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RANGE VOLTAGE MODIFICATION MODELING BASED ON ORDER STATISTICS THEORY

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Abstract—*Range of the voltage change is one of important power quality indicator. In this article new method of this indicator estimation, based on stochastic model of power voltage is offered. The dependence of the statistical estimations reliability on the sample size is investigated by the order statistic theory methods.*

Index terms—Range of the voltage change; order statistics.

I. INTRODUCTION

Energy saving issues in case of design and exploitation of lighting systems are inseparably associated with electric energy quality category which determines economy, exergity, ergonomics and reliability of the electric consumption process [5] – [12].

The main electric energy quality indexes which are regulated by electric lighting systems supply are the range voltage modification and the flicker dose [8]. The infringement of regulating requirements for these indexes causes the electromagnetic, technologic and social compounds of the damage at the power supply system due to increase of the active power loss at lighting network, the adverse effect on the visual perception due to light sources flickering, increase of the visual fatigue.

In international practice the estimation of the electric voltage fluctuations effect on visual perception is considered from point of ergonomics, which presents the human visual analyzer as the adaptive inertial system with variable amplification factor which is the frequency function of the voltage fluctuations in the electric lighting network. The infringement of regulating requirements evokes the unsteady visual transformation of light sources luminous flux process into the nervous energy which is accompanied by malaise and visual fatigue [5], [7], [11], [12].

According to research materials of General Electric Company (which had established the admissible standard for advertising boards) the ranges more than 0.5% in case of two fluctuations per second are inadmissible.

II. PROBLEM STATEMENT

The main approach of the voltage fluctuations range estimation which is applied by light technicians of USA and Europe is the cumulative principle which determines the accumulation of the visual fatigue to the flicker dose level by which the fulfillment of the visual task tends to be impossible. Therefore the flicker dose can be estimated as [7]:

$$A = \int_0^T w_t^2(\omega) g(\omega) d\omega, \qquad (1)$$

where $w_t(\omega)$ is the voltage fluctuations range in the function of frequency; $g(\omega)$ is the weighting amplification factor.

Acting in Ukraine GOST 13109–97 regulates rather complex and cumbersome method of determining the voltage range and flicker dose based on piecewise – constant envelope model of harmonic voltage with abrupt changes. It is not given to the theoretical justification for the number of measurements required and the reliability of the estimates.

In reality, the changes in mains voltage amplitude are stochastic due to many random factors like instability generators, spontaneous incorporation of different users, interference, etc.

Mathematical modeling of the process of power consumption should be based on probabilistic - statistical methods. Therefore, to account for the peculiarities of electric energy as a use-value, taking into account the requirements to the valuation of its quality, energy quality indexes should be simulated by random variables on the time interval sufficient for the analysis of information with the guaranteed accuracy.

In case of electric energy indexes in the lighting network static control it is necessary to solve the following task: for sampling of the n volume to find such random interval $[L, V]$ as the portion γ of the voltage fluctuation range belongs to this interval with

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probability β. The order statistics theory offers the solution of this task based on the construction of the nonparametric tolerant intervals [1].

Tolerant interval, as a confident interval has random ends but the main difference is the following: the confident interval includes the unknown value with assignment probability, then the tolerant interval determines the probability degree, concentrated on it, and such degree, so as it is not less than γ with probability β.

Let the voltage supply presents the harmonic process with random amplitude

$$E(t) = u(t) \times \cos(\omega_0 t + \varphi), \qquad (2)$$

where $u(t)$ is the amplitude; ω_0 is the radial frequency; φ is the phase.

Requirements to the electric power quality impose limits to the change of the amplitude $u(t)$ in time. These limits concern the range of the amplitude alteration of the voltage supply and its spectral structure.

In general case $u(t)$ can be modeled as the random process with some probabilities distribution law of $f(u)$ values and the correlative function $R(\tau)$. The spectral voltage power density can be obtained as the Fourier Transform of the correlative function:

$$S(\omega) = \int_{-\infty}^{\infty} R(\tau) \exp(-j\omega\tau) d\tau. \qquad (3)$$

For the estimation of the electric power quality the following procedure is offered in (Fig. 1).

By this the task of the authentic estimation of the range of the voltage change with help of the sample range $w_n = u_{\max,n} - u_{\min,n}$ arises.

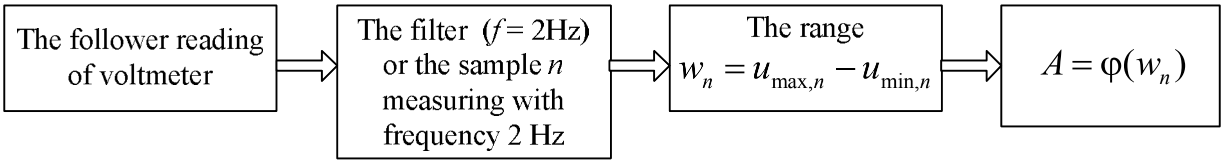

Fig. 1. The estimation of the electric power quality

III. VOLTAGE RANGE INDICATOR ESTIMATION

The sample range w_n is the nonparametric estimation of the random variable range of values and it does not depend on the distribution density law. In order to calculate the sample range it is necessary to use the voltage sample values of the size n. This sample is taken with the frequency 2 Hz (or with another frequency, which represents the interest). The sample size is determined by the requirement probability γ with which the sample range covers the range of the voltage supply alteration (by the probability degree of the random interval w_n) and by the limitation β to this probability. Herewith the condition must be fulfilled:

$$P\left\{ \int_{u_{\min,n}}^{u_{\max,n}} f(u) du > \gamma \right\} >= \beta. \qquad (4)$$

The minimal size n by which the condition (4) is fulfilled, can be found as a solution of the equation [1]:

$$n\gamma^{n-1} - (n-1)\gamma^n = 1 - \beta. \qquad (5)$$

The range distribution density can be found in accordance with the expression:

$$p(w) = n(n-1) \cdot \int_{-\infty}^{\infty} f(x)[F(x+w) - F(x)]^{n-2} f(x+w) dx, \qquad (6)$$

where $f(x)$ and $F(x)$ are correspondingly differential and integral probability distribution functions of the supply voltage amplitude; n is the sample size.

Considering the distribution of the amplitude of the supply voltage as the Gauss law, the expression for the range distribution density may be obtained:

$$p(w) = n(n-1) \int_{-\infty}^{\infty} \frac{1}{2\pi\sigma_u^2} \exp\left(-\frac{x^2}{2\sigma_u^2}\right) \left[\Phi\left(\frac{x+w}{\sigma_u}\right) - \Phi\left(\frac{x}{\sigma_u}\right)\right]^{n-2} \exp\left(-\frac{(x+w)^2}{2\sigma_u^2}\right) dx,$$

$$\Phi(z) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{z} \exp\left(-\frac{z^2}{2}\right) dz,$$

$\Phi(z)$ is the integral of probabilities in Laplace representation. Figure 2 depicts the graphics of the range sample distribution densities out of Gauss distribution in case of different n.

The dependencies of the statistical characteristics of the range from the sample size can be approximated by the following expressions depicted in Fig. 3.

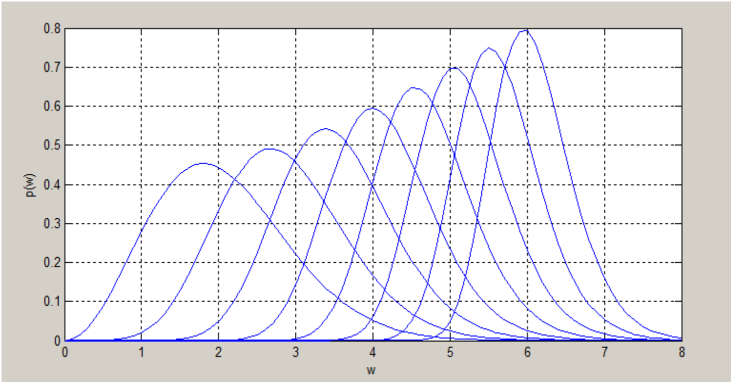

Fig. 2. The distribution density of the sample from normed normal distribution by different sample sizes
n = 4, 8, 16, …, 512

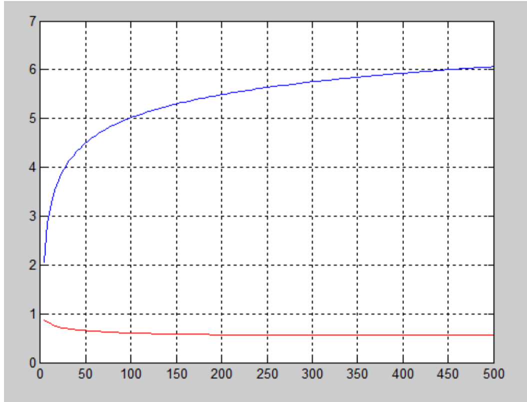

Fig. 3. The dependance of the mathematic expectation and standard range deviation from normed normal distribution on the sample size n

The dependence of the mathematical expectation from the sample size:

$$m_{1w}(n) = (a\log_2(n) + b)\sigma_u,$$

$$a = 4/7; \quad b = 6/7.$$

The dependence of the standard range deviation on the sample size:

$$\sigma_w(n) = (-0.053\cdot\log_2(n) + 0.986)\sigma_u,$$

σ_u is the standard deviation of the amplitude of the supply voltage.

The range of the supply voltage alteration (it's the standard deviation σ_u) can be estimated to measuring range as:

$$\sigma_u^* = \frac{w}{\frac{4}{7}\log_2(n) + \frac{6}{7}}.$$

This equation can be used to estimate range voltage indicator like

$$w_t = \frac{\sigma_u^*}{u_{\text{pow}}}\cdot 100\%,$$

where u_{pow} is nominal power voltage.

The results of calculations according to equation (5) are presented in Table I at different values of confident probabilities γ and β.

TABLE I

THE SAMPLE SIZE n

β \ γ	0.750	0.775	0.800	0.825	0.850	0.875	0.900	0.925	0.950
0.750	18	21	25	29	36	45	59	84	137
0.775	19	21	25	30	36	46	61	86	140
0.800	19	22	26	31	37	47	62	88	142
0.825	20	23	26	31	38	48	63	90	145
0.850	20	23	27	32	39	49	65	92	149
0.875	21	24	28	34	41	51	67	95	153
0.900	22	25	29	35	42	53	70	98	158
0.925	23	27	31	37	44	56	73	102	164
0.950	25	29	33	39	47	59	77	108	173

By analyzing the range of the voltage alterations the registration of the abnormal extreme voltage values is possible. In the order statistics theory the criterions for abnormal observations depending on presence of the information about mathematical expectation and root-mean-square deviation of the research process are developed[1], [3], [4].

To solve the task of discarding abnormal extreme values, it is possible to use Dixon's r – statistics which are considered to be the ratio of the differences of voltage amplitudes order statistics [1], [4]:

$$r_{10} = (x_{(n)} - x_{(n-1)})/(x_{(n)} - x_{(1)}), \qquad (7)$$

where $x_{(k)}$, $k = \overline{1, n}$ are order statistics of the sample $x_1, ..., x_n$ voltage values.

Percentage statistical distribution points (7) are shown in [4].

IV. CONCLUSIONS

Modeling of voltage range at random fluctuations in a power supply network that has been developed in this paper based on the theory of order statistics allows:

– determining the necessary sample size of the voltage values for obtaining the information on extreme statistics with guaranteed preciseness out of dependence from probability distribution law of the extremes;

– analyzing the abnormal supply voltage amplitude measurements of the voltage extremes by different degrees of the initial data;

– estimating the variation of voltage fluctuations for solving the energy saving tasks.

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І. Г. Прокопенко, О. Й. Чуріна. Моделювання розмаха зміни напруги на основі теорії порядкових статистик

Діапазон зміни напруги є одним з найважливіших показників якості електроенергії. Запропоновано новий метод оцінки цього показника, на основі стохастичної моделі напруги живлення. Досліджено залежність достовірності статистичних оцінок від розміру вибірки за допомогою методів теорії порядкових статистик.

Ключові слова: розмах зміни напруги; порядкові статистики.

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И. Г. Прокопенко, А. Й. Чурина. Моделирование размаха изменения напряжения на основе теории порядковых статистик

Диапазон изменения напряжения является одним из важнейших показателей качества электроэнергии. Предложен новый метод оценки этого показателя, на основе стохастической модели напряжения питания. Исследована зависимость достоверности статистических оценок от размера выборки с помощью методов теории порядковых статистик.

Ключевые слова: размах изменения напряжения; порядковые статистики.

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