.95$$

The values of the distribution function were found from the tables of the Poisson function, for $\lambda = 0.95$, values given in column 3 of table 1. All the calculations which have finally led to the determination of the value of $\chi^2\left(\chi^2 = \Sigma \frac{(n_i - np_i)^2}{np_i}\right)$ equal to 3.266, can be followed from the table. The calculated value is to be compared to a tabular value, in keeping with a level of significance α chosen and the number of the degrees of freedom (the number of values k, minus $l = 1$ the number of the parameters of the law, minus 1). For a level of significance $\alpha = 0.05$ and a size of the degrees of freedom $f = k - l - 1 = 6 - 2 = 4$, theva lue $\chi^2_{0.05;4} = 9.49$ results tabuarily [13].

As:

χ^2 calculated (3.26) $< \chi^2_{0.05;4}$(9.49),

it results that we have no sufficient reason to reject the hypothesis according to which the distribution of falls is of a Poisson type.

Two conditions make possible the introduction of the graph method of controlling reliability, which we recommend:

— the admittance of the possibility of the appearance of falls;

— the admittance of the possibility of the production of errors in the taking of decisions.

If we note:

r_1 — the frequency of falls considered as accepted in the system;

r_2 — the tolerated limit frequency of the falls;

the hypotheses which have to be tested are the following [11]:

$$H_1 : r \leqslant r_1, \tag{1}$$

if the frequency of the falls r in the time interval T is lower or equal to r_1 — the accepted limit value and

$$H_2 : r > r_2 \tag{2}$$

the counterhypothesis of the first.

Taking into consideration the fact that the decisions concerning the reliability of the system are being taken on the basis of the study of several time selections, errors may inevitably take place, errors which may be of two types:

— the consideration as inadequate of the system from the point of view of reliability, whereas in reality it is adequate, an error called of the first type;

— the acceptance as adequate of the system from the point of view of reliability, wheas in reality it does not correspond to the formulated requirements, an error called of the second type.

The probability of making an error of the first type represents a risk of the first type α and an error of the second type, the risk of the second type -β.

The values which are being chosen for parameters r_1, r_2, α and β depend on the economic consequences of some erroneous decisions.

When hypothesis $H_1 : r \leqslant r_1$ is real, thus when the system is adequate from the point of view of reliability, the rejection probability must be smaller, at most α, thus the acceptance probability must be greater:

$$P_a(r_1) = 1 - \alpha \tag{3}$$

When hypothesis $H_2 : r \geqslant r_2$ is real, the acceptance probability must be smaller, at most equal to the risk of the second type:

$$P_a(r_2) = \beta \tag{4}$$

Further, we shall consider the limit situations of the two hypotheses, namely: when $r = r_1$ and $r = r_2$.

If we note with $P_{r_1,a}$ — the probability for the system (in the hypothesis that $r = r_1$) to have r falls in the T interval and with $P_{r_2,a}$ — the probability that the system, which the hypothesis $r = r_2$ is characteristic of, should register r falls in the same time interval and taking into

account the previous definition of risks α and β, a decision can be taken in connection with the reliability of the system, based on the Wald criterion, the criterion of the relation of probabilities [14].

If:

$$\frac{P_{r_2, a}}{P_{r_1, a}} \leqslant \frac{\beta}{1-\alpha}$$

the system is considered as acceptable from the point of view of reliability, and if:

$$\frac{P_{r_2, a}}{P_{r_1, a}} \geqslant \frac{1-\beta}{\alpha}$$

as inadequate.

In case that:

$$\frac{\beta}{1-\alpha} < \frac{P_{r_2, a}}{P_{r_1, a}} < \frac{1-\beta}{\alpha}$$

the situation is considered as uncertain, and no final decision can be taken.
If we define also two numbers A and B of acceptance and rejection of the number of falls; if hypothesis $r = r_1$ is real, the probability that A accepted falls should take place in the T time interval is defined by relation:

$$P(A) = \frac{(r_1 T)^A e^{-r_1 T}}{A!} \tag{5}$$

In case that hypothesis $r = r_2$ is real, the probability that the accepted number of falls A should take place in the T time interval is:

$$P(A) = \frac{(r_2 T)^A e^{-r_2 T}}{A!} \tag{6}$$

For obtaining the probability of the appearance of the number of rejection R, the relations (also in the case of the two above-mentioned hypotheses) are:

$$P(R) = \frac{(r_1 T)^R e^{-r_1 T}}{R!} \tag{7}$$

if hypothesis $r = r_1$ is correct and

$$P(R) = \frac{(r_2 T)^R e^{-r_2 T}}{R!} \tag{8}$$

if hypothesis $r = r_2$ is correct.
Thus, according to the Wald's criterion, the relation of the two probabilities is:

$$\frac{P_{r_2, a}}{P_{r_1, a}} = \frac{(r_2 T)^A e^{-r_2 T}}{(r_1 T)^A e^{-r_1 T}} \left(\frac{r_2}{r_1}\right)^A \cdot e^{-T(r_2 - r_1)} \tag{9}$$

If we note the relation:

$$\frac{r_2}{r_1} = v \tag{10}$$

and the mean of falls in T time interval with

$$\lambda = rT \tag{11}$$

(in the 2 variants, for r_1 and r_2 as follows: $\lambda_1 = r_1 T$ and $\lambda_2 = r_2 T$) then, the Wald's criterion is:

$$\frac{P_{r_2,\,a}}{P_{r_1,\,a}} = v^A e^{-\lambda_1(v-1)} \tag{12}$$

or, in case of the rejection number R:

$$\frac{P_{r_2,\,a}}{P_{r_1,\,a}} = v^R e^{-\lambda_1(v-1)} \tag{13}$$

It results that following these transformations, the acceptance and rejection conditions will be:

$$v^A e^{-\lambda_1(v-1)} \leqslant \frac{\beta}{1-\alpha} \tag{14}$$

the acceptance condition

$$V^R e^{-\lambda_1(V-1)} \geqslant \frac{1-\beta}{\alpha} \tag{15}$$

the rejection condition.

These notions once defined, the T time interval can be determined.

The values of the accepted and tolerated frequencies r_1 and r_2 must be known as wll as the size of the two risks α and β.

It was initially verified that the law of the appearance of the falls is of a Poisson type with the mean $\lambda = rT$. If we consider that the variable z (16) follows a Gauss law:

$$Z = \frac{A-\lambda}{\sqrt{\lambda}} \tag{16}$$

where

$\lambda = rT$ represents the mean number of falls;
T — time interval;
r — frequency of falls;
A — acceptance number;

the values of the numbers of accepted and rejected falls can be further determined.

The number of acceptance A can be obtained from relation (16):

$$A = \lambda + z\sqrt{\lambda} \tag{17}$$

For the limit cases of the two hypotheses H_1 and H_2, the relation changes into (for r_1 and r_2):

$$A_\alpha = \lambda_1 + z_\alpha \sqrt{\lambda_1}, \tag{18}$$

$$A_\beta = \lambda_2 - z_\beta \sqrt{\lambda_2}. \tag{19}$$

But, practically, operating with a single acceptance number A, the two numbers A_α and A_β must be equal, thus:

$$\lambda_1 + z_\alpha \sqrt{\lambda_1} = \lambda_2 - z_\beta \sqrt{\lambda_2}. \tag{20}$$

From these relations, the value of T is also obtained, given by relation

$$T = \left[\frac{z_\alpha \sqrt{r_1} + z_\beta \sqrt{r_2}}{r_2 - r_1}\right]^2 \tag{21}$$

Practically, the risks α and β are chosen equal (there can be no question, as in the case of the control of the lots of products, of the protection of one of the contractors), because in their

majority the consumers are of an industrial nature, consumers who cannot bear a risk smaller than that of the producer, a case in which relation (21), taking relation (10) also into consideration, becomes:

$$T = \frac{1}{r_1}\left[\frac{z_\alpha + z_\alpha \sqrt{v}}{v-1}\right]^2 \tag{22}$$

Setting out from the acceptance and rejection conditions, two straight lines of acceptance and rejection can be obtained by logarithmization for a sequential control of reliability.

However, the aim of our study was to follow the number of falls, a reason why we give up this method now and shall divide the interval T, determined in several subselections, calculating for each of them the number of falls accepted as normal.

Considering as accepted a risk $\alpha = 2.5\%$, a risk equal to β, the value of z_α is established from relation (23) as follows:

$$\alpha = \frac{1}{2} - \Phi(z);\ 0.025 = 0.5 - \Phi(z). \tag{23}$$

$$\Phi(z) = 0.475$$

then tabularily [12], resulting $z_\alpha = 1.96$.

For the frequency of falls, accepted and tolerated, the values $r_1 = 0.0005$ and respectively $r_2 = 0.0013$ are considered.

A value of relation (10) equal to $v = \frac{r_2}{r_1} = 2.6$ results in this case. By using relation (22) a size of the T time interval equal to 20 500 hours is obtained.

$$T = \frac{1}{0.0005}\left[\frac{1.96 + 1.96\sqrt{2.6}}{2.6 - 1.}\right]^2 \simeq 20\,500 \text{ hours.}$$

To obtain subselections of 2050 hours each (the size 2050 is the multiple of 20 500), such a value is chosen for the risks α and β which should give this size of the subselection; thus for $\alpha = \beta = 26.76\%$ the desired size of the subselection is obtained,

$$T = \frac{1}{0.0005}\left[\frac{0.62 + 0.62 \times 1.6124}{1.6.}\right]^2 = 2050 \text{ hours.}$$

Then, z_α is calculated corresponding to each subinterval, giving in relation (22) for T the values: 2050, 4100, 6150, 8200, 10250, 12300, 14350, 16400, 18450, 20500.

For example: for the subselection with the order number 2, which has the size $T_2 = 4\,100$, the risk α_2 and the size z_{α_2} corresponding to it are obtained as follows:

$$4100 = 2000\left[\frac{z_{\alpha_2} + z_{\alpha_2}(1.6124)}{1.6}\right]^2$$

From where $z_{\alpha_2} = 0.87$ results.

Based on those shown at relation (23), the risk corresponding to the subselection no. 2 is obtained: $\alpha_2 = 19.2\%$.

The same is done with the other subintervals, the results being given in columns 2 and 3 of table 2.

Then, with the aid of relation (24), the numbers of accepted falls ,A_i, corresponding to each of these subintervals are calculated. The relation is based on the general formula (17) in which values specific of each subinterval are given (where $\lambda = r \times T$; $r_1 = 0.0005$, $T = 2050, \ldots, 20500$)

$$A_i = \lambda_{1i} + z\alpha_i \sqrt{\lambda_1 i} \tag{24}$$

Thus, for the subinterval nr. 1 ($T_1 = 2050$), the number of acceptance is:

$$A_1 = 0.0005 \times 2050 + 0.62 \sqrt{0.0005 \times 2050} \simeq 2$$

(the question being of a number of accepted falls, thus whole numbers, the values obtained by calculation are rounded).

The result of the calculation of the acceptance numbers for all subselections is given in column 4 of table 2.

Table 2

No.	Subintervals T_i	α_i%	$Z_{\alpha i}$	No. of acceptance A_i
0	1	2	3	4
1	2 050	26.76	0.62	2
2	4 100	19.21	0.87	3
3	6 150	14.45	1.06	5
4	10 250	8.38	1.38	8
5	12 300	6.55	1.51	10
6	14 350	5.05	1.64	12
7	16 400	4.00	1.75	13
8	18 450	3.14	1.86	15
9	20 500	2.50	1.96	17

On the basis of all these data, an efficient control graph can be drawn up, as follows: time divided on the calculated subintervals is registered on the axis of the abscisses and the number of falls is marked on the ordinate, specifying for each subinterval the number of accepted falls.

By drawing a line which indicates the limit number of the accepted falls of each subinterval, a broken line is obtained dividing the graph into two zones: the normal zone to be found under this line and the alert zone-above it. (Fig. 1).

How is this graph operated?

The number of falls registered in the respective period, by an abscissa point equal to the centre of the respective time subinterval and equally ordinated to the number of falls registered in the respective interval, is represented at the end of each time subinterval.

The operation is repeated at the end of each time subinterval, the number of falls being cumulated.

CONTROL GRAPH OF FALLS

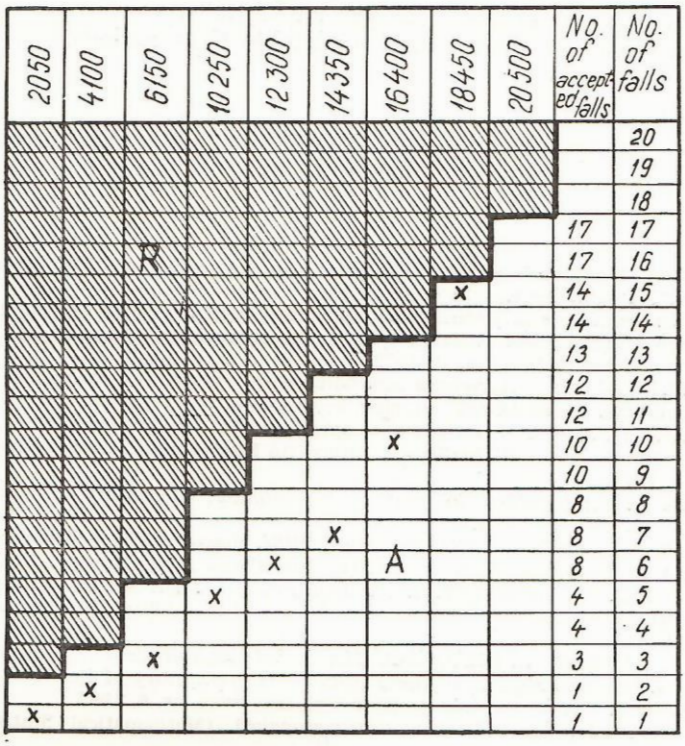


Figure 1

If, at a given moment, the point is found above the demarcation line, in the alert zone, the reliability of the equipment is no longer within the accepted limits, indicating by this the necessity of taking measures for the elimination of the causes which had led to this state.

What are the advantages of this method?

— the evolution in time of the reliability is pursued, revealing the shiftings of the state of the equipment to the alert line, thus towards an unsafety in the future, thus giving the possibility of taking measures for preventing such a situation to be reached;

— a reduced control cost;

— comfortableness and facility in operation;

— it necessitates no calculations during its effective use; the graph once drawn up, its use is extremely simple, no special training of the controller being necessary;

— the recalculations and reconstruction of the graph are made only in the hypothesis of a change in the parameters of the control plan;

— it can be drawn up on pieces and component parts of the installations, thus allowing the emphasizing of the weak points of the system, favouring the concretization of the measures for preventing falls.

— graph can be drawn up for variable time periods.

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UTILISATION DU GRAPHIQUE DE CONTROLE DANS LA POURSUITE DE LA FIABILITE D'UNE CENTRALE ELECTRIQUE

L'auteur présente une méthode opérative pour poursuivre la fiabilité des installations. Cette méthode a les avantages suivants: elle indique l'évolution en temps de la fiabilité, mettant en évidence les déplassements vers une future incertitude du produit; elle assure un coût

réduit du contrôle; la commodité et la facilité de manoeuvre; ne nécessite pas des calculs pendant l'utilisation proprement dite; peut être élaborée par sous-ensembles et parties du système, relevant les points moins fiables.

ПРИМЕНЕНИЕ КОНТРОЛЬНОГО ГРАФИКА ДЛЯ НАБЛЮДЕНИЯ ЗА НАДЕЖНОСТЬЮ РАБОТЫ ЭЛЕКТРОСТАНЦИИ

Автор представляет оперативный метод наблюдения за надежностью работы установок. Этот метод имеет следующие преимущества: показывает эволюцию во времени надежности работы, выявляя изменения, которые в будущем приведут к ненадежности выработки электроэнергии; низкая стоимость контроля; удобное и легкое маневрирование; не требует расчетов в самом процессе применения; может быть применен по узлам и частям системы, выявляя менее надежные точки.