P. D. Lezhnyuk, Dr. Sc. (Eng.), Prof., V. M. Lagutin, Cand. Sc. (Eng.), Assist. Prof., V. O. Komar, Cand. Sc. (Eng.), Assist. Prof.

QUANTITATIVE ESTIMATION OF FUNCTIONING QUALITY OF DISTRIBUTIVE ELECTRIC NETWORKS BY MEANS OF CRITERIAL MODEL

In the article the technique of determination of functioning quality criterion of distributive electric networks is offered. Dependence of functioning quality on change of reliability indices and electric energy quality on the example of two-circuit power supply system is shown.

Keywords: *distributive networks, functioning quality, reliability of power supply, electric energy quality, Markov processes, criterial modeling.*

Introduction

Modern production with its complex technological systems, wide use of automatic control facilities and processes monitoring is impossible without accurate operation of all engineering resources. It requires strict observance of requirements to their reliability. However, it is obvious that to create highly reliable technical units is senseless if corresponding reliability of their power supply with corresponding quality indices of electric power is not provided. Construction of new distributive networks and modernization of existing ones requires their quality estimation.

According to [1], general requirements to criterion of operation quality of complex system, distributive electric networks including, are: objective reality reflection; estimation of efficiency, quality and optimality; possibility of physical and abstract explanation; possibility of calculation, at least using computer; rationing and display of "extreme" system states accounting potentially and really possible ones; criterion should be in certain degree generalizing (characterize separate subsystems and systems as a whole in all life cycles); criterion should be easily decomposed into quotient and combined into summarizing indices ; criterion should have theoretical basis and allow to develop a new theory or improve the old one ; criterion should be in possession of heuristics, allow to make decision on basis of experience and intuition etc. For distributive network quality of operation is determined by set of system properties substantiating its suitability to provide the schedule of loadings of certain consumer with corresponding [2] indices of electric energy quality [3].

Recently the process of transition to electric heating [4] that requires reconstruction of distributive electric networks has become more rapid. In conditions of limited financial resources needed for carrying out objective and total comparison of possible variants of electric power supply systems realization, it is necessary while their estimation take into consideration indices which determine power supply quality of the consumers. These indices include: reliability of power supply system which is determined by such factors, as uninterrupted operation, reliability of elements of the circuit, maintainability, durability, long service life, scheme configuration; quality of electric energy, characterized by quality indices of frequency and voltage.

Modelling of functioning quality with purpose of quantitative estimation of functional readiness of power supply system is urgent.

Analysis of dependence of functioning quality criterion estimated by criterial model, on change of reliability indices and electric energy quality is **the goal** of this article.

Criterial model of operation quality of distributive electric network

In [5] the criterial model obtained as a result of combination of Markov processes theory and criterial method is offered. General view of criterial model is:

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

where P_i - criterion of similarity which in this case, is the probability of finding system operation in state i (component which takes into account the reliability of the system); $\prod_{j=1}^{n} x_{*j}^{\nu_{ji}}$ - index of state i efficiency (component which takes into account the quality of electric energy); x_{*j} – independent parameters which characterize basic properties of the system (probabilities of conformity of quality indices of electric power to normative documents).

For estimation of operation quality of distributive electric network criterial model will have the following form :

$$\begin{aligned} E = \sum_{i=1}^{n} P_i \cdot \frac{1}{P_i\left[A_{min} \le A \le A_{max}\right]^{\nu_{ii}}} \prod_{\substack{j=1 \\ j \ne i}}^{n} P_j\left[A_{min} \le A \le A_{max}\right]^{\nu_{ji}} - \\ - \sum_{i=n+1}^{m} P_i \prod_{j=1}^{n} P_j\left[A_{min} \le A \le A_{max}\right]^{\nu_{ji}} , \end{aligned} \qquad (2)$$

Where m - total quantity of possible states of distributive electric network, $m=n+k$; n - quantity of operating states; k - quantity of non-operating states; $P_j\left[A_{min} \le A \le A_{max}\right]$ - probability that quality index of electric energy quality A is in admissible limits if the system is in state j; A - value of quality index of electric energy; ν^{ji} - elements of matrix of transitions which are algebraic sums of failure rates λ and intensity of restorations μ.

For practical calculations of operation quality E solution of the problem concerning those indices of electric energy quality which should and can be considered in (2) is essential.

Separate consumer cannot affect frequency in system, therefore indices of frequency quality can be eliminated from consideration.

Probability of voltage deviation is determined by operating modes of consumers which are of probabilistic character. Therefore accounting of this index at determination of operation quality of distributive electric network is mandatory.

For determination of probability of voltage deviation conformity to ГОСТ(State standard) $P_j\left[V_{min} \le V \le V_{max}\right]$ the graph $V_{П}(t)$ [6] should be constructed. The diagram of voltage deviation change can be constructed by means of such relation:

$$V_{П} = \frac{U_{*П} U_{б} - U_{н}}{U_{н}} ,$$

where $U_{н}$ - rated voltage of considered network; $U_{б}$ - base value of voltage; $U_{*П}$ - relative value of voltage of consumption point determined by the curve $U_{*П} = f(S)$.

As total resistance of line $z_{л}$ and dependence of active resistance and reactance of line $r_{л}/x_{л}$ are different for each of system states $i = 0,1,2$, therefore the graph $V_{iП}(t)$ (fig. 1) should be constructed for each of them. In the same Figure the area of admissible values of voltage deviation in place of loading connection (shaded strip) is represented. Curve sections $V_{iП}(t)$ which are in limits of admissible deviations, are effective sections , from the point of view of voltage mode providing. Then

$$P\left[V_{min} \le V \le V_{max}\right] = \frac{T_e}{T} , \qquad (3)$$

where T_e – time interval within which the condition $V_{min} \le V \le V_{max}$ is satisfied; T – number of operating hours of power supply system within a year.

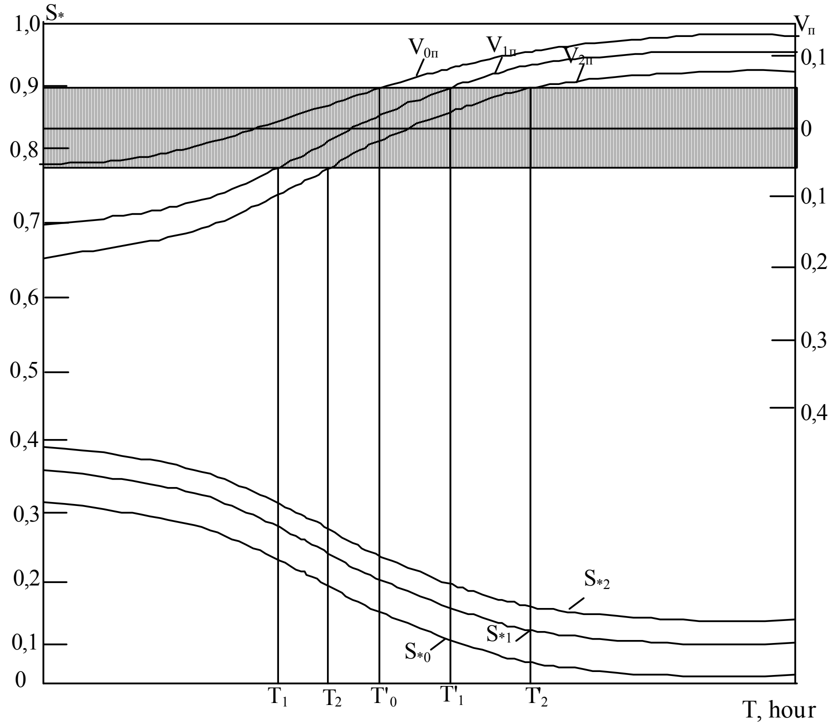

Fig. 1. Dependence of voltage deviation in time on loading diagram

Quality estimation of distributive electric network

Let us illustrate quantitative estimation of network operation quality on example of the scheme presented in Fig. 2. Quality estimation of this system we will carry out taking into account voltage deviation in supply node.

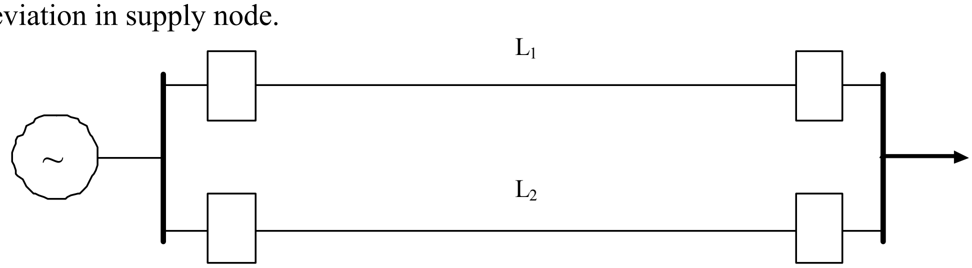

Fig. 2. Distributive electric networks

For this scheme the graph of states change will have the form shown in Fig. 3. Explanation of states are the following:

State 1 – both lines operate;

State 2 – line L_1 has failure, L_2 operates;

State 3 – line L_2 has failure, L_1 operates;

State 4 – both lines have failures.

While construction of graph it was assumed, that automatics and relay protection in this system are ideally reliable.

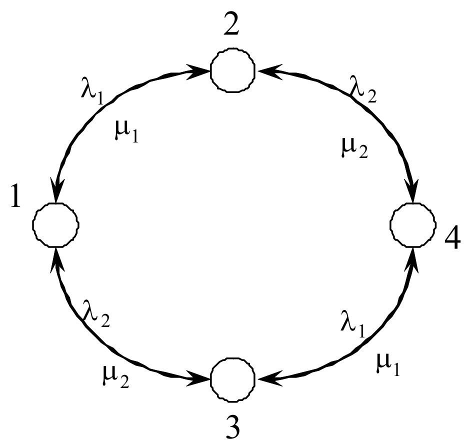

Fig. 3. System states graph

Proceeding from the graph (Fig. 3) the equations system (4) is composed which in general view is the following:

$$\mathbf{v} \cdot \mathbf{p} = \mathbf{b},$$

where $\mathbf{v} = \begin{vmatrix} -(\lambda_1+\lambda_2) & \mu_1 & \mu_2 & 0 \\ \lambda_1 & -(\mu_1+\lambda_2) & 0 & \mu_1 \\ \lambda_2 & 0 & -(\mu_2+\lambda_1) & \mu_2 \\ 1 & 1 & 1 & 1 \end{vmatrix}$; $\mathbf{p} = \begin{vmatrix} P_1 \\ P_2 \\ P_3 \\ P_4 \end{vmatrix}$; $\mathbf{b} = \begin{vmatrix} 0 \\ 0 \\ 0 \\ 1 \end{vmatrix}$.

$$\begin{cases} \nu_{11}P_1 + \nu_{12}P_2 + \nu_{13}P_3 = 0, \\ \nu_{21}P_1 + \nu_{22}P_2 + \nu_{24}P_4 = 0, \\ \nu_{31}P_1 + \nu_{33}P_3 + \nu_{34}P_4 = 0, \\ P_1 + P_2 + P_3 + P_4 = 1. \end{cases} \tag{4}$$

Having solved the equations system (4) relatively P_i, probabilities of system operation in corresponding states can be determined.

For considered distributive network the criterial model will have the form

$$\begin{aligned} E = {} & P_1 \cdot \frac{1}{P_1[V_{min} \le V \le V_{max}]^{\nu_{11}}} P_2[V_{min} \le V \le V_{max}]^{\nu_{21}} P_3[V_{min} \le V \le V_{max}]^{\nu_{31}} + \\ & + P_2 \cdot P_1[V_{min} \le V \le V_{max}]^{\nu_{12}} \frac{1}{P_2[V_{min} \le V \le V_{max}]^{\nu_{22}}} P_3[V_{min} \le V \le V_{max}]^{\nu_{32}} + \\ & + P_3 \cdot P_1[V_{min} \le V \le V_{max}]^{\nu_{13}} P_2[V_{min} \le V \le V_{max}]^{\nu_{23}} \frac{1}{P_3[V_{min} \le V \le V_{max}]^{\nu_{33}}} - \\ & - P_4 \cdot P_1[V_{min} \le V \le V_{max}]^{\nu_{14}} P_2[V_{min} \le V \le V_{max}]^{\nu_{24}} P_3[V_{min} \le V \le V_{max}]^{\nu_{34}}. \end{aligned} \tag{5}$$

Taking into account (3) we will rewrite (5)

$$\begin{aligned} E = {} & P_1 \cdot \left(\frac{T}{T_1'}\right)^{\nu_{11}} \left(\frac{T_2' - T_2}{T}\right)^{\nu_{21}} \left(\frac{T_3' - T_3}{T}\right)^{\nu_{31}} + P_2 \cdot \left(\frac{T_1'}{T}\right)^{\nu_{12}} \left(\frac{T}{T_2' - T_2}\right)^{\nu_{22}} \left(\frac{T_3' - T_3}{T}\right)^{\nu_{32}} + \\ & + P_3 \cdot \left(\frac{T_1'}{T}\right)^{13} \left(\frac{T_2' - T_2}{T}\right)^{\nu_{23}} \left(\frac{T}{T_3' - T}\right)^{\nu_{33}} - P_4 \cdot \left(\frac{T_1'}{T}\right)^{14} \left(\frac{T_2' - T_2}{T}\right)^{\nu_{24}} \left(\frac{T_3' - T_3}{T}\right)^{\nu_{34}}. \end{aligned}$$

We should note, that for solution of practical problems it is necessary to put not one, but two areas of admissible values of voltage deviation - one for state $i = 1$ and another for state $i \neq 1$, thus other area will be larger than the first one since operating norms supposes increase in borders of voltage deviation in post- emergency modes.

The initial information for calculation of operation quality is given in Table 1. Data are suggested for those situations: distributive network only is put into operation; network reconstruction was carried out; network should be replaced.

Table 1

Initial data

	Reliability parameters	*Cable line L1*	*Cable line L2*
1. Both lines at the beginning of operation	*λ (1/year)*	*0,0122*	*0,0122*
	μ (1/year)	*292*	*292*
2. First line after certain operation term	*λ (1/year)*	*10*	*0,0122*
	μ (1/year)	*292*	*292*
3. Lines are to be replaced	*λ (1/year)*	*100*	*100*
	μ (1/year)	*100*	*100*

Results of calculations taking into account change of probability of voltage deviation in state 1 are shown in Fig. 4. Having analyzed it we can draw a conclusion , that at reliable system change of electric power quality practically does not influence the quality of operation (case 1). Similar conclusion can be made and for unreliable system (case 3). For intermediate variant of reliability (case 2) operation quality of power supply system is determined not only by reliability but also by the quality of electric energy.

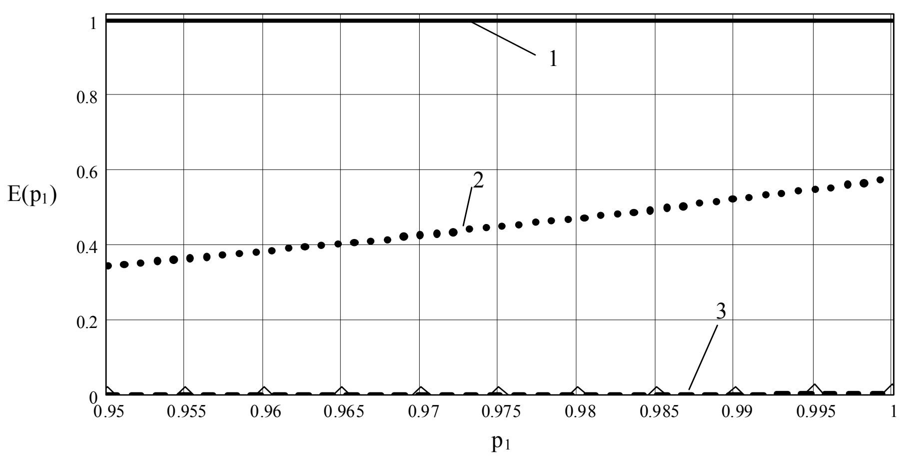

Fig. 4. Dependence of functioning quality index on the quality of electric energy

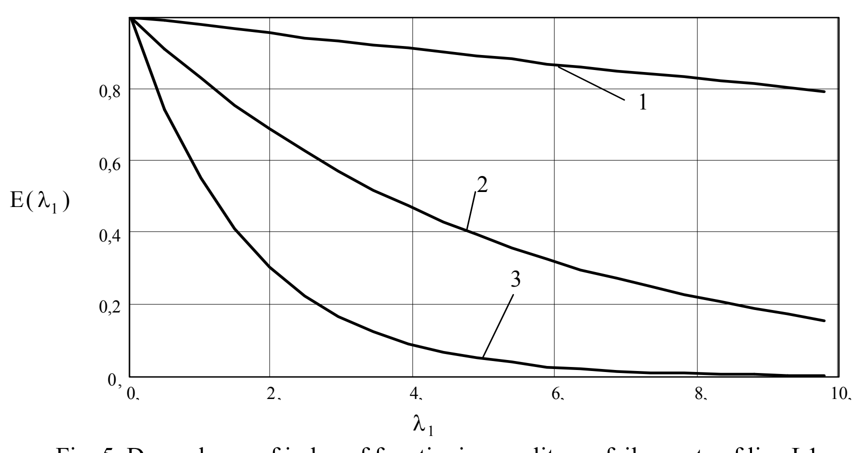

Fig. 5. Dependence of index of functioning quality on failure rate of line L1

By the results of calculation shown in Fig. 5 it is possible to make conclusion concerning change of functioning quality depending on change of failure rate λ_1 of cable line L_1. Three cases which differ by the electric energy quality are considered:

1 – probability of conformity of voltage deviation to ГОСТ(State standard) in state 1, 2 and 3 correspondingly 1; 0,98; 0,98;

2 – probability of conformity of voltage deviation to ГОСТ(State standard) in state 1, 2 and 3 correspondingly 0,98; 0,97; 0,97;

3 – probability of conformity of voltage deviation to ГОСТ(State standard) in state 1, 2 and 3 correspondingly 0,98; 0,95; 0,95.

Conclusions

Obtained criterial model allows to estimate quantitatively functioning quality of distributive electric network. Estimation is carried out in relation to "ideal" system, therefore comparison of different variants of power supply systems can be made without determination of technical and economic indices. By obtained results it is possible to carry out the project of stage-by-stage plan of reconstruction of distributive electric networks necessary in case of transition to electric heating.

REFERENCES

1. Кузьмін І. В. Критерії оцінки ефективності, якості та оптимальності складних систем // Вісник Вінницького політехнічного інституту. – № 1 (2). – 1994. – С. 5 – 9.

2. Электрическая энергия. Совместимость технических средств электромагнитная. Нормы качества электрической энергии в системах электроснабжения общего назначения: ГОСТ 13109-97 (IEK, IEC). – [Чинний від 1997-11-21]. – Минск : Межгосударственный Совет по стандартизации, метрологии и сертификации, 1997, 38 с.

3. Оценка надежности работы электрической сети (Трактат) [Електронний ресурс] / В. А. Скопинцев, В. И. Чемоданов, М. И. Чичинский. – М.: – 2004. – 37 с. Режим доступу: http://www.oaoesp.ru/file/b2b72409/pub4.doc

4. Ключко В. П. К вопросу о разработке схем развития распределительных электрических сетей энергоснабжающих компаний / В. П. Ключко // Новини енергетики. – 2008. – № 6. – С. 28 – 33.

5. Критерій оцінки якості функціонування розподільних мереж [Електронний ресурс] / Лежнюк П. Д., Комар В. О., Кравцов К. І. // Наукові праці Вінницького національного технічного університету. – № 3. – 2008. Режим доступу до журн.: http://www.nbuv.gov.ua/e-journals/VNTU/2008-3.files/uk/ 08pdlodn_ua.pdf

6. Фокин Ю. А. Оценка надёжности систем электроснабжения / Ю. А. Фокин, В. А. Туфанов. – М.: Энергоиздат, 1981. – 224 с.

Lezhnyuk Petro – Dr. Sc (Eng.), Head of the Department of Electric Power Stations and Systems.

Lagutin Valeriy – Cand Sc(Eng), Assistant professor of the Chair of Electric stations and Systems.

Komar Vyacheslav – Cand Sc(Eng), Assistant professor of the Chair of Electric stations and Systems.
Vinnitsa National Technical University.