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Application of non-Euclidean metric in the electric power industry for reduction of measurement uncertainty

The paper proposes the use of the non-Euclidean metric to reduce the uncertainty that occurs when measuring voltage for the tasks of ongoing continuous control of electric power consumption in large, branched high-voltage electric networks. The problem is that for continuous control of electric power consumption, it is necessary to install the active and reactive power measuring equipment in each node of the electric network (at each substation) and to ensure the transmission of measurement information to dispatching control centers. For countries with large electric networks, long distances between electric grid nodes and dispatch control centers, this requires huge capital costs. Therefore, it is advisable to place equipment for measuring electric power and voltage only in individual nodes of the electrical network, and then calculate the parameters of the remaining nodes based on Kirchhoff's laws. But at the same time, there is a significant measurement uncertainty, because the complex value of the voltage is usually not measured, only the modulus of the voltage values is used for the calculation. The use of non-Euclidean metrics provides the reduction of the input data uncertainty, which are necessary to control the consumption of electric power in each node of the electric network.

Keywords: non-Euclidean metric, high-voltage electric network, electric power, measurement uncertainty, measurement information.

Introduction

In order to ensure continuous monitoring of electric power consumption, it is necessary to install equipment for measuring active and reactive power at each node of the electric network (at each substation) and to ensure their connection with dispatching control centers. For countries with large electric networks, large distances between power grid nodes and control centers, this approach requires large capital expenditures, so it makes sense to place measuring equipment only in individual nodes, and then reproduce (identify) all unknown network mode parameters according to Kirchhoff's laws. Devices for measuring complex power values in the power grid (its active and reactive components) are simple in principle and relatively cheap, since the phase shift angle is determined between the current and voltage measured on the same power supply line. As for devices for measuring complex voltage values on substation buses, the difficulty in this case is that the phase shift angle must be determined between the voltages of different substations. Such measuring equipment requires significant capital investments, which complicates the implementation of such measuring procedures. In practice, in most cases, it is possible to receive only voltage modulus in network nodes from telemetric measuring devices. It follows that the input data of the task of reproducing the modes of electrical networks have significant uncertainty. Therefore, it is important to develop new mathematical models and methods that allow to reduce the level of measurement results uncertainty [1].

Non-Euclidean geometry is a relatively new and powerful mathematical apparatus, which is currently used for analysis and calculations in the field of automation and robotics [2–4], in physics [5, 6], medicine [7, 8], information technologies [9–11], the educational process [12], and other fields of science. Recently, non-standard methods of analyzing processes in electric circuits and networks have been actively developed [13, 14]. Non-Euclidean geometry in the theory of electric circuits is a non-standard method of analysis, it is used for the analysis of multi-port electric circuits [15, 16], its application in electromechanics [17, 18] is promising, as well as for calculating load modes, determining the parameters of load mode regulators of power electric circuits [19, 20].

The purpose of the work is to create the method of using a non-Euclidean metric to reduce the uncertainty of voltage measurement for tasks of controlling electricity consumption in large, branched high-voltage electrical networks.

Non-Euclidean modulus of the voltage vector

Consider the proposed method of reducing the uncertainty of input measured data, which is associated with the practical impossibility of measuring the phase shift angle between the voltages of different substations.

The space of complex electrotechnical parameters can be represented as a two-dimensional linear metric space with the Euclidean metric. The modulus of the voltage vector at any node of the network in this space has the form:

$$U = \sqrt{U_a^2 + U_p^2}\,, \tag{1}$$

where U_a — active component of the voltage vector, U_p — reactive component of the voltage vector.

In order to emphasize the dependence of this value on the selected space metric, let's call it the Euclidean modulus of the voltage vector. This modulus in the any network node significantly depends on the network parameters, the voltages of the power sources and the currents in the network coils.

But in such a two-dimensional linear metric space, the metric does not necessarily have to be Euclidean — it should only correspond to the axioms of the metric:

$$\rho(x, y) = 0 \Leftrightarrow x = y, \tag{2}$$

$$\rho(x, y) = \rho(y, x), \tag{3}$$

$$\rho(x, z) \le \rho(x, y) + \rho(y, z), \tag{4}$$

where $\rho(x, y)$ — the distance in this space between the points *x* and *y*.

Let's try to find the certain generalizing parameter that characterizes the voltage at any network node, and at the same time depends much less than the Euclidean modulus of the voltage vector on the network parameters, the voltages of the power sources and the currents in the network coils.

One of the directions of the search for such a generalizing parameter is the use of a metric different from the Euclidean metric in the space of complex electrotechnical parameters. Quite often, various non-Euclidean metrics are used to solve different tasks [2–12]. These can be linear non-Euclidean metrics for which $\rho(x, y)$ is a linear function, quadratic non-Euclidean metrics for which $\rho(x, y)$ is a quadratic function, etc [8]. A detailed comparative analysis of these metrics is the subject of a separate study and is beyond the scope of this paper. We only note that to achieve our local goal it is quite sufficient to use a linear non-Euclidean metric for which

$$\rho(x, y) = \beta\,|\, y_1 - x_1 \,| + |\, y_2 - x_2 \,|\,, \tag{5}$$

where β — the reduction factor, that is a positive real number.

Let's verify what the expression (5) confirms to the axioms of the metric. For the first axiom we can write:

$$x = y \Rightarrow \rho(x, y) = \beta\,|\, x_1 - x_1 \,| + |\, x_2 - x_2 \,| = 0. \tag{6}$$

The second axiom has the form:

$$\beta\,|\, y_1 - x_1 \,| + |\, y_2 - x_2 \,| = \beta\,|\, x_1 - y_1 \,| + |\, x_2 - y_2 \,|. \tag{7}$$

The validity of expressions (6) and (7) is obvious. Correspondence of (5) to the third axiom is not so obvious, so let's prove that

$$\beta\,|\, x_1 - z_1 \,| + |\, x_2 - z_2 \,| \le \beta\,|\, x_1 - y_1 \,| + |\, x_2 - y_2 \,| + \beta\,|\, y_1 - z_1 \,| + |\, y_2 - z_2 \,|. \tag{8}$$

If the coordinates of the vectors *x*, *y*, *z* satisfy the condition $(x_1 \ge y_1 \ge z_1) \wedge (x_2 \ge y_2 \ge z_2)$, then expression (8) will take the form

$$\beta(x_1 - z_1) + (x_2 - z_2) \le \beta(x_1 - y_1) + (x_2 - y_2) + \beta(y_1 - z_1) + (y_2 - z_2). \tag{9}$$

After carrying out the transformation of expression (9), we get

$$\beta x_1 - \beta z_1 + x_2 - z_2 \le \beta x_1 - \beta y_1 + x_2 - y_2 + \beta y_1 - \beta z_1 + y_2 - z_2. \tag{10}$$

After reducing the identical terms of expression (10), we have

$$\beta x_1 - \beta z_1 + x_2 - z_2 = \beta x_1 - \beta z_1 + x_2 - z_2 \qquad (11)$$

which had to be proved.

If the coordinates of the vectors *x*, *y*, *z* satisfy the condition $(x_1 \le y_1 \le z_1) \wedge (x_2 \le y_2 \le z_2)$, expression (8) will take the form

$$\beta(-x_1 + z_1) + (-x_2 + z_2) \le \beta(-x_1 + y_1) + (-x_2 + y_2) + \beta(-y_1 + z_1) + (-y_2 + z_2). \qquad (12)$$

After opening the parentheses and reducing the identical terms, we get

$$-\beta x_1 + \beta z_1 - x_2 + z_2 = -\beta x_1 + \beta z_1 - x_2 + z_2, \qquad (13)$$

which had to be proved.

In a similar way, the correspondence of expression (5) to the third axiom of the metric is proved for other ratios of coordinates of vectors *x*, *y*, *z*.

Let's consider how the modulus of the voltage vector in any node of the network will look with the use of such a metric, and what properties it will have. By analogy with the usual Euclidean modulus of the voltage vector, it is possible to write

$$U = \beta |U_a| + |U_p|. \qquad (14)$$

Let's call this value the linear non-Euclidean modulus of the voltage vector. To determine the properties of this value, consider the equivalent circuit of the electrical network section (Fig.).

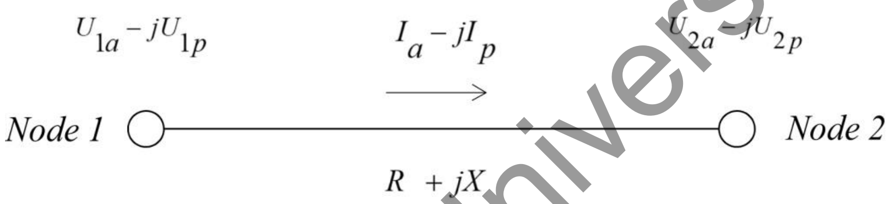

Figure. Equivalent circuit of the electrical network section

It should be noted that installation of telemetry equipment at individual nodes of the electrical network and subsequent determination of all unknown regime parameters according to Kirchhoff's laws has a high cost in networks of 110-35 kV, since these networks contain hundreds of nodes. The number of nodes in 330–750 kV networks is much smaller, and equipping all nodes with telemetry devices is much cheaper [16].

The following notations are used in Figure: $U_{1a} - jU_{1p}$ — complex voltage of the power supply (U_{1a}, U_{1p} — active and reactive components, respectively); $U_{2a} - jU_{2p}$ – complex voltage of the load node (U_{2a}, U_{2p} — active and reactive components, respectively); $I_a - jI_p$ — complex section current (I_a, I_p — active and reactive components, respectively); $R + jX$ — complex resistance of the section (note that in 110–35 kV networks this resistance has an active and inductive components).

Let's denote the linear non-Euclidean modulus of the voltage vectors of the first and second nodes, respectively

$$U_1^{\#} = \beta |U_{1a}| + |U_{1p}| \qquad (15)$$

and

$$U_2^{\#} = \beta |U_{2a}| + |U_{2p}|. \qquad (16)$$

Let's find how they depend on network parameters and currents. According to Ohm's law, it can be written

$$\begin{aligned} U_{2a} - jU_{2p} &= U_{1a} - jU_{1p} - \sqrt{3}(I_a - jI_p)(R + jX) = \\ &= U_{1a} - \sqrt{3}I_aR - \sqrt{3}I_pX - jU_{1p} - j\sqrt{3}I_aX + j\sqrt{3}I_pR = \\ &= U_{1a} - \sqrt{3}(I_aR + I_pX) - j\left(U_{1p} + \sqrt{3}(I_aX - I_pR)\right). \end{aligned} \qquad (17)$$

It follows from (17)

$$U_{2a} = U_{1a} - \sqrt{3}(I_aR + I_pX), \qquad (18)$$

$$U_{2p} = U_{1p} + \sqrt{3}\left(I_a X - I_p R\right). \tag{19}$$

So

$$U_1^{\#} = \beta |U_{1a}| + |U_{1p}|, \tag{20}$$

$$U_2^{\#} = \beta |U_{2a}| + |U_{2p}| = \beta |U_{1a} - \sqrt{3}\left(I_a R + I_p X\right) + |U_{1p} + \sqrt{3}\left(I_a X - I_p R\right)|. \tag{21}$$

By analogy with the voltage loss in the section (Fig.), which is defined as

$$\Delta U = \sqrt{U_{1a}^2 + U_{1p}^2} - \sqrt{U_{2a}^2 + U_{2p}^2}, \tag{22}$$

let's introduce the concept of linear non-Euclidean voltage loss, which is defined as

$$\Delta U^{\#} = U_1^{\#} - U_2^{\#} = \beta |U_{1a}| + |U_{1p}| - \beta |U_{2a}| - |U_{2p}| = \\ = \beta |U_{1a}| + |U_{1p}| - \beta |U_{1a} - \sqrt{3}\left(I_a R + I_p X\right)| - |U_{1p} + \sqrt{3}\left(I_a X - I_p R\right)|. \tag{23}$$

In expression (23), let's reveal the sign of the absolute value, taking into account the fact that for networks of 110–35 kV with an inductive load, U_{1a}, U_{1p}, U_{2a}, U_{2p}, I_a, I_p — positive real numbers. In addition, the ratios are valid for the same conditions

$$U_{1a} >> \sqrt{3}\left(I_a R + I_p X\right), \tag{24}$$

$$I_a X > I_p R. \tag{25}$$

As a result, we get

$$\Delta U^{\#} = \beta |U_{1a}| + |U_{1p}| - \beta |U_{1a} - \sqrt{3}\left(I_a R + I_p X\right)| - |U_{1p} + \sqrt{3}\left(I_a X - I_p R\right)| = \\ = \beta U_{1a} + U_{1p} - \beta U_{1a} + \sqrt{3}\beta I_a R + \sqrt{3}\beta I_p X - U_{1p} - \sqrt{3} I_a X + \sqrt{3} I_p R = \\ = \sqrt{3}\left(\beta I_a R + \beta I_p X + I_p R - I_a X\right). \tag{26}$$

It is obvious that depending on the parameters of the network, parameters of the mode and the reduction factor β, the linear non-Euclidean voltage loss $\Delta U^{\#}$ (unlike traditional voltage loss) can be equal to 0, and also take a positive or negative value.

It is quite clear that in order to solve the problem of reproducing all the unknown parameters of the network mode, we will be primarily interested in the cases of zero linear non-Euclidean voltage loss, i.e. the condition $U_1^{\#} = U_2^{\#}$. Therefore, let's formulate and prove the corresponding theorem, namely:

Theorem.

For networks of 110–35 kV with an inductive load, the linear non-Euclidean voltage loss in the section is 0 if and only if the condition $\frac{R_0}{X_0} = \frac{1 - \beta \operatorname{tg}\varphi}{\beta + \operatorname{tg}\varphi}$ is fulfilled, where R_0 — resistivity of the section, X_0 — inductive resistivity of the section, φ — phase shift angle between voltage and current, β — reduction factor.

Proof.

Let's solve the equation

$$\Delta U^{\#} = \sqrt{3}\left(\beta I_a R + \beta I_p X + I_p R - I_a X\right) = 0. \tag{27}$$

If I — current modulus, then $I_a = I\cos\varphi$ and $I_p = I\sin\varphi$, in addition, $R = R_0 L$, $X = X_0 L$, where L — section length. Taking these ratios into account, equation (27) can be written in the form

$$\sqrt{3} I\left(\beta R_0 L\cos\varphi + \beta X_0 L\sin\varphi + R_0 L\sin\varphi - X_0 L\cos\varphi\right) = 0. \tag{28}$$

Dividing the left and right sides of equation (28) by $\sqrt{3} IL\cos\varphi$, we get

$$\beta R_0 + \beta X_0 \operatorname{tg}\varphi + R_0 \operatorname{tg}\varphi - X_0 = R_0\left(\beta + \operatorname{tg}\varphi\right) - X_0\left(1 - \beta\operatorname{tg}\varphi\right) = 0. \tag{29}$$

It follows from equation (29)

$$R_0\left(\beta + \operatorname{tg}\varphi\right) = X_0\left(1 - \beta\operatorname{tg}\varphi\right) \tag{30}$$

and

$$\frac{R_0}{X_0} = \frac{1 - \beta \operatorname{tg} \varphi}{\beta + \operatorname{tg} \varphi}, \tag{31}$$

which proves the theorem for all cases except those for which $I = 0$, or $\cos\varphi = 0$, which we exclude from consideration as not occurring in practice.

Condition $\frac{R_0}{X_0} = \frac{1 - \beta \operatorname{tg} \varphi}{\beta + \operatorname{tg} \varphi}$ can be recorded in other forms. It is obvious that there are identities:

$$\frac{R_0}{X_0} = \frac{1 - \beta \operatorname{tg} \varphi}{\beta + \operatorname{tg} \varphi} \Leftrightarrow \operatorname{tg} \varphi = \frac{X_0 - \beta R_0}{\beta X_0 + R_0} \Leftrightarrow \beta = \frac{X_0 - R_0 \operatorname{tg} \varphi}{X_0 \operatorname{tg} \varphi + R_0}. \tag{32}$$

Therefore, if one of the conditions (32) is fulfilled for any 110–35 kV section with an inductive load, the equation $U_1^{\#} = U_2^{\#}$ is valid, that is, the linear non-Euclidean modulus of the voltage vector at the beginning of the section is equal to the linear non-Euclidean modulus of the voltage vector at the end of the section.

Estimation of the limits of use of the linear non-Euclidean modulus of the voltage vector

Let's analyze the conditions (32) of the theorem proved above from the point of view of its use to reduce the uncertainty of measurements. It is obvious that resistivity of the section R_0 and inductive resistivity of the section X_0 are constant and independent quantities. Phase shift angle between voltage and current φ although constantly changing (within narrow limits), it is also an independent quantity. So it is the only quantity that can be influenced by the researcher to ensure the condition $U_1^{\#} = U_2^{\#}$, is the reduction factor β. Table 1 shows the values β, which ensure the validity of the theorem depending on the values R_0, X_0 and $\cos\varphi$. They are designed for overhead lines for a range of cross-sections from 50 to 240 mm^2 and $\cos\varphi$ from 0.85 to 0.99. As follows from Table 1, in these ranges, β can take values from 0.887 to 2.141. From the above, we state that by choosing the appropriate value β for each line of a certain section and with a certain value of the power factor, it is possible to ensure the fulfillment of condition $U_1^{\#} = U_2^{\#}$.

Table 1

Dependence of the reduction factor β on the values R_0, X_0 and power factor cosφ

Cross-section, mm^2	50	70	95	120	150	185	240
R_0, Ohm/km	0.603	0.428	0.31	0.25	0.199	0.158	0.122
X_0, Ohm/km	0.452	0.441	0.43	0.423	0.417	0.41	0.401
cosφ							
0.85	0.089	0.251	0.413	0.523	0.642	0.757	0.878
0.86	0.108	0.271	0.435	0.548	0.67	0.788	0.913
0.87	0.128	0.293	0.459	0.574	0.699	0.821	0.95
0.88	0.149	0.315	0.485	0.602	0.73	0.856	0.99
0.89	0.171	0.339	0.511	0.632	0.764	0.894	1.034
0.90	0.195	0.364	0.54	0.664	0.8	0.935	1.081
0.91	0.219	0.391	0.571	0.698	0.839	0.98	1.134
0.92	0.245	0.42	0.604	0.736	0.882	1.03	1.192
0.93	0.273	0.451	0.641	0.777	0.93	1.086	1.258
0.94	0.304	0.486	0.681	0.823	0.984	1.149	1.333
0.95	0.338	0.524	0.727	0.876	1.046	1.223	1.422
0.96	0.376	0.568	0.78	0.938	1.12	1.311	1.529
0.97	0.42	0.62	0.843	1.012	1.21	1.42	1.665
0.98	0.474	0.684	0.924	1.108	1.328	1.566	1.849
0.99	0.549	0.774	1.039	1.248	1.504	1.79	2.141

Let's consider the cases when conditions (32) are not fulfilled. Inequalities follow from equations (27) and (32):

$$\beta > \frac{X_0 - R_0 \operatorname{tg}\varphi}{X_0 \operatorname{tg}\varphi + R_0} \Rightarrow \Delta U^{\#} > 0\,, \tag{33}$$

$$\beta < \frac{X_0 - R_0 \operatorname{tg}\varphi}{X_0 \operatorname{tg}\varphi + R_0} \Rightarrow \Delta U^{\#} < 0\,. \tag{34}$$

Let’s perform the comparative analysis of the relative losses of conventional and non-Euclidean voltage for one of the widespread cross-sections of 120 mm^2 at the value of $\cos\varphi = 0.92$, quite typical for a 110 kV network. Voltage losses are determined at the current modulus value of 100 A and the section length of $L = 30$ km. Let’s calculate the non-Euclidean voltage loss for different values of the reduction factor β. For simplification, let's take $U_1 = U_{1a} = 115$ kV, $U_{1p} = 0$. We will calculate the relative losses according to the formulas

$$\frac{\Delta U}{U_1} = 1 - \sqrt{\left(1 - \frac{\sqrt{3} IL\left(R_0\cos\varphi + X_0\sin\varphi\right)}{U_1}\right)^2 + \left(\frac{\sqrt{3} IL\left(X_0\cos\varphi - R_0\sin\varphi\right)}{U_1}\right)^2}\,, \tag{35}$$

$$\frac{\Delta U^{\#}}{U_1^{\#}} = \frac{\sqrt{3} IL\left(\beta R_0\cos\varphi + \beta X_0\sin\varphi + R_0\sin\varphi - X_0\cos\varphi\right)}{U_1^{\#}}\,. \tag{36}$$

The results of the calculations are shown in Table 2.

Table 2

Conventional and non-Euclidean voltage loss in the section AC-120 at cosφ = 0.92, *I* = 100 A, *L* = 30 km and different reduction factors β

ΔU,%	$\Delta U^{\#}$,%	
1.78	$\beta = 0.600$	–0.24
	$\beta = 0.700$	–0.06
	$\beta = 0.736$	0
	$\beta = 0.800$	0.11
	$\beta = 0.9$	0.29

Let's analyze the results given in Tables 1 and 2. It is obvious that even if the researcher inaccurately predicts cosφ in the section, and accordingly inaccurately determines the reduction factors β, then the value of $\Delta U^{\#}$ in this case will be 6–15 times less than the value of ΔU. This makes it reasonable to use the linear non-Euclidean modulus of the voltage vector $U^{\#}$ when reproducing the modes of electrical networks. To do this, it is necessary to calculate the network mode at average statistical loads, determine the values of the reduction factor β that provide for each section $\Delta U^{\#} = 0$, and then determine the value of $U^{\#}$ in each node. If we assume that the values of cosφ in the sections under current loads remain unchanged, then it can be assumed that the values of $U^{\#}$ in each node under current loads will also not change, and after receiving from the telemetry devices the voltage values in the nodes, it will be possible to calculate the active and reactive components of node voltage. Since in networks of 110-35 kV, the values of cosφ fluctuate in a rather narrow range, the uncertainty of measuring the active and reactive components of the node voltage is quite acceptable for the task of reproducing the modes of electrical networks.

The method of reproducing the modes of electric networks using the linear non-Euclidean modulus of the voltage vector $U^{\#}$ was implemented in the software complex “Analytical system of reproducing electricity consumption”, which was implemented in the divisions of the energy supply company “Vinnytsiaoblenergo”, the city of Vinnytsia, Ukraine. In the process of operating the developed software complex, both company specialists and developers continuously assessed the uncertainty of network mode reproduction.

In the conditions of providing the software complex with telemetric information at 70% of the maximum level, it was established that due to the use of the non-Euclidean modulus of the voltage vector, the standard deviation of the modes integral indicators decreased by almost 50% compared to traditional methods. This practically proves the expediency of using non-Euclidean metrics in power industry.

Conclusions

To ensure continuous current control of electric power consumption, the optimal solution is to place sensors of active and reactive power in each node of the electric network and transfer measurement information to dispatching control centers, which for large networks requires huge capital costs. Therefore, it is advisable to install such sensors only in individual nodes, followed by reproducing of all unknown parameters of the network mode based on Kirchhoff's laws.

Measuring complex values of voltage on substation buses requires determining the phase shift angle between the voltages of different substations, which is an extremely difficult task, requires significant capital investments, and in most cases leads to the impracticality of such measurements. In order to solve this problem, it is proposed to receive from telemetry devices only modulus of voltages in the network nodes, which means that the input data for the task of reproducing the electrical networks modes have the significant uncertainty. In order to reduce this uncertainty, the expediency of using not the usual quadratic Euclidean metric, but a linear non-Euclidean metric to determine the node voltage modulus has been theoretically proven and practically confirmed.

Based on the calculations and practical studies, it was established that the uncertainty of reproducing network mode parameters according to Kirchhoff's laws, in the presence of the necessary telemetry information for the “Analytical system of reproducing electricity consumption” software complex, is significantly smaller when using a linear non-Euclidean modulus of the voltage vector than when using the usual voltage vector modulus.

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Өлшеу қателігін азайту үшін электр энергетикасында евклидтік емес көрсеткіштерді қолдану

Мақалада ірі, тармақталған жоғары вольтты электр желілерінде электр энергиясын тұтынуды үздіксіз бақылау есептерінде кернеуді өлшеу кезінде туындайтын белгісіздікті азайту үшін евклидтік емес метриканы пайдалану ұсынылған. Мәселе мынада, электр энергиясын тұтынуды үздіксіз бақылау үшін электр желісінің әрбір торабында (әрбір қосалқы станцияда) белсенді және реактивті қуатты өлшеу құралдарын орнату және диспетчерлік басқару орталықтарына өлшеу ақпаратын беруді қамтамасыз ету қажет. Ірі электр желілері бар, электр тораптары мен диспетчерлік орталықтар арасындағы үлкен қашықтық бар елдер үшін бұл үлкен күрделі шығындарды талап етеді. Сондықтан электр қуаты мен кернеуді өлшеуге арналған жабдықты тек электр желісінің жеке тораптарына орналастырған жөн, содан кейін Кирхгоф заңдары негізінде қалған тораптың параметрлерін есептеген жөн. Бірақ сонымен бірге өлшеудің айтарлықтай белгісіздігі бар, өйткені күрделі кернеу мәні әдетте өлшенбейді және есептеу үшін тек кернеу мәндерінің модулі қолданылады. Евклидтік емес көрсеткіштерді пайдалану электр желісінің әрбір торабында электр энергиясын тұтынуды бақылау үшін қажетті кіріс деректерінің белгісіздігін төмендетуді қамтамасыз етеді.

Кілт сөздер: евклидтік емес метрика, жоғары вольтты электр желісі, электр қуаты, өлшеу белгісіздігі, өлшеу ақпараты.

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Применение неевклидовой метрики в электроэнергетике для уменьшения погрешности измерения

В статье предложено использовать неевклидову метрику для уменьшения неопределенности, которая возникает при измерении напряжения в задачах непрерывного контроля потребления электроэнергии в крупных, разветвленных высоковольтных электрических сетях. Проблема заключается в том, что для непрерывного контроля потребления электроэнергии необходимо в каждом узле электрической сети (на каждой подстанции) установить средства измерения активной и реактивной мощности и обеспечить передачу измерительной информации в диспетчерские центры управления. Для стран с крупными электрическими сетями, большими расстояниями между узлами электросетей и диспетчерскими центрами это требует огромных капитальных затрат. Поэтому оборудование для измерения электрической мощности и напряжения целесообразно размещать только в отдельных узлах электрической сети, а затем рассчитывать параметры остальных узлов на основе законов Кирхгофа. Однако в то же время существует значительная неопределенность измерения, поскольку комплексное значение напряжения обычно не измеряется, а для расчета применяется только модуль значений напряжения. Использование неевклидовых метрик обеспечивает снижение неопределенности входных данных, необходимых для контроля потребления электроэнергии в каждом узле электрической сети.

Ключевые слова: неевклидова метрика, высоковольтная электрическая сеть, электрическая мощность, неопределенность измерений, измерительная информация.

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