Application Of Probabilistic Methods In Voltage Quality Analysis In City Distribution Power Grids

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Annotation. The article examines the distribution of random voltage change curves and the probability of their occurrence using a probability calculation method, taking into account the randomness of the voltage change at the connection points of electric consumers when evaluating the operating modes of city distribution power networks. Differential and integral histograms of the voltage deviation are given.

Key words: distribution power grid, power quality, voltage deviation, random value, probability value, frequency deviation.

Introduction

The operating modes of urban distribution power grids are probability based, with the most efficient voltage estimation being a sufficiently complex task. Urban distribution power grids are very abundant, with a large number of electricity consumers connected at various points. Changes in electrical loads over time are in most cases random. Therefore, the change in voltage at certain points of the electrical network and in the clamps of electric consumers also has the property of randomness. At a number of points in the electrical circuit, the change in voltage is a function of $U_n(t)$, while the deviation of the voltage from the nominal value is sified by the dependence $V(t)$. The variation of this function at the point being seen depends on many of the following factors:

- change of voltage mode in the supply center (SC) tire;
- change in electrical charge value;
- types of electricity consumers;
- daily, annual running time, etc.

In these conditions, the most well-founded probabilistic method is considered analysis, in which an event or process is studied on the basis of generalized indicators that characterize it. The probability calculation method can be assessed by applying sufficient reliability for the sum of each electric consumer supplied from the city distribution power grid under consideration to allow voltage deviations to occur in most electricity consumers, one or the other. In this case, a series of voltage quality integrally generalized criteria can be applied in distributive electrical networks [1].

Problem statement

In voltage mode analysis, the voltage deviation at an arbitrary connection point of an electrical network can be viewed as a random time function or a random process. This shows that this function looks different at different times. In other words, it consists in carrying out random processes. For practical calculations, the random process being seen shows its convenience in losing long-time implementations and taking its random values sequentially. In addition, a number of specific periods of daily time are often of interest, for example, the change in random functions of voltage deviation during the largest and smallest electrical charge hours. In this case, the study represents random values in the moment of time. The possibility of such a limitation of the task, that is, the study of its values in the place of random processes, significantly simplifies the voltage mode.

When using probabilistic methods, the distribution of the values of random curves is considered. They establish a connection between random values and their probability of occurrence.

It is understood in probability that this reality may or may not occur. Under the conditions under consideration, random events at this moment of time coincide with the occurrence of a deviation V at a number of points of the electrical network. A value V can have a number of essences, each of which corresponds to its own P value probability with its own P value probability. Probabilistically identifiable random event law is manifested from a sufficient number of observations or experiments (statistics). To describe in figure 1.a, values the random V values of the abscissa axis sequentially, in the ordinate axis the probability density $\varphi(V)$ is set. From distribution curve outputs (figure 1.a) it is seen that the probability essence of random values under the conditions under consideration is a series of its average *V* value, giving the greatest probability in this case $\varphi(V)_{e.k.}$ the value holds [2].

In probability theory, the average value of a random magnitude is called mathematical expectation. In statistical description, The probability of mathematical expectation is approximately equal to the arithmetic mean of the observed value.

For a discrete variable random magnitude *V*, the following expression is appropriate:

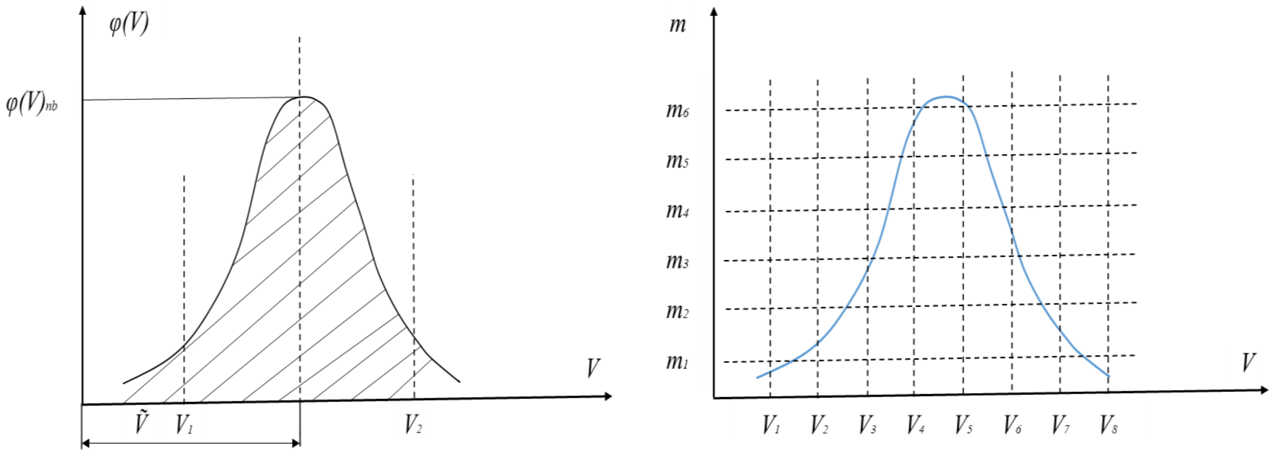
$$\tilde{V} = \frac{\sum_{i=1}^{n} \tilde{V}_i}{n} \quad (1)$$

For a continuously changing magnitude, the following expression is appropriate:

$$\tilde{V} = \frac{1}{T}\int_0^T V dt \quad (2)$$

here, $n - t$ the number of qymat of the work of the voltage obtained from the observation of the process under consideration at a time interval.

In the statistical analysis of the voltage deviation, the distribution of the deviation is constructed in the form of a stepped histogram or a uniform curve of the variation series. In the abscissa axis (V_1, V_2), the possible value of the deviation is sequential, while in the ordinate axis, the deviation frequency or change frequency is constructed. In this case, the frequency of this Vt deviation is understood as the amount of its absolute value, which has in the observed range *T*. Frequency deviation is understood as the relative value of the frequency, that is, the proportion of all values of the observed *N* voltage deviation. The total area of histograms is equal to the sum of frequencies, that is, one.



a) *b)*

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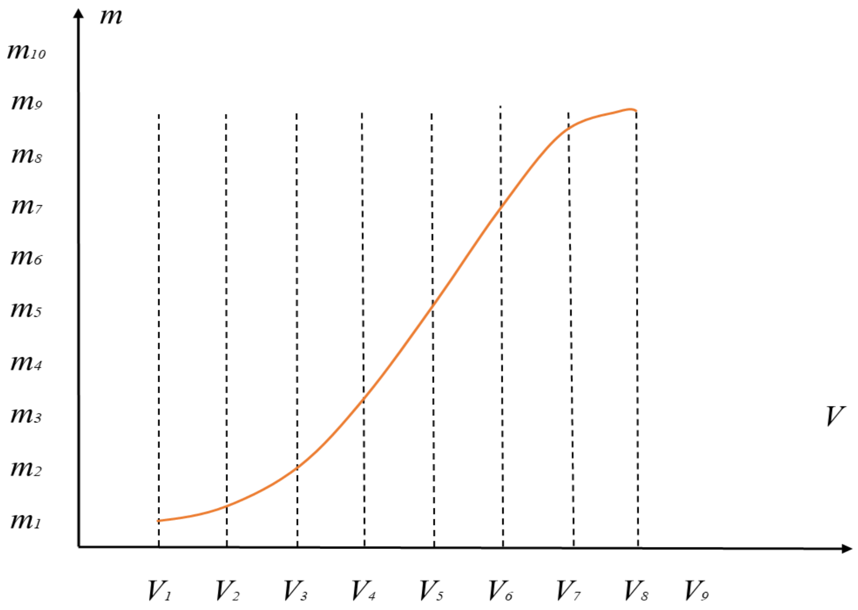

c)

Figure 1. Random value distribution curves and series: *a* - a curve distributed in normal law is; *b* - differential histogram and uniform distribution curves; *c* - integral (cumulative) histogram and uniform distribution curves.

The uniform distribution of histogram or voltage deviation curves is differential, when the value of the V_1 voltage deviation in each range on the ordinate axis is equal to its frequency m_1 (figure 1.b) may be true. Which part of the deviation they all observed is at *Y* or other limit (figure 1.c) shows that it has a small value [5].

From mathematical expectation, the dispersion of random values of the value of the voltage deviation as the spread of the generalized indicator (or average arithmetic) is taken. *Y* is equal to the square of the deviation of the random value from its mathematical expectation. In statistical determination of probability dispersion, approximately equal to:

$$D = 6^2 = \frac{\sum_{i=1}^{n}(V_i - \tilde{V})^2}{n} \qquad (3)$$

here, in non-multiple quantitative observations of the ratio n, the dispersion value from the 3-expression must be corrected by multiplying the value *D* by the relation [*n*·(*n*-1)].

For values that change continuously, it is equivalent to:

$$D = 6^2 = \frac{1}{T}\int_0^T (V - \tilde{V})^2 dt \qquad (4)$$

The value σ equal to the average square deviation is called the standard deviation. The size of σ corresponds to the size of the random value *V*. In a number of cases, different voltage deviations can be used.

$$N = (\tilde{V})^2 + \sigma^2 \qquad (5)$$

In some cases, an average modulus of random value *V* from the mathematical expectation $\tilde{V}$ representing the mean deviation mv is used to estimate the spread.

For a discrete random value, is equivalent to:

$$m_v = \frac{\sum_{i=1}^{n}(V_i - \tilde{V})}{n} \qquad (6)$$

For continuity, is equivalent to:

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$$m_v = \frac{1}{T}\int_0^T (V - \tilde{V})dt \qquad (7)$$

The analytical description of normal law is quite simple - it depends only on two parameters: mathematical expectation $\tilde{V}$ and standard deviation σ. figure 1.a describes the scattering curves of the deviation from the nominal voltage based on the normal law. Its equation has the following appearance:

$$\varphi(V) = \frac{1}{6\cdot\sqrt{2\pi}} e^{-\frac{(V-\tilde{V})^2}{2\cdot 6^2}} \qquad (8)$$

The normal scattering curve is symmetric with respect to the corresponding mathematical expectation ordinate of deviation $\tilde{V}$. Has the greatest ordinate value:

$$\varphi(V)_{e.k.} = \frac{1}{6\cdot\sqrt{2\pi}} \approx \frac{0,4}{6} \qquad (9)$$

The dependence of standard deviation σ and deviation m_v is determined from $\sigma=1.25\cdot m_v$. Its probability is that the difference in voltage deviation over absolute values $V-\tilde{V}$ does not exceed some number $k=t\cdot\sigma$ The integral probability is determined from Φ (t):

$$\Phi(t) = \frac{2}{\sqrt{2\pi}}\int_0^t e^{-\frac{t^2}{2}} dt \qquad (10)$$

Using the probability integral, it is possible to determine that probability P ($V_1<V<V_2$) is located at any interval (V_1 V_2) with deviation V subject to the normal law that the approximation changes (figure 1.a):

$$P(V_1 < V < V_2) = \frac{1}{2}\Phi(t_2) - \frac{1}{2}\Phi(t_1) \qquad (11)$$

here, $t_1 = \frac{V_1-\tilde{V}}{6}$; $t_2 = V_2 - \tilde{V}$; $\Phi(-t)= -\Phi(t)$ (11a)

We think, $V_1 = - t\,\sigma$ and $V_2 = t\,\sigma$ ($t_1 = t$ and $t_2 = t$). Then the probability deviation V and the mean value $\tilde{V}$ difference do not exceed $\pm\sigma t$, determined from the following expression:

$$\frac{1}{\sqrt{2\pi}}\int_{-t}^t e^{-\frac{t^2}{2}} dt=\frac{2}{\sqrt{2\pi}}\int_0^t e^{-t^2} dt= \Phi(t) \qquad (12)$$

here, $t=(V-\tilde{V})\,/\,2$.

From the table of Integral probabilities, the mean value for the characteristic values of t $\tilde{V}$ its sought V value will have the following probability value [1]:

table 1

t	3	2,5	2	1,5	1	0,5
Probability value	0,9973	0,9876	0,9544	0,8664	0,6826	0,3830

Thus, knowing the values the mathematical expectation $\tilde{V}$ and the standard deviation σ, it is possible to determine the probability location of the magnitude V that is being sought during the time interval being seen in a given circle. We describe this in a specific example. Suppose, based on measurements, that T is the value of the average arithmetic deviation during some interval of time $\tilde{V}$=2%, and σ is the standard deviation from the value σ, 2%. It is required to determine that the probability of deviation from the nominal voltage at the point being seen does not deviate from ±5% [6-7]. This corresponds to values V_1=-5% and V_2=+5%. From the expression (11a) we define:

$$t_1 = \frac{V_1-\tilde{V}}{6}=\frac{-5-2}{2}=-3,5\% \qquad t_2 = \frac{V_2-\tilde{V}}{6}=\frac{5-2}{2}=1,5\%$$

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From table 1 [3] we define:

$$0{,}5\cdot\Phi(t_1) = 0{,}5\cdot\Phi(-3{,}5) = -0{,}4995 \text{ and } 0{,}5\cdot\Phi(t_2) = 0{,}5\cdot\Phi(+1{,}5) = 0{,}433.$$

We define the probabilities being sought from the expression (11):

$$P\ (-5\% < V < 5\%) = 0{,}433-(-0{,}4995) = 0{,}932.$$

It is seen from expression that if the voltage deviation curve converges to the law of normal distribution, quantification of voltage quality descriptors over a number of T timeframes is done simply enough. The distribution curve shown in real often does not conform to normal law, so it becomes complicated to obtain a quantitative assessment of voltage quality [8, 9].

The relationship between the values σ and m_v can be determined from the following approximation in different distribution laws:

$$m_v \cong (1{,}2\text{-}1{,}25)\cdot\sigma \qquad (13)$$

In a number of cases the voltage regime analysis has to have a system of several random magnitudes describing the correlation. A system of two random magnitudes can be described in terms of random points with X and Y coordinates on the cross-sectional Surface [4]. There may or may not be a functional link between them [10, 11]. This connection is expressed in linear terms. In a number of cases, there is a probability or correlation cross-positive correlation between the two system magnitudes. It is characterized by the moment of quantitative probable bond correlation:

$$k_{XY} = \sum_{ij}(X_i - X)(Y_i - Y)P_{ij} = \sum X_i Y_i P_{ij} - XY \qquad (14)$$

If the magnitudes X and Y are not related, then the correlation moment is zero. If the relation is rectilinear, then:

$$k_{XY} = \pm r 6_X 6_Y \qquad (14a)$$

A positive sign is acceptable if the growth of one magnitude is consistent with the growth of the other, in the negative – inverse case. It is convenient to use the correlation coefficient in practical terms, in which its value is obtained below:

$$r_{XY} = \pm\frac{k_{XY}}{6_X 6_Y}$$

In the associated magnitudes, $r = 0$. $r=\pm1$ when there is a functional link, $-1<r<1$ when there is a probability link. If the magnitude dispersion and correlation coefficient are determined from a bounded n-number experiment, then they must be multiplied by $n\cdot(n\text{-}1)$.

The numerical descriptions of the two related magnitudes are defined as follows: $\tilde{V}=\tilde{V}_X+\tilde{V}_Y$; dispersion: $D=D_X+D_Y+2\cdot r\cdot\sigma_X\cdot\sigma_Y$.

For unrelated random magnitudes: $D=D_X+D_Y$; for functionally connected quantities: $\sigma^2=(\sigma_X\pm\sigma_Y)^2$.

Let us show the application of the correlation coefficient in the evaluation of different electrical loads of certain lines connecting to SC, using the example of choosing the desired law of adjusting the voltage to SC. It is known that the correlation moment of one different electrical charge graphs of different types of electrical loads can be characterized by a numerical or correlation coefficient r. One different level of the electrical loading graph affects one kind of voltage graph at different points in the network at a certain level. But from the truth, different types of electrical loadings flow from a single line section itself [12]. Therefore, the change in the voltage graph at some point in the urban distribution electric grid will depend only on the electric load connected to that point of the grid, and the electric load graph connected to other points of that grid. [2, 3] shown, the sum of the voltage loss dispersion on a number of sections of the line is the result of

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the sum of the voltage loss dispersion from certain electrical loads. Each of them is involved in the sum with a oscillation v, and the sum of the hesitant correlation moments is taken downstream:

$$6_{\Delta}^{2} = \sum_{i=1}^{n} 6_{\Delta i}^{2}\, b_i + 2\sum_{i,j=1} r_{i,j} 6_{\Delta i} 6_{\Delta j} b_i\, b_j \qquad (15)$$

From the expression (15) it follows that under other equal conditions, the smaller the rij magnitude, the smaller the dispersion of the voltage loss. This shows that the connection of each different electrical load to one distribution line reduces the distribution of voltage loss to a certain extent and, as such, reduces the distribution of voltage deviation. The result of the calculations shows that the magnitude of the Hatto connected to one line is relatively high in the degree of uniformity of the voltage graph on the graph of various electrical loads. It can be seen from this that when grouping the types of electrical loadings connected to a single general distribution electrical grid line, it is not necessary to strive for a high degree of uniformity of the electrical loadings graph. If, in this case, the correlation coefficient between certain electrical loads is in the range $r \geq 0.6$, then is itself sufficient.

If different lines of the medium voltage (MV) power grid provide different electrical loads of the same type at each line boundary, one type of graph of the voltage of certain lines will be close to one type of load graph. In this case, it is desirable to group the lines of a large degree of one-variety graphs, for example $r \geq 0.8$.

Conclusion

1. When assessing voltage quality in urban power grids, it is recommended to use an integrated statistical method in which the measurement volume does not depend on sufficient duration. In this case, in a sufficiently long implementation of a random function, the time is divided into discrete slices and replaced by a sequence of random magnitudes.

2. Standard magnitude σ is not considered a criterion of voltage quality. In all cases, it does not provide data that satisfies the requirements of voltage quality analysis and control. Sufficient complete information can be obtained when both description – mathematical expectation $\tilde{V}$ and standard deviation σ are used together. If the distribution of the voltage deviation is subject to the normal law, then it is possible to obtain complete information about the quality of the voltage based on these two descriptions.

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Rezyume: Maqolada shahar taqsimlovchi elektr tarmoqlarining ish rejimlarini baholashda elektr iste'molchilarning ulanish nuqtalarida kuchlanish oʻzgarishining tasodifiyligini hisobga olgan holda ehtimollik hisoblash usulini qoʻllash orqali tasodifiy kuchlanish oʻzgarishi egri chiziqlarini taqsimlanishi va ularni yuzaga kelish ehtimolligi koʻrib chiqiladi. Kuchlanish ogʻishining differensional va integral gistogrammalari keltiriladi

Резюме: В статье рассматривается распределение кривых случайных изменений напряжения и вероятность их возникновения путем применения вероятностного метода расчета с учетом случайности изменения напряжения в точках подключения электропотребителей при оценке режимов работы распределительных электрических сетей постоянного тока. Приведены дифференциальные и интегральные гистограммы отклонений напряжения.

Kalit soʻzlar: taqsimlovchi elektr tarmoq, elektr energiyasi sifati, kuchlanishning ogʻishi, tasodifiy qiymat, ehtimollik qiymat, chastotaning ogʻishi

Ключевые слова: распределительная электрическая сеть, качество электроэнергии, отклонение напряжения, случайное значение, вероятность значение, отклонение частоты.

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