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General Aspects of the Theory of Power Systems Reliability

Rational designing of large power systems, or of supply installations for large users, is linked with the existence of adequate methods to compute numerical indicators constituting objective criteria for comparing the various solutions analyzed.

The problem of the reliability of power systems has nowadays become a major problem of energetics owing to the economic consequencesit implies at the level of national economy as a whole.

In its more general form, reliability can be defined as the probability for no refusal (breakdown) to occur in the time interval under consideration, i.e., that the operating condition assigned to the respective element or system should not fail to be fulfilled. Hence, reliability stands out as a probability function having as variables the time and the possible behaviour of the system. Probability always refers to a certain event which, in the present case, will be called the state of success of the scheme or installation taken into consideration. Therefore, the reliability of an electric connection or of an installation is the probability of its state of success.

The estimation of reliability will be made on basis of numerical indicators of a probabilistic nature, expressing various aspects of reliability in operation for an electric installation.

Thus:

— the best suited criterion of comparison for the various types of connection from the standpoint of their economic efficiency — because it concomitantly allows a financial estimation to be made, of the losses resulting from the adoption of each of the technical solutions — is the mean breakdown duration within a time interval $(0, t)$;

— the best criterion for comparing the various types of schemes from the standpoints of their reliability in operation is the mean operating time within a time interval $(0, t)$;

— in some cases it is sufficient to know the probability of the state of success at a certain moment (t);

— for the rational planning of reserve equipment or in view of establishing planned overhauls (that are carried out after a certain number of breakdowns) it is necessary to know the mean number of breakdowns within an interval $(0, t)$;

— in view of studying the operation of an electric installation within a given time interval, the probability of the continuous operation of this installation in the interval $(t, t + x)$ will be considered.

1. METHOD OF INVESTIGATION

A power scheme is made up of components set according to a certain pattern favouring the production or conveyance of electric power from source to user. The various possible combinations of faulty and operating components define the states through which the system can vary with the time. Some of these states occasion a total or partial break of the power flow, while others don't. The first define the state of refusal and the others the state of success of the scheme.

The adequate mathematical model to describe the operation in time of electric complexes is constituted by the Markov type stochastic process.

In the course of time the complex passes from one state to another as some of its components break down (are out of operation) while others are repaired (come into operation). Thus, the breakdown and the repair of the various components are events which show the evolution of the system from one state to another.

Example 1 — The following states are characteristic of the continuous operation shown in the scheme in Fig. 1 with a power of at least P MW:

state 0 — operation of the power unit at the integral power of 2 P MW;
state 1 — operation of the power unit with a single boiler (hence with the power P MW);
state 2 — accidental shut down.

Example 2 — The following states are characteristic of the operation shown in the scheme in Fig. 2:

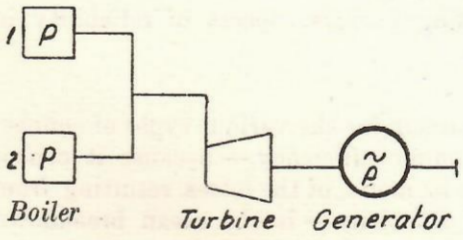

Fig. 1

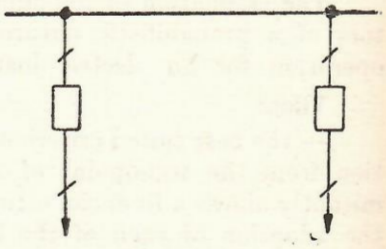

Fig. 2

state 0 — all the elements of the scheme (both cells) are in operation;
state 1 — breakdown of one line insulator (only one cell in operation);
state 2 — breakdown of a switch (only one cell in operation);
state 3 — breakdown of a bar insulator (both cells are out of operation);
state 4 — breakdown in the bar system (both cells are out of operation);
state 5 — breakdown of a switch at a line insulator (both cells are out of operation);
state 6 — breakdown of a line insulator and a bar insulator, belonging to different cells (both cells are out of operation);
state 7 — breakdown of a line insulator and of the bar system (both cells are out of operation);
state 8 — breakdown of two switches belonging to different cells (both cells are out of operation);
state 9 — breakdown of a switch and a bar insulator, belonging to different cells (both cells are out of operation);
state 10— breakdown of a switch and of the bar system (both cells are out of operation).

The breakdown or repair of the circuit elements leads to the transition of the system from one state into another. For instance:

— the breakdown of a switch following the previous breakdown of a line insulator marks the passing from *state* 1 to *state* 5;

— the repair of the faulty line insulator marks the passing from *state* 1 to *state* zero.

In normal operating conditions the interruption, or reinstatement in operation, of a circuit element are considered as events not dependent on the moments when they occur, but only on the duration of the interval in which they occur. We are thus led to stationary Markov chains.

Between the stochastic vector $P(t)$ of the process absolute probabilities and the stochastic matrix $[p_{ij}(\Delta t)]$ of the process transition probabilities, the following differential equation subsists:

$$P'(t) = P(t) \parallel p'_{ij}(0) \parallel \tag{1.1}$$

which univoquely defines the stochastic vector $P(t)$, if the initial state of the system, concretized in the stochastic vector $P(0)$, is known.

The breakdown of an element in a circuit whatever is an event whose probability of occurrence within an elementary time interval Δt is:

$$\lambda \Delta t$$

where the parameter λ is called breakdown intensity.

Likewise, the repair of an element in a circuit whatever is an event whose probability of occurrence within an elementary time interval Δt, is:

$$\mu \Delta t,$$

where the parameter μ is called repair intensity.

In the case of a single element the corresponding Markov chain has only two states:

state 0 — operating state of the element;
state 1 — breakdown state of the element.

The transition probabilities will have the following expressions:

$$p_{01}(\Delta t) = \lambda \Delta t, \quad p_{00}(\Delta t) = 1 - \lambda \Delta t$$

$$p_{10}(\Delta t) = \mu \Delta t, \quad p_{11}(\Delta t) = 1 - \mu \Delta t$$

Equation (1), in this case, becomes explicit as follows:

$$P_0'(t) = -\lambda P_0(t) + \mu P_1(t); \quad P_0(0) = 1$$

$$P_1'(t) = \lambda P_0(t) - \mu P_1(t); \quad P_1(0) = 0$$

There results:

$$P_0(t) = \frac{\mu + \lambda e^{-(\lambda+\mu)t}}{\lambda + \mu}$$

$$P_1(t) = \frac{\lambda}{\lambda + \mu}[1 - e^{-(\lambda+\mu)t}]$$

When only the evolution of the process from *state* 0 to *state* 1 is taken into account, the matrix of the transition probabilities will be

$$p_{01}(\Delta t) = \lambda \Delta t, \quad p_{00}(\Delta t) = 1 - \lambda \Delta t$$

$$p_{10}(\Delta t) = 0, \quad p_{11}(\Delta t) = 1$$

and it leads to the following system of equations:

$$P_0'(t) = -\lambda P_0(t); \quad P_0(0) = 1$$

$$P_1'(t) = \lambda P_0(t); \quad P_1(0) = 0$$

which defines the distribution function of the operating periods $P\{T_f\}$ of the respective element. Indeed:

$$P\{T_f > t\} = P_0(t) = e^{-\lambda t}$$

Analogously, if only the evolution of the process from *state* 1 to *state* 0 is taken into account, the distribution function of the breakdown periods $P\{T_b\}$ will be obtained for the respective element.

The matrix of the transition probabilities is written:

$$p_{01}(\Delta t) = 0, \quad p_{00}(\Delta t) = 1$$

$$p_{10}(\Delta t) = \mu \Delta t, \quad p_{11}(\Delta t) = 1 - \mu \Delta t)$$

and leads to the following system of equations:

$$P_0'(t) = \mu P_1(t); \quad P_0(0) = 0$$

$$P_1'(t) = -\mu P_1(t); \quad P_1(0) = 0$$

from which:

$$P\{T_b > t\} = P_1(t) = e^{-\mu t}$$

This method is general and can be applied to any connection made up of heterogeneous elements. The general operation of this connection is variously conditioned by the nature, position and mode of operation of each element within the whole. However, its application may give rise to important difficulties with regard to the computation. In order to better realize this, it is sufficient to point to the fact that a system composed of N elements, each of which may independently evoluate in two states, presents, in time, a sequence of 2^N possible distinct states. Hence, in the general case, the accuracy of the method is faced with the integration of a system of 2^N differential equations. Nevertheless, in the case of thermal or electric schemes in power plants and stations these computation difficulties do not constitute an obstacle to the application of the method. The integration of differential equations (1.1) is easily achieved by means of analog or digital electronic computers.

2. INFORMATION REQUIRED BY METHOD

The study of electric connection reliability by the investigation method previously shown is based on the knowledge of the distribution functions

$$F(t) \equiv P\{T_f \leqslant t\} = 1 - e^{-\lambda t}$$

$$G(t) \equiv P\{T_b \leqslant t\} = 1 - e^{-\mu t}$$

of the operating and breakdown periods of each circuit element.

The evaluation of the parameters λ and μ which define the respective distributions is made on basis of statistical data in agreement with the evaluation theory. Thus, the method of maximum likeliness leads us to the conclusion that the most likely values of $\frac{1}{\lambda}$ and $\frac{1}{\mu}$ are, respectively, equal to the selection means:

$$\overline{T}_f = \frac{1}{n} \sum_{i=1}^{n} T_f^i$$

$$\overline{T}_b = \frac{1}{n} \sum_{i=1}^{n} T_b^i$$

$\{T_f^i\}$ and $\{T_b^i\}$ represent an alternating set of operating and breakdown periods, corresponding to the respective element.

Likewise, there results that $\overline{T}_f$ and $\overline{T}_b$ constitute, respectively, absolutely correct evaluations of the parameters $\frac{1}{\lambda}$ and $\frac{1}{\mu}$.

In conclusion, the information required to apply this method of investigation is provided by the historiograms of the various elements (switch, separator, bar, tanks, turbines, generator, etc.) which make up the analyzed circuits.

3. NUMERICAL INDICATORS OF RELIABILITY

Hereafter, the numerical indicators taken into consideration will be presented, with examples of computations regarding various simple power diagrams.

3.1. *Mean duration of states of success.*

Electric connecting diagram with a single system of bus bars and a transfer bar (Fig. 3)

We associate a Markov chain with the following states, to the phenomenon:

state 0 — all cells operate, without the instrumentality of the transfer coupling cell;

state 1 — all cells operate through the instrumentality of the transfer coupling, owing to the breakdown on a switch;

state 2 — $(n-1)$ cells operate;

state 3 — no cell operates;

(the transfer coupling cell and transfer bar, being emergency elements, are considered as certainly operating).

Success state: 0 $\cup$ 1

$$p_{01}(\Delta 1) = n\lambda_i \Delta t, \quad p_{02}(\Delta t) = n\lambda_s \Delta t$$

$$p_{03}(\Delta t) = (\lambda_b + n\lambda_s)\,\Delta t, \quad p_{00}(\Delta t) = 1 - \lambda_0 \Delta t$$

$$\lambda_0 = \lambda_b + n(\lambda_i + 2\lambda_s)$$

$$p_{10}(\Delta t) = \mu_i \Delta t, \quad p_{12}(\Delta t) = (n-1)\,(\lambda_i + \lambda_s)\,\Delta t, \quad p_{13}(\Delta t) =$$

$$= [\lambda_b + (n-1)\,\lambda_s]\,\Delta t, \quad p_{11}(\Delta t) = 1 - \lambda_1 \Delta t$$

$$\lambda_1 = \lambda_b + \mu_i + (n-1)\,(\lambda_i + 2\lambda_s)$$

$$p_{20}(\Delta t) = 0, \quad p_{21}(\Delta t) = 0, \quad p_{23}(\Delta t) = 0, \quad p_{22}(\Delta t) = 1$$

$$p_{30}(\Delta t) = 0, \quad p_{31}(\Delta t) = 0, \quad p_{32}(\Delta t) = 0, \quad p_{33}(\Delta t) = 1$$

$$P_0'(t) = -\lambda_0 P_0(t) + \mu_i P_1(t); \quad P_0(0) = 1$$

$$P_1'(t) = n\lambda_i P_0(t) - \lambda_1 P_1(t); \quad P_1(0) = 0$$

$$P_2'(t) = n\lambda_s P_0(t) + (n+1)\,(\lambda_i + \lambda_s)\,P_1(t); \quad P_2(0) = 0$$

$$P_3'(t) = (\lambda_b + n\lambda_s)\,P_0(t) + [\lambda_b + (n-1)\,\lambda_s]\,P_1(t); \quad P_3(0) = 0$$

$$M(T_f) = \int_{\infty}^{0} [P_0(t) + P_1(t)]\, dt = \frac{\lambda_1 + n\lambda_i}{\lambda_0\lambda_1 - n\lambda_i\mu_i}$$

3.2. *Mean duration of refuse states*
Generator-turbine unit (Fig. 4)

The following Markov chain is associated to the phenomenon:
state 0 — power unit operation;
state 1 — boiler breakdown;
state 2 — turbine breakdown;
state 3 — generator breakdown.

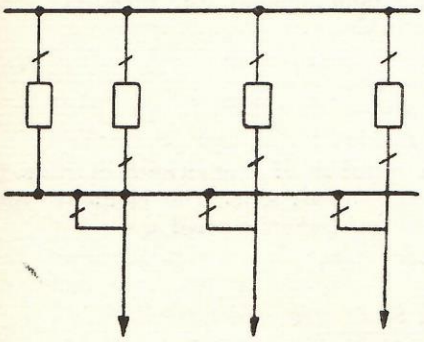

Fig. 3

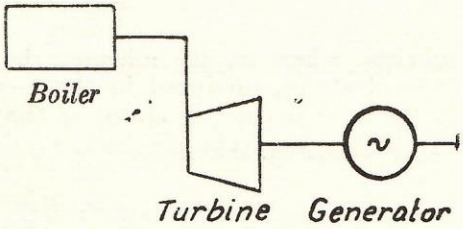

Fig. 4

Refuse state: $1 \cup 2 \cup 3$

$$p_{01}(\Delta t) = 0, \quad p_{02}(\Delta t) = 0, \quad p_{03}(\Delta t) = 0, \quad p_{00}(\Delta t) = 1$$

$$p_{10}(\Delta t) = \mu_b \Delta t, \quad p_{12}(\Delta t) = 0, \quad p_{13}(\Delta t) = 0, \quad p_{11}(\Delta t) = 1 - \mu_b \Delta t$$

$$p_{20}(\Delta t) = \mu_t \Delta t, \quad p_{21}(\Delta t) = 0, \quad p_{23}(\Delta t) = 0, \quad p_{22}(\Delta t) = 1 - \mu_t \Delta t$$

$$p_{30}(\Delta t) = \mu_g \Delta t, \quad p_{31}(\Delta t) = 0, \quad p_{32}(\Delta t) = 0, \quad p_{33}(\Delta t) = 1 - \mu_g \Delta t$$

$$P_0'(t) = \mu_b P_1(t) - \mu_t P_2(t) + \mu_g P_3(t); \quad P_0(0) = 0$$

$$P_1'(t) = -\mu_b P_1(t); \quad P_1(0) = \frac{\lambda_b}{\lambda}$$

$$P_2'(t) = -\mu_t P_2(t); \quad P_2(0) = \frac{\lambda_t}{\lambda}$$

$$P_3'(t) = -\mu_g P_3(t); \quad P_3(0) = \frac{\lambda_g}{\lambda}$$

$$\lambda = \lambda_c + \lambda_t + \lambda_g$$

$$M(T_d) = \int_0^\infty [P_1(t) + P_2(t) + P_3(t)] \, dt = \frac{\lambda_b}{\lambda} \frac{1}{\mu_b} + \frac{\lambda_t}{\lambda} \frac{1}{\mu_t} + \frac{\lambda_g}{\lambda} \frac{1}{\mu_g}$$

3.3. *Probability of a success state at a moment* t, *whatever*

3.4. *Probability of a refusal state at a moment* t, *whatever*

Examples of the computation of these indicators, referring to the operation of a single element, have been given previously.

3.5. *Mean number of refusals in a time interval* $(0, t)$.

Again referring to the simple case of a single element, the formula

$$\varphi_{01}(t) = \frac{\lambda^2}{(\lambda+\mu)^2} + \frac{\lambda\mu}{\lambda+\mu}\,t - \frac{\lambda^2\, e^{-(\lambda+\mu)t}}{(\lambda+\mu)^2}$$

subsists, where $\varphi_{01}(t)$ indicates the mean number of transitions in *state* 1 (refusal state), produced in the interval considered, since the element was in the *state* 0 (success state) at the beginning of the interval.

It is shown that:

$$\lim_{t\to\infty} \frac{\varphi_{01}(t)}{t} = \frac{1}{M(T_f) + M(T_d)}$$

3.6. *Mean duration of success in a time interval* $(0, t)$.

3.7. *Mean duration of refusal in a time interval* $(0, t)$.

Summing up
$\alpha(t)$ — total duration of success states in the interval $(0, t)$;
$\beta(t)$ — total duration of refusal states in the interval $(0, t)$.
The following formulae subsist:

$$M[\alpha(t)] = \int_0^t P_0(\tau)\, b\tau$$

$$M[\beta(t)] = \int_0^t P_1(\tau)\, b\tau$$

where:

$P_0(\tau)$ — probability of success state at moment $\tau \in (0, t)$;
$P_1(\tau)$ — probability of refusal state at moment $\tau \in (0. t)$.
It is shown that:

$$\lim_{t\to\infty} \frac{M[\alpha(t)]}{t} = \frac{M(T_f)}{M(T_f) + M(T_b)}$$

$$\lim_{t\to\infty} \frac{M[\beta(t)]}{t} = \frac{M(T_b)}{M(T_f) + M(T_b)}$$

3.8. *Probability of success state within one interval* $(t, t + x)$. (Reliability in a time interval whatever).

3.9. *Probability of refusal state within one interval* $(t, t + x)$. (Service reliability).

Referring to the simple case of a single element the formulae

$$S(x; t) = P_0(t)\, e^{-\lambda x}$$

$$R(x; t) = P_1(t)\, e^{-\mu x}$$

subsist, where:

$P_0(t)$ — probability of success state at moment t

$P_1(t)$ — probability of refusal state at moment t.

We notice that $1 - R(x; t)$ represents the probability of the following event:

— either the complex is in operation at moment t;

— or, if it is not in operation, it will again start operating by a certain moment previous to $t + x$.

The indicator $1 - R(x; t)$ is called, in practice, service reliability.

Indeed, it is sufficient to choose x so that the duration of the refusal be acceptable and the indicator considered will express the probability for the installation to operate at any moment t in acceptable conditions.

4. DETERMINATION OF DAMAGE PRODUCED TO USERS CONSEQUENTLY TO BREAKDOWNS AND TO DEVIATIONS FROM THE QUALITY CONDITIONS

The damage caused to national economy by the breakdown of electric power supply is of an aleatory character and can be determined as probabilistic magnitude:

$$P(\mathrm{D}) = K \times T_i \times D_\Sigma$$

where $P(D)$ — probable damages expressed in lei;
T_i — duration of breakdown, in hours;
$D\Sigma$ — damages for one hour;
K — coefficient, which takes into consideration the increase in breakdown duration in view of re-establishing the normal production process

$$K = \frac{T_{\text{teh}}}{T_s}$$

where T_{teh} — is the production stopping time;
T_s — is the breakdown duration of electric power supply.

The sizes of damages for one hour can be broken up in two component parts:

$$D_\Sigma = D_{\text{dir}} + D_{\text{ind}}$$

where D_{dir} — direct damages proceeding from breakdowns and faults of technologic equipment, depreciation of raw material, payment of wages, redeeming expenses, ratio of expenses that are independent of equipment operation (taxes, rates, overhead expenses, etc.);

D_{ind} — indirect damages suffered by national economy consequently to failure in fulfilling the plan production.

The elements mentioned, which make up the total damages resulting from the interruption of electric power supply, are again found in a certain form in the expression for computing the cost price, respectively the delivery price (which adds to the cost price the profit of the enterprise and the circulation tax).

In the specialty literature there are disputed standpoints regarding the determination of damages to be included in the economic computation. In the Romanian literature, indirect damages are also included, whereas foreign authors do not recommend such an inclusion.

The automatic inclusion of indirect damages results in the increase of reserves, respectively in important supplementary unreasonable investments. Supporters of the second standpoint base their argumentation mainly on the idea of the recovery of unsupplied production by a more rhythmic organization of production. Although this thesis is valid for the enterprises where manufacture is based on the supply of semi-manufactured raw material, etc., where negative deviations from normal rhythmicity frequently occur, it is not adequate for the extracting industries (crude oil, coal, etc.), for the continuous flow processing industries (refineries, enrichment plants, sorting plants, etc.) or for the chemical industries using methane gas, or air as raw material, etc., which does not lead to fluctuations in production.

When indirect damages are taken into consideration, one must likewise take into account the requirements of national economy for the respective products (whether they are scarce or in excess.)

To effect the economic computations for determining the degree of reliability it is advisable to compute the specific damages:

$$d = \frac{D}{\Delta E} \text{ (lei/kWh)}$$

$$\Delta E = P \times K_f \times T_{teh}$$

where:

D — damages for the entire period of power breakdown and of production process restoring;

ΔE — undelivered power in kWh;

K_f — shape coefficient of load curve.

It is shown in the specialty literature that the value of specific damages may reach values equal to 10—20 times the selling price of electric power, increases of about 100 times being even reached in some special industries.

Electric power quality is determined by the deviations to which frequency and voltage are subjected during operation at the consumption points $D_{cal} = f(\Delta U, \Delta f)$. The operation of electric equipment and motors at the technic-

al-economical specifications for which they were designed is possible in conditions where voltage and frequency are maintained practically constant, or suffer deviations within acceptable limits.

Voltage decrease accross receiving apparatuses has as a consequence a decrease in the power of the unit in case of asynchronous motor operation, or a decrease in the light of electric lamps. Various researchers have studied the economic consequences, respectively the damages suffered by national economy when the quality conditions of electric power are not observed.

The problem of mains operation at voltage values within limits that are rational from the economic standpoint cannot be solved by classical methods but requires the application of statistical and probabilistic methods. This is the only manner in which it is possible to appreciate the probability of apperance and the duration of voltage deviations, as well as their economic consequences on the users. The maintenance of a constant frequency, respectively, the determination of the active power that must be available to the system, becomes possible by resorting to the statistic processing of the frequency variations of the energetic system and by determining, on this basis, the reserve of active power in the system. Studies achieved in a series of specialized organizations abroad have led to the financial expression of deviations from the quality conditions (Ailleret's criterion).

A knowledge of the damages caused by quality deviations is very important in the supply of economic argumentation in view of mounting additional installations, either as active and reactive power sources, or as adjusting installations.

5. ECONOMIC COMPUTATION TO SUPPLY A BASIS FOR THE REQUESTED DEGREE OF RELIABILITY

The economic computation of the consequences resulting from the non-observance of some ascertainment, respectively of a certain degree of reliability on the one hand, as well as the determination of the measures required to maintain, during the planned time, the necessary degree of reliability on the other hand, make up stages of computation and research aspects of this problem.

Various points of view are found in the specialty literature regarding the definition of reliability in a power system. Thus, in England, a standard is in force, defining the reliability R as

$$R = \frac{E_{TR} - E_b}{E_{TR}}$$

where

E_{TR} — total required power
E_b — undelivered power, due to breakdowns;

In 1965, in England, a reliability of 99.98% was achieved, tending towards 99.99%.

In the U.S.A. the exploiting organization Edison-Detroit has elaborated a design fixing the durations and frequencies of breakdowns as follows:

Standard design regarding reliability in operation elaborated by the Edison-Detroit Company

Category	Mean breakdowns per user and per year				
	Instantaneous *	Short duration *		Long duration *	
		No.	mean	No.	mean
0	1	2	3	4	5
Rural centres	10	10	10	1.3	100
Isolated urban communities in a predominantly rural region	10	3	3	0.4	40
Suburban centres	8	1	2	0.4	40
Urban centres	8	0.5	1	0.2	20
Cities	5	0.3	0.5	0.1	8

* Instantaneous breakdowns = 0— 1/4 min.
* Short breakdowns 1/4—5 min.
* Long breakdowns 5 or more minutes

In a series of works published in Romania the determination of reliability is achieved by comparing the damages caused by breakdowns, expressed in monetary form, with the investments required for the additional reliability increase.

The practice of power system exploitation has shown that the consequences of breakdowns vary from user to user. This has led to the necessity of grouping the consumers into groups or categories, in agreement with their importance. According to the present grouping, category I includes users that cannot afford breakdowns in electric power supply such as: the post office, telephone system, radio and television broadcasting systems, particularly important state institutions, technological processes whose interruption endangers men's lives. At least two independent sources must be provided for this category of users. If the system constitutes one source, the second source should be independent of the first (storage batteries, Diesel units, gas turbines, etc.). Category II includes users for which an interruption leads to the ruining of equipment, degradation of raw material, disorganization of the production process, etc., requiring a lengthy time to restore production. Category III includes the users for which the interruption of electric power supply only leads to decreased production. Since the users in categories II and III can afford interruptions in electric power supply, the degree of reliability should, for them, be determined on basis of technical economic computations.

With respect to reliability in operation of power systems, the tendency is to achieve a 99.99% degree of reliability, the size of the reserve in the system being computed on this basis.

When determining the supply schemes of the system users, studies are required, taking into account the actual peculiarities of the technological process. The use of the computation stages mentioned above, together with detailed knowledge of the actual technological conditions and of the implications arising from the interruption of electric power supply, or from quality deviations, should lead us to determine the computation expenses of the supply variants:

$$Z = pI + E_E + \Delta Z_b + \Delta Z_{qd};$$

where

Z = yearly computation expenses
p = standard coefficient, equal to 0.1 for $T = 10$ years
I = investments
E_E = yearly exploitation expenses
ΔZ_b = expenses caused by interruptions (breakdowns) in electric power supply
ΔZ_{qd} = expenses caused by quality deviations (frequency and voltage).

The choice of ths optimum variant of power supply should, however, be compared, as indicated by former experience, with the additional yearly expenses imposed by measures taken at the consumers' in the technological process itself:

$$Z_{\text{techn. } R} = pI_{\text{techn. } R} + E_{E\,\text{techn. } R}$$

where

$Z_{\text{techn. } R}$ = computation expenses determined by additional measures in the technological process, to increase reliability;

$pI_{\text{techn. } R}$ = required investments in the technological process, to increase reliability;

$E_{E\,\text{techn. } R}$ = additional exploitation expenses for increased reliability.

The additional expenses required by an increased degree of reliability in electric power supply should also stand out in the selling price of electric power to the respective users. The present situation stimulates the waste of funds invested in generous but not always economically justified supply schemes.

In the specialty literature the determining of the degree of reliability in the users' supply with thermal and electric power is called "the optimum compromise for the user" between power cost and frequency of interruptions. In many countries the degree of reliability is correlated with the selling price of electric power.

6. DETERMINING THE MEASURES TO BE TAKEN DURING EXPLOITATION IN VIEW OF MAINTAINING THE DESIGNED DEGREE OF RELIABILITY

The maintenance of the computed degree of reliability requires some measures to be taken regarding current breakdown prevention and repairs to be carried out in view of maintaining the economical and technical per-

formance of the equipment and units at values as close as possibile to their initial values (period of maturity). Historiograms of the operation of various equipment and units point to a great number of breakdowns in the first stage, determined by deficiencies in manufacture and exploitation, after which there follows a period with a minimum number of breakdowns. The processes of insulation aging and fatigue of the materials lead to a noticeable increase in the number of breakdowns during the last stage of operation of the equipment and apparatuses.

6.1. *Repairs*

The scientific organization of repair activity has become imperative at the present stage consequently to the large volume of work and to the demands regarding the quality of repairs effected.

Even in prospective studies for important units in the power system, the reservation for repairs which must ensure the periodic interruption in the operation of these units, for repairs, is taken into consideration.

In very many countries the policy of carrying out repairs centrally, is used, this ensuring high productivity, short repair delays and superior quality. The planning of repair achievement at the power system level, given the very large number of units, can be carried out satisfactorily by solving this problem on the basis of mathematical models. In some studies elaborated at the I.S.P.E. (Institute of Power Study and Design) mathematical models have been suggested and tested, allowing to determine, on basis of the technical and economic data of the units, the moments when the units should go into repair.

The actual carrying out of repairs calls for an important volume of work under conditions of high quality. However, in view of reaching this objective, adequate organizing is required, both for the repairs proper and for the preparing work. This can be achieved by utilizing the "critical path" method. The application of this method in carrying out repairs can objectively ensure both the fulfilment of the planned terms and superior quality of the repairs proper.

6.2. *Measures in view of preventing breakdowns*

The different operating conditions and the stresses to which the installations composing the power system are subjected require a systematic organization during their operation by taking some measures of a preventive character. Cases are known where the insulation was polluted, as well as the action of chemical agents on conductors, etc., all these factors being able to noticeably modify the degree of reliability of the respective installations.

It is therefore necessary to draw up a programme of measures of a preventive character to be taken during exploitation, in keeping with the operating conditions and the manufacturing features of the equipment. In some fields these measures are established taking into account both the outer conditions in which the respective element operates and the aging curves of the equipment as a whole, or of some component parts of the respective apparatus (lamps in the regulators of automatizing installations in power stations).

6.3. *Replacement of elements and apparatuses which have exceeded a certain degree of wear.*

To maintain in operation equipment and apparatuses having reached a certain degree of wear, besides decreasing the reliability of the system in which it operates, also requires important maintenance expenses. The opportunity of replacing equipment or an apparatus that is very worn and provides decreased reliability in operation results from the comparison of the volume of new investments and the associated exploitation expenses, including the expenses connected with the degree of reliability, with the exploitation expenses of such an equipment or apparatus.

There results from the above that the theory of reliability of power systems enjoys a unitary feature, characterized by: mathematical investigation methods, economic methods, a special terminology and a specific flow of information.

The analysis made shows that, in the technical economic computations carried out in view of comparing the variants, the economic consequences of the degree of reliability should be reflected for each variant in part.

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ASPECTS GENERAUX DE LA THEORIE DE LA FIABILITE DES SYSTEMES ENERGETIQUES

L'établissement judicieux du projet des grands réseaux énergétiques ou des installations d'alimentation des grands consommateurs, est relié à l'existence de méthodes adéquates pour le calcul d'indicateurs numériques qui puissent constituer des critères objectifs de comparaison entre les différentes solutions analysées.

L'interruption du fonctionnement ou la déviation des paramètres nominaux ont des conséquences économiques menant à la hausse des prix de revient, autant pour l'énergie que pour les produits des branches industrielles consommatrices, à des dommages dans les secteurs industriels respectifs (destruction ou dégradation des outillages).

Les méthodologies techniques et économiques actuelles de comparaison des différentes variantes omettent de refléter également le degré de sûreté. On montre dans cet article l'interdépendance existant entre l'économie des solutions et le degré de fiabilité dans l'alimentation en énergie électrique et thermique. On apprécie également que le choix de la variante la plus rationnelle au point de vue économique et de la fiabilité doit être effectué sur la base d'un processus d'optimisation comprenant un nombre de solutions aussi complet que possible.

ОБЩИЕ ЗАМЕЧАНИЯ ПО ТЕОРИИ НАДЕЖНОСТИ ЭНЕРГЕТИЧЕСКИХ СИСТЕМ

Правильное проектирование крупных энергетических систем или питательных установок крупных потребителей связано с наличием адекватных методов расчета некоторых числовых показателей, представляющих объективные критерии сравнения различных анализируемых решений.

Перерыв в функционировании или отклонения от заданных параметров ведут к экономическим последствиям, которые повышают себестоимость как электроэнергии, так и изделий отраслей промышленности, потребляющих электроэнергию, ведут к потерям в соответствующем промышленном секторе (уничтожение или износ оборудования).

Современные технико-экономические методологии сравнения различных вариантов не отражают и степень надежности. В работе показана взаимозависимость, существующая между экономичностью решений и степенью надежности в питании электрической и тепловой энергией. Также, подчеркивается, что выбор наиболее рационального варианта с экономической точки зрения и с точки зрения надежности функционирования должен быть сделан на основе процесса оптимизации наибольшего числа решений.