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CRITERION OF FUNCTION QUALITY ESTIMATION OF DISTRIBUTION NETWORKS

In the article the analysis of properties to be considered in criterion of function quality of distribution networks is carried out. The method of its determination which is based on integration of Markov processes theory and criterial method is offered.

Keywords: *quality of functioning, distribution networks, reliability, efficiency, safety.*

Introduction

Stable, qualitative electric energy supply of customers and industry is a determining condition of economic development of the country. Today technical and economic problems of electrical power industry consist in progressive process of equipment aging. The condition of electrical power engineering after long period of insufficient investment is characterized by serious wear of both generating and network equipment. So, as a result of distribution networks maintenance for last 15 years when development, restoration and modernization have lagged behind process of physical aging and the factor of defectiveness of distributive electric systems of Ukraine has reached 13 %, rather reliable supply by electric energy can become unreliable and inadequate concerning quality of electric energy [1].

Because of resources limitation of electro-supplying companies the problem of rational distribution of financial resources for the purpose of choice of priority sites of reconstruction and equipment modernization. Decision-making concerning measures being financed should be based on data about quality of electrical network functioning. That is, estimation of measures, carried out, in other words how the functioning of distribution networks has improved.

The analysis of distribution networks characteristics for solution of the problem aimed at determination of evaluation criterion of functioning quality is **purpose of this article**.

Characteristic of the object of research

The electrical network represents a complex of electric equipment and devices intended for transmission and distribution of electricity. Modern electrical networks by their structure, maintenance organization and management principles belong to technical complexes (systems). At decision-making concerning the control of such system, the estimation of its functional readiness or quality of functioning are important.

Distribution network is a "difficult" object which consists of various elements - transformer substations, cable and overhead transmission lines etc. Quality of functioning of such "difficult" object depends on reliability of each element of the network and structural connections between them.

Quality of functioning of complex system is the set of properties which determine the ability of the system to perform tasks put forward at its manufacturing [2, 3]. The primary goal of distribution network is providing reliable supply with qualitative electric energy of consumers connected to it.

Certain functional excess in the structure of distribution networks leads to occurrence of separate elements failures or minor alteration of some operational parameters and this, in its turn, can result not in complete failure of energy-supply system but only to certain degradation of functioning quality and decreasing of its efficiency as a whole. Therefore for estimation of functioning quality of distributing system, introduction of the quantity index which would consider the influence of such failures is expedient.

It is obvious, that the choice of corresponding index of functioning quality in each concrete case is determined by system type, its designation, kind of carried out problem, character of different external factors [4]. For distribution network the quality index should consider reliability of consumers' electro-supply with the energy of corresponding quality. Another important property is profitability, which is characterized by indices of using resources, put in electrical network [3].

Recently the property of system safety becomes more and more important. In the problem of safety of complicated technical complexes two directions are to be allocated. The first of them belong to their normal operation. Inevitable technogenic influences on man and environment. The second direction is connected with technological infringements, that is, industrial safety. Industrial safety of technical object means its ability to provide protection of person, environment and property against dangerous influences occurring during failures and incidents on this object [3].

During research of industrial safety, cause-effect relations of failures occurrence and other infringements with their consequences (social, ecological, economic) are determined. Risks of consequences of failures and incidents which show a safety measure of consequences from infringements for some period of time are indices of industrial safety.

Reliability assessment, efficiency and safety gives rather complete idea of system functioning quality in normal conditions (Fig. 1).

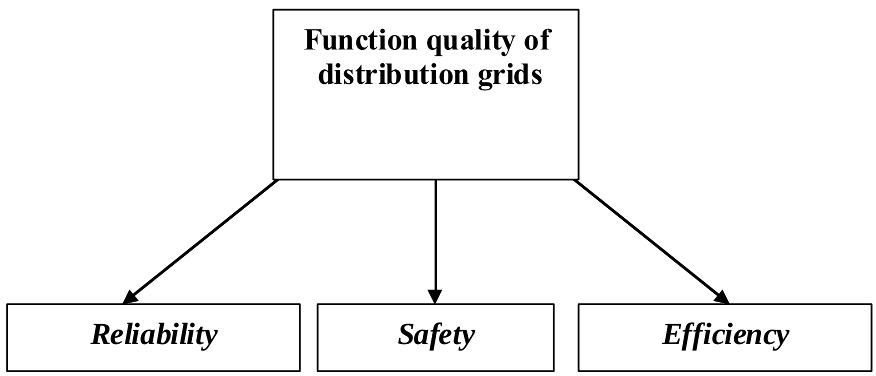

Fig. 1. Properties, determining for quality of distribution network functioning

Concentrating the attention, for example, only on efficiency indices does not guarantee keeping of admissible levels of social and ecological safety or performance of treaty obligations regarding the reliability of consumers energy supply. In its turn, the reliable electrical network regarding performance of necessary functions cannot be economic and meet the requirements of safety.

Quality index of complex system functioning

In due course the complex system passes from state to state by change of elements state, it consists of, (failures of elements, their renewal, different external influences etc). Each concrete state of the system can be characterized by certain conventional quality index of functioning. This index characterizes the result of performance of functions by system which is in this very state.

If we denote via p_i probability of the fact that the system at the moment of time t is in i^{th} state, and via Φ_i - factor of this state (conventional index of system functioning in i^{th} state) then the index of system functioning quality can be determined by the formula [4]

$$E(t) = \sum_{i=1}^{m} p_i(t)\Phi_i \tag{1}$$

where addition is carried out by all states of the system.

Determination of effectiveness factor of concrete states of system is the most labour-intensive and essentially complicated problem during the estimation of systems efficiency. The basic methods of obtaining necessary factors are [4]:

1. Analytical method. In certain cases factors can be determined analytically. For example, the factor can be explicit function of quantity of working elements of some type. Certain complexities appear with determination of factors for the trajectory. However relatively simple expressions are sometimes possible here.

2. Modeling method. For determination of factors method of physical and mathematical modeling of states and trajectories can be used. This method can have independent meaning during research of principles of systems functioning, and also be used for specification and correction of quality factors obtained approximately analytical method.

For determination of quality factors (especially for classes of trajectories) and method of statistical modeling can be used.

3. Method of direct experiment with use research sample. This method, actually, shows physical modeling on real object. States and system trajectories are simulated by switching off certain elements at corresponding moments of time. This method is usually used for system quality control.

The state effectiveness factor can have any physical content, for example, conditional probability, absolute or relative error, loss, power etc.

Use non normalized effectiveness factor allows to compare by average value of output effect even different systems.

Functioning quality index of distribution network

During the estimation of functioning quality of distribution network, all approaches stated above, can be used as for complex system.

For the description of process of distribution network functioning, the theory of Markov processes can be used. The basic assumption, exercised at modeling, is an exponential law of distribution of occurrence of incidents connected with failures and restorations of elements of electro-supply system. Available data [5, 6] prove more complex character of time distribution law of failures occurrence and restorations time, than exponential, however using exponential distribution during calculation of probability of non-failure operation of these elements can be considered as standard. It can be explained by the following:

- while there is no generally accepted approach regarding valid law of time distribution of failures and restorations;

- application of exponential distribution law of time between two failures leads to error towards certain decrease of estimated probability of non-failure operation compared with actual, that is, it cannot be the cause of unreliable system creation;

- there are works, for example [7] in which systems having elements, time of failures and restorations of which is a combination exponential, weibull and normal-logarithmic distribution are considered, and it was shown, that at long enough time interval these systems behave as if all their elements would have exponential distribution of time of failures and restorations.

Functioning process can be represented in the form of the graph (fig. 2) with the help of which Kolmogorov system of differential equations can be created [8]. Taking into consideration the assumption about not taking into account the dynamic of transients between separate states ($\frac{dp_i}{dt}=0$), the system of differential equations will have the form:

$$\left.\begin{aligned} &\sum_{i=1}^{m} \nu_{ji} p_i = 0, \quad j=\overline{2,n} \\ &\sum_{i=1}^{m} p_i = 1, \end{aligned}\right\}, \tag{2}$$

where p_i – vector of state probabilities of researched system; ν_{ij} -elements of matrix $\mathbf{v}$ which is the matrix of intensities of transitions from one state to another; m - quantity of possible states of researched system; n - quantity of directions of states change proceeding from operational state 1 (see fig. 2).

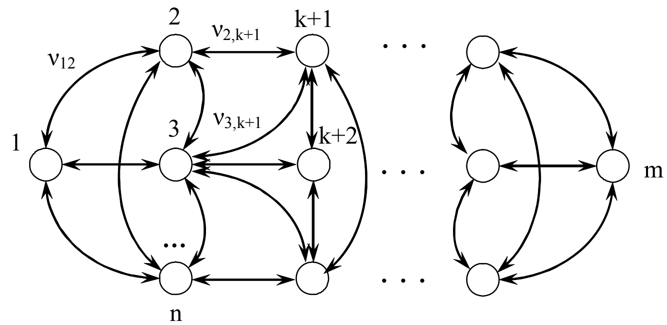

Fig. 2. Graph of system states change

For determination of probabilities operational states and estimation of quality of research system functioning it is necessary to solve the algebraic equations system (2) which in more general form is written:

$$\mathbf{v} \cdot \mathbf{p} = \mathbf{b}\,. \tag{3}$$

In criterial programming the system of equations of orthogonality and normalization can be written [9]

$$\boldsymbol{\alpha} \cdot \boldsymbol{\pi} = \mathbf{b}\,, \tag{4}$$

where α - matrix of indices; π -vector of similarity criteria.

Having analyzed the system of equations (3) and (4), it is possible to note, that the matrix of factors $\mathbf{v}$ of equations system (3) is similar to matrix of dimensionalities $\boldsymbol{\alpha}$ of equations system (4) that is applied in similarity theory [8, 9, 10]. Vector $\mathbf{p}$ which components are actually weighting coefficients of investigated process states, by their content correspond to the vector of similarity criteria π which elements are dimensionless relations of system parameters and in that case when they are determined by the method of integrated analogues, also are weighting coefficients of components of objective function (normalized to 1) [9]. Then it is possible to draw the analogy between system equations (3) and (4).

For confirming the analogy (one of similarity kinds) between the system of equations of orthogonality and Kolmogorov's system of equations we use theorems of the similarity theory. For this purpose we will build multinomials from the matrixes α and ν.

If the interpolating multinomial is used [11] then matrix $\boldsymbol{\alpha}$ of the system of equations of orthogonality (3) of criterial programming and matrix of transitions $\mathbf{v}$ of equations system (4) it is possible to lead to a matrix multinomial. For this purpose the exponential function $f(z) = e^{zt}$ is used. If the minimum multinomial (in this case is characteristic multinomial $\Delta(z)$) consists only of linear factors $(z - z_k)$ it is sufficient to determine the function $f(z)$ in characteristic points $z_1, z_2, \ldots, z_m$. The system of equations for factors of interpolative multinomial looks like:

$$f(z_k) = a_0 + a_1 z_k + \ldots + a_{m-1} z_k^{m-1}, \tag{5}$$

or in matrix form

$$\begin{bmatrix} f(z_1) \\ f(z_2) \\ \ldots \\ f(z_m) \end{bmatrix} = \begin{bmatrix} 1\ z_1\ z_1^2\ \ldots\ z_1^{m-1} \\ 1\ z_2\ z_2^2\ \ldots\ z_2^{m-1} \\ \ldots\ \ldots\ \ldots\ \ldots\ \ldots \\ 1\ z_m\ z_m^2\ \ldots\ z_m^{m-1} \end{bmatrix} \cdot \begin{bmatrix} a_0 \\ a_1 \\ \ldots \\ a_{m-1} \end{bmatrix}.$$

Having solved this system relatively $a_0, a_1, \ldots, a_{m-1}$, we obtain:

$$f(A) = \sum_{i=0}^{m-1} a_i A^i .$$

Then, in a general view matrix $\boldsymbol{\alpha}$ will have the multinomial of the type:

$$f(\boldsymbol{\alpha}) = \sum_{i=0}^{m-1} a_i \boldsymbol{\alpha}^i . \tag{6}$$

And matrix $\mathbf{v}$:

$$f(\mathbf{v}) = \sum_{i=0}^{m-1} a_i \mathbf{v}^i . \tag{7}$$

Having made such transformation, all properties of scalar multinomials, including consequences of theorems of similarity theory can be used.

It is known [12], that for similarity establishment between original and model instead of conditions:

$$\pi_i = \frac{a_i \prod_{j=1}^{n} u_j^{\alpha_{ji}}}{f} = \text{idem} , \tag{8}$$

equivalent expressions can be used

$$\mu_i = \frac{\mu_{a_i} \prod_{j=1}^{n} \mu_{u_j}^{\alpha_{ji}}}{\mu_f} = 1 , \tag{9}$$

where π_i - criteria of similarity, determined by the method of integrated analogues; μ_i - indices of similarity determined by scales of corresponding factors and model parameters.

Having used these conditions, it is possible to prove similarity of matrix multinomials and matrixes corresponding to them.

For matrix multinomials (6) and (7) the condition (9) can be written down:

$$\frac{\mu_{a_1}}{\mu_f} = 1 ; \quad \frac{\mu_{a_2} \mu_{\alpha/\nu}}{\mu_f} = 1 ; \quad \frac{\mu_{a_3} \mu_{\alpha/\nu}}{\mu_f} = 1 \text{ etc.,}$$

where $\mu_{a_i} = \frac{a_{i\alpha}}{a_{i\nu}}$; $\mu_{\alpha/\nu} = \alpha \cdot \nu^{-1}$; $\mu_f = \frac{e^{|\alpha| t}}{e^{|\nu| t}}$.

In the theory of matrixes there is a section of matrix transformations [11]. According to which equivalent transformation can be considered as transitions to new co-ordinate bases for vectors **x** and **y**, then $\mathbf{x}' = \mathbf{Q}^{-1}\mathbf{x}$ and $\mathbf{y}' = \mathbf{P}\mathbf{y}$. Then transformation $\widetilde{\mathbf{A}} = \mathbf{PAQ}$ corresponds to independent transformations of co-ordinates which are determined by matrixes $\mathbf{Q}^{-1}$ and **P** (non-singular square matrixes).

If vectors **x** and **y** turn to one co-ordinate basis it is possible to write down $\mathbf{P} = \mathbf{Q}^{-1}$. Then we pass to transformation of similarity $\widetilde{\mathbf{A}} = \mathbf{Q}^{-1}\mathbf{AQ}$. The important property of transformation of similarity is that the matrix determinant is invariant relatively this transformation:

$$det\, \widetilde{\mathbf{A}} = det\, \mathbf{A} .$$

Then such transformation does not change own meanings of the matrix, therefore it can be writing

$$det[\, \mathbf{zE} - \widetilde{\mathbf{A}}\,] = det[\, \mathbf{zE} - \mathbf{A}\,] .$$

The result of equations system (5) solution for matrixes $\widetilde{\mathbf{A}}$ and **A** will be identical.

The role of transformed matrix **Q** is played by modal matrix **H** [11], then $\widetilde{\mathbf{A}} = \mathbf{H}^{-1}\mathbf{A}\mathbf{H}$. It can be determined as totality of columns $h^{(i)}$ which are the solution of the homogeneous equations:

$$(\mathbf{z_i}\mathbf{E} - \mathbf{A})\mathbf{h}^{(i)} = 0 \quad i = \overline{1,n}, \ (10)$$

where n - rank of matrix **A**.

At building of matrixes $\boldsymbol{\alpha}$ and $\boldsymbol{\nu}$ the matrix H can be found, which would satisfy the system of homogeneous equations (10). Then, $\mu_{a_i} = \dfrac{a_{i\alpha}}{a_{i\nu}} = 1$; $\mu_{\alpha/\nu} = \boldsymbol{\alpha} \cdot \boldsymbol{\nu}^{-1} = 1$; $\mu_f = \dfrac{e^{\left|\boldsymbol{\alpha}^t\right|}}{e^{\left|\mathbf{v}^t\right|}} = 1$, and conditions (9) which confirm similarity of orthogonality matrixes of criterial programming and transitions of system Kolmogorov equation therefore are met.

Similarity of modeling of Markov processes and criterial modeling allows to apply to the system of equations (3) principles of criterial programming [9].

As a result the function by means of which it is possible to estimate quality of functioning of distribution network can be obtained. In the criterial form it will look like [9]:

$$f(x_*) = \sum_{i=1}^{m} P_i \prod_{j=1}^{n} x_{*j}^{\nu_{ij}} . \qquad (11)$$

where P_i - criterion of similarity which in this case is probability of system stay in state i; $\prod_{j=1}^{n} x_{*j}^{\nu_{ij}}$ - index of state functioning quality i; x_{*j} – independent parameters, characterizing the basic properties of system in corresponding states.

As the base value the functioning quality of "ideal" distribution network the preparedness factor of which equals 1 [7] is taken. Criterion obtained in such a way allows to estimate change of quality of distribution network functioning and on its basis to substantiate capital investments.

Conclusions

In the article the basic properties of distribution network which directly influence its quality of functioning are determined. The method of determination of criterion of functioning quality estimation of distribution network which is substantiated association the theory Markov processes and criterial method is offered. Using such approach, the following problems can be solved:

1. To determine strategy of improvement of quality of system functioning by set level in conditions of natural aging of elements and restrictions on resources.
2. To estimate necessity and to determine sequence of measures aimed at modernization of elements.
3. To estimate necessity and to determine structure of measures for system reconstruction by the criterion of functioning quality.
4. To estimate necessity and to determine sequence of measures for prolongation of service life of elements.

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