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INNOVATIVE TECHNIQUE FOR EVALUATING ELECTRIC POWER DISTORTION IN CABLE TRANSMISSION LINE

Purpose. The rationale for use of electrical power components produced by current and voltage harmonics with different frequencies to assess its impact on the electrical energy transmission process.

Methodology. PI-section equivalent circuit of the cable line is used. Insulation conductivity is assumed to be infinitely small. Using the results of known studies, the change in active resistance with increasing current frequency is taken into account. The cable power line is represented by a quadripole, whose equations are written in the A-form. With the constant voltage composition at the end of the line, for two cases of alternating non-sinusoidal current at the end of the line, its similar current value and the nonlinear distortion coefficient, the quadripole mode parameters are calculated. Based on the obtained parameters of the line mode, according to the existing methods for determining the power components, their numerical calculation was performed. According to the results of the analysis obtained power components for the two cases, their concurrency at the beginning of the line and the discrepancy at the end of the line were noted. Based on this, a conclusion was drawn on the low information content of power components calculated by the known method.

Findings. Using an alternative method for determining the components of instantaneous power, depending on the combination of harmonic frequencies of current and voltage, a number of power distortion indicators are proposed. At the same time active and reactive powers are traditionally used. Performing a numerical calculation of the indicated power indices for the power line, under the conditions of two previously agreed experiments, their effectiveness is demonstrated. It is noted that for the conditions of conducted numerical experiments, the indices of the share of pseudo-canonical and non-canonical components differ significantly depending on the distribution of the amplitudes of current harmonics for the same current value, and the nonlinear distortion coefficient

Originality. The theory of instantaneous electrical power has been developed in terms of power distortion indicators, determined taking into account the combination of frequencies of polyharmonic current and voltage in single-phase electrical systems.

Practical value. Innovative indicators of electrical power distortion, obtained based on the analysis of the composition of instantaneous power, reflect the low quality of electrical energy. Additional introduction of the proposed indicators into the electricity metering procedure is a prerequisite for motivating participants in the process to improve quality.

Keywords: *cable transmission line, current and voltage harmonics, power components, norm of power*

Introduction. Semiconductor converters are widely used in the modern power industry for the mode control of the electric power system elements. At the same time, distribution of connections of low and medium power generating complexes to the power system is noted. These complexes use the technique of electrical energy converting of direct or alternating current of varying frequency into electrical energy that will be inverted into the electrical power network. As a rule, part of the electric power system or power supply system comes in view of researchers [1]. A negative impact on the electrical energy quality is exerted by increasing the installed capacity of electrical technology of consumers with devices of semiconductor technique, which are also an element of the electric power system. In this case, the problems of electromagnetic compatibility are solved successfully taking into account the quality level of electrical energy [2]. Small generating systems are installed close to consumers' location. They are connected to the power supply system with the limited capacity lines. A striking example in this case involves the co-generating devices. The generators of these installations perceive and sometimes aggravate the electrical energy quality, which affects their mode and characteristics as a result [3]. Thus, a number of tasks arise in assessing the distortion of electrical energy, and its effect on the electricity system elements [4].

Literature review. The influence of higher harmonics of the consumer current (load) on the capacity of transmission lines of electric energy is taken into account by line impedance increasing. Special attention is paid to the skin effect. In research [5], based on the early experience of scientists, it is shown that the presence of higher current harmonics necessitates a decrease in the cable lines' load capacity due to increase a power loss and increase in the temperature of cable cores. Similarly in [6] a need is noted to adjust the line load for public utility company networks that provide LED lighting systems power. In this case, emphasis is placed on the growth of the active resistance of the line with an increase in the nonlinear current distortion rate. In general, higher harmonics are characteristic not only of current, but also of voltage. However, in [3], using the example of a cable transmission line, it was concluded that voltage distortion does not effect the line losses level. In turn, in work [7] a section of the power supply system of a mining enterprise with a voltage of 6 kV with semiconductor converters is considered. Converters, providing power to DC motors operating in intermittent duty cycles, generate harmonic current into the network, while distorting the voltage. The analytical expressions obtained in [7] and results of measuring operation mode parameters prove the effect of current and voltage distortion on the growth of power supply system losses. Thus, the prerequisites are created to take into account the impact of both the power level of the consumer and its distortion nature on the losses level. The most solid document that declares the components of electrical power is the standard of the Institute of Electrical and Electronics Engineers (IEEE) – IEEE 1459-2010 [8]. However, studies by a number of scientists show that the indicated components are not exhaustive [9]. The effect of inactive power components on network mode parameters is considered in work [10]. To quantify this effect, quadratic norms of the electric power components are used [11]. A similar technique for the selection of electrical power alternative indicators was proposed in work [12]. Separating the power components formed by the interaction of current harmonics and voltage harmonics depending on their frequency, the work [13] theoretically justifies an approach to accounting for the quantity and quality of electrical energy.

Purpose. The rationale for use of electrical power components produced by current and voltage harmonics with different frequencies to assess its impact on the electrical energy transmission process.

Results. Standard [8] sets several components of electric power that are recommended for determination. In particular, for a single-phase circuit, voltage and current are taken in the form

$$u = U_0 + \sum_k u_k = U_0 + \sqrt{2}\sum_k U_k \sin\left(k\omega t + \psi_{uk}\right); \quad (1)$$

$$i = I_0 + \sum_n i_n = I_0 + \sqrt{2}\sum_n I_n \sin\left(n\omega t + \psi_{in}\right), \quad (2)$$

where U_0, I_0 are constant components of voltage and current, respectively; k, n are voltage and current harmonics orders, respectively; U_k, I_n are effective values of voltage and current harmonics, respectively; ψ_{uk}, ψ_{ik} are voltage and current harmonics phase shift, respectively; ω is angular frequency; t is time. In the future, we take the current and voltage constant components equal to zero ($I_0 = 0$; $U_0 = 0$). RMS values of current and voltage are used

$$I = \sqrt{\frac{1}{T}\int_{t_0}^{t_0+T} i^2 dt} = \sqrt{\sum_n I_n^2}; \quad U = \sqrt{\frac{1}{T}\int_{t_0}^{t_0+T} u^2 dt} = \sqrt{\sum_k U_k^2},$$

where T is the fundamental period, $T = 2\pi/\omega$; t_0 is reference time. The RMS value of current and voltage higher harmonics is

$$I_H = \sqrt{\frac{1}{T}\int_{t_0}^{t_0+T}\left(\sqrt{2}\sum_{n\neq 1} I_n \sin\left(n\omega t + \psi_{in}\right)\right)^2 dt} = \sqrt{\sum_{n\neq 1} I_n^2};$$

$$U_H = \sqrt{\frac{1}{T}\int_{t_0}^{t_0+T}\left(\sqrt{2}\sum_{k\neq 1} U_k \sin\left(k\omega t + \psi_{uk}\right)\right)^2 dt} = \sqrt{\sum_{k\neq 1} U_k^2}.$$

The total harmonic distortion of current and voltage is

$$THD_U = \frac{U_H}{U_1} = \sqrt{\left(\frac{U}{U_1}\right)^2 - 1}; \quad THD_I = \frac{I_H}{I_1} = \sqrt{\left(\frac{I}{I_1}\right)^2 - 1}.$$

The instantaneous power is defined as

$$p = ui = \sum_{k,n} U_k I_n \cos\left[\left(k-n\right)\omega t + \psi_{uk} - \psi_{in}\right] - \sum_{k,n} U_k I_n \cos\left[\left(k+n\right)\omega t + \psi_{uk} + \psi_{in}\right]. \quad (3)$$

Then, to characterize the electric power, the following components are introduced:

- active power

$$P = \frac{1}{T}\int_{t_0}^{t_0+T} p dt;$$

- fundamental active power

$$P_1 = U_1 I_1 \cos(\psi_{u1} - \psi_{i1});$$

- non-fundamental active power

$$P_H = \sum_{h\neq 1} U_h I_h \cos\left(\psi_{uh} - \psi_{ih}\right);$$

- fundamental reactive power

$$Q_1 = U_1 I_1 \sin(\psi_{uh} - \psi_{ih});$$

- apparent power

$$S = UI;$$

- fundamental apparent power

$$S_1 = U_1 I_1;$$

- non-fundamental apparent power

$$S_N = \sqrt{S^2 - S_1^2};$$

- current distortion power

$$D_I = U_1 I_H = S_1 THD_I;$$

- voltage distortion power

$$D_U = I_1 U_H = S_1 THD_U;$$

- harmonic apparent power

$$S_H = U_H I_H = S_1 THD_I THD_U;$$

- harmonic distortion power

$$D_H = \sqrt{S_H^2 - P_H^2};$$

- non-active power

$$N = \sqrt{S^2 - P^2}.$$

Consider an element of the power supply system – a cable transmission line with a voltage rate of 10 kV. Let us take the cable transmission line type – SBG 16, 5 km long. The cable equivalent circuit is shown in Fig. 1.

Let us set the voltage and current at the end of the cable transmission line (*Finish line*) for two experiments (*Exp1* and *Exp2*, Table 1). Using the superposition principle, we perform calculation for each voltage and current harmonic (h) at the beginning of the cable transmission line $(\dot{U}_{beg}(h), \dot{I}_{beg}(h))$, given the voltage and current harmonic at the end of the cable transmission line $(\dot{U}_{fin}(h), \dot{I}_{fin}(h))$. To do this, we use the A-form quadripole equations in a complex form for scheme (Fig. 1)

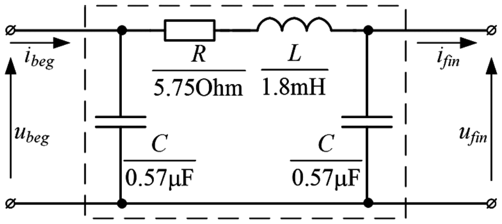
$$\dot{U}_{beg}(h) = A(h)\dot{U}_{fin}(h) + B(h)\dot{I}_{fin}(h);$$
$$\dot{I}_{beg}(h) = C(h)\dot{U}_{fin}(h) + D(h)\dot{I}_{fin}(h),$$

where $A(h) = 1 + Y(h)Z(h)$; $B(h) = Z(h)$; $C(h) = Y(h)(1 + Y(h)Z(h))$; $D(h) = 1 + Y(h)Z(h)$ are quadripole parameters; $Y(h) = j\omega hC$ is transverse line capacitive conductance; $Z(h) = R(h) + j\omega hL$ is line longitudinal impedance.

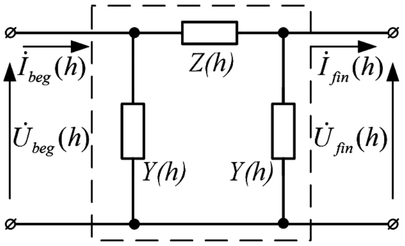
The transmission line resistance $R(h)$ depends on the frequency (harmonic order h) of the current due to the action of the skin effect. As noted in [5, 6], this dependence can be expressed as

$$R(h) = R_1\left(0.187 + 0.532\sqrt{h}\right),$$

where R_1 is active resistance to the fundamental frequency current.



a



b

Fig. 1. The equivalent circuit of the cable transmission line

The voltage and current initial data at the end of the line (*Finish line*) and the calculated voltage and current at the beginning of the line (*Beginning line*) are given in Table 1.

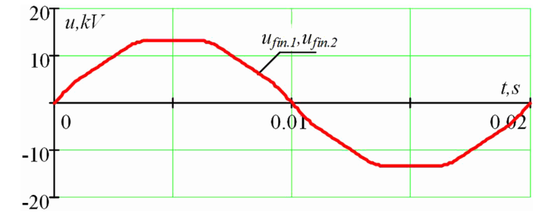
The voltage and current obtained as a calculation result will be expressed as a time function in accordance with equations (1, 2) (Figs. 2, *a, b*). The power calculated by the equation (3) for both experiments is shown in the time diagram form in Fig. 2, *c*. The power at the beginning of the line in Fig. 2 is not represented, due to a slight visual difference from the power at the end of the line.

For the currents and voltages given when making experiments, we define the power indices in accordance with the standard [8]. The calculations results are summarize in Table 2. The calculation result analysis shows that the power components' integral indices at the beginning of line are the same for both experiments. It is necessary to pay attention to the difference in power components at the beginning of the line for two experiments: active power ΔP = 2.7 [kW]; non-fundamental active power ΔP_H = 2.7 [kW]; non-fundamental apparent power ΔS_N = 1.17 [kVA]; current distortion power ΔD_I = 1.42 [kvar]; harmonic distortion power ΔD_H = 7.13 [kvar]. Consequently, taking into account the different values of power components at the beginning of the line, with the same power components' values at the end of the line, it is reasonable to question their information content. A more important disadvantage is the fact that the values of these components are the same, for different instantaneous power (Fig. 2, *c*).

Table 1

Voltage and current at the beginning and end of the cable transmission line for two experiments (Fig. 1)

Parameter	Exp1		Exp2	
	Finish line	Beginning line	Finish line	Beginning line
$\dot{U}(1)$	1414 ∠ 0°	1433 ∠ 0°	1414 ∠ 0°	1433 ∠ 1°
$\dot{U}(3)$	400 ∠ 0°	593.1 ∠ 0.1°	400 ∠ 0°	463.73 ∠ 2.3°
$\dot{U}(7)$	400 ∠ 0°	491.7 ∠ 0.1°	400 ∠ 0°	684.3 ∠ 10.4°
$\dot{I}(1)$	64 ∠ 39°	67.3 ∠ 42°	64 ∠ 39°	67.3 ∠ 42.1°
$\dot{I}(3)$	30 ∠ 0°	29.9 ∠ 1°	10 ∠ 0°	10 ∠ 2.7°
$\dot{I}(7)$	10 ∠ 0°	10 ∠ 6.4°	30 ∠ 0°	29.9 ∠ 2.6°



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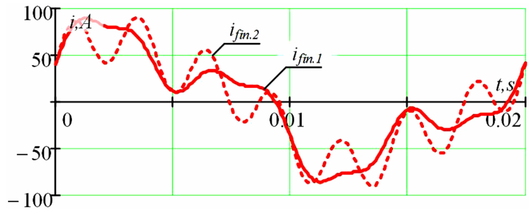

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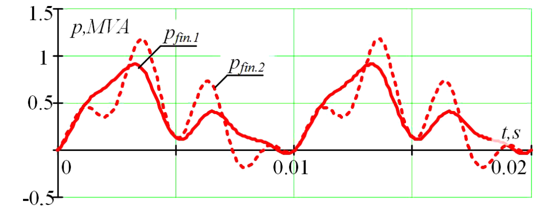

c

Fig. 2. Parameter diagrams over time at the end of the line:

a – voltage; b – current; c – power

Table 2

The calculation results of power components at the end and the beginning of the line

Parameter	Exp1		Exp2	
	p_{fin1}	p_{beg1}	p_{fin2}	p_{beg2}
P, [kW]	361.5	374.0	361.5	371.30
P_1, [kW]	353.5	362.70	353.5	362.70
P_H, [kW]	8	11.30	8	8.54
Q_1, [kvar]	–285.70	–321.90	–285.70	–313.70
S, [kVA]	505.20	533.40	505.20	533.00
S_I, [kVA]	454.47	485.05	454.47	485.14
S_N, [kVA]	220.65	221.91	220.65	220.74
D_I, [kvar]	219.51	220.70	219.51	219.28
D_U, [kvar]	17.27	25.22	17.27	27.65
S_H, [kVA]	8.34	11.47	8.34	12.49
D_H, [kvar]	2.34	2.00	2.34	9.13
N, [kvar]	352.91	380.32	352.91	382.39

Let us estimate the process of energy transfer in the cable transmission line (Fig. 1) under the same conditions (Table 1), using the power components proposed in work [13]. We present power in the form

$$p=\sum_{k,n}\left[U_kI_n\cos\left(\psi_{uk}-\psi_{in}\right)\right]\cos\left(k-n\right)\omega t+$$
$$+\sum_{k,n}\left[-U_kI_n\cos\left(\psi_{uk}+\psi_{in}\right)\right]\cos\left(k+n\right)\omega t+$$
$$+\sum_{k,n}\left[-U_kI_n\sin\left(\psi_{uk}-\psi_{in}\right)\right]\sin\left(k-n\right)\omega t+$$
$$+\sum_{k,n}\left[U_kI_n\sin\left(\psi_{uk}+\psi_{in}\right)\right]\sin\left(k+n\right)\omega t.$$

Following the separation, which was adopted in [13], we will consider the power components in this way:

1. Zero frequency cosine component (active power)

$$p_{a.0}=\sum_{k,n}\left[U_k I_n \cos\left(\psi_{uk}-\psi_{in}\right)\right]\cos\left(k-n\right)\omega t = \\ = P\cos(0), \quad \text{for } k-n=0.$$

2. Zero frequency sinus component (reactive power)

$$p_{b.0}=\sum_{k,n}\left[-U_k I_n \sin\left(\psi_{uk}-\psi_{in}\right)\right]\sin\left(k-n\right)\omega t = \\ = Q\sin(0), \quad \text{for } k-n=0.$$

3. The canonical component, product of current and voltage harmonics of the same frequency

$$p_c=\sum_{k,n}\left[-U_k I_n \cos\left(\psi_{uk}+\psi_{in}\right)\right]\cos\left(k+n\right)\omega t + \\ +\sum_{k,n}\left[U_k I_n \sin\left(\psi_{uk}+\psi_{in}\right)\right]\sin\left(k+n\right)\omega t = \\ =\sum_s P_{b.c.s}\sin(s\omega t)+\sum_s P_{a.c.s}\cos(s\omega t), \\ \text{for } s=k+n=2k=2n,$$

where $P_{a.c.s}$, $P_{b.c.s}$ are the amplitudes of cosine and sine canonical components, respectively, due to the same frequency harmonics of current and voltage.

4. A pseudo-canonical component, product of current and voltage harmonics of different frequency, the addition or subtraction of which gives an even result

$$p_{pc}=\sum_{k,n}\left[U_k I_n \cos\left(\psi_{uk}-\psi_{in}\right)\right]\cos\left(k-n\right)\omega t + \\ +\sum_{k,n}\left[-U_k I_n \cos\left(\psi_{uk}+\psi_{in}\right)\right]\cos\left(k+n\right)\omega t + \\ +\sum_{k,n}\left[-U_k I_n \sin\left(\psi_{uk}-\psi_{in}\right)\right]\sin\left(k-n\right)\omega t + \\ +\sum_{k,n}\left[U_k I_n \sin\left(\psi_{uk}+\psi_{in}\right)\right]\sin\left(k+n\right)\omega t = \\ =\sum_s P_{a.pc.s}\cos(s\omega t)+\sum_s P_{b.pc.s}\sin(s\omega t), \\ \text{for } s=\left|k\pm n\right|=(2k \text{ or } 2n) \text{ and } k\neq n,$$

where $P_{a.pc.s}$, $P_{b.pc.s}$ are the amplitudes of cosine and sine pseudo-canonical components, respectively, due to the different frequency harmonics of current and voltage, the addition or subtraction of which gives an even result.

5. A non-canonical component, product of current and voltage harmonics of different frequency, the addition or subtraction of which gives an odd result

$$p_{nc}=\sum_{k,n}\left[U_k I_n \cos\left(\psi_{uk}-\psi_{in}\right)\right]\cos\left(k-n\right)\omega t + \\ +\sum_{k,n}\left[-U_k I_n \cos\left(\psi_{uk}+\psi_{in}\right)\right]\cos\left(k+n\right)\omega t + \\ +\sum_{k,n}\left[-U_k I_n \sin\left(\psi_{uk}-\psi_{in}\right)\right]\sin\left(k-n\right)\omega t + \\ +\sum_{k,n}\left[U_k I_n \sin\left(\psi_{uk}+\psi_{in}\right)\right]\sin\left(k+n\right)\omega t = \\ =\sum_s P_{a.nc.s}\cos(s\omega t)+\sum_s P_{b.nc.s}\sin(s\omega t), \\ \text{for } s=\left|k\pm n\right|\neq(2k \text{ or } 2n) \text{ and } k\neq n,$$

where $P_{a.nc.s}$, $P_{b.nc.s}$ are the amplitudes of cosine and sine non-canonical components, respectively, due to the different frequency harmonics of current and voltage, the addition or subtraction of which gives an odd result.

To estimate the individual contribution of the indicated components to the instantaneous power, let us use the RMS value, determined on the repeatability period of power [13], considering it as a signal

$$\|p\|=\sqrt{\frac{1}{T}\int_{t_0}^{t_0+T}p^2dt}.$$

For this purpose, we introduce the following indicators:

1. Active power degree

$$q_P=\frac{P}{\|p\|}.$$

2. Reactive power degree

$$q_Q=\frac{Q}{\|p\|}.$$

3. Canonical power degree

$$q_c=\frac{\sqrt{\frac{1}{T}\int_{t_0}^{t_0+T}p_c^2dt}}{\|p\|}=\sqrt{\frac{\sum_s\left(P_{a.c.s}^2+P_{b.c.s}^2\right)}{2\|p\|^2}}.$$

4. Pseudo-canonical power degree

$$q_{pc}=\frac{\sqrt{\frac{1}{T}\int_{t_0}^{t_0+T}p_{pc}^2dt}}{\|p\|}=\sqrt{\frac{\sum_s\left(P_{a.pc.s}^2+P_{b.pc.s}^2\right)}{2\|p\|^2}}.$$

5. Non-canonical power degree

$$q_{nc}=\frac{\sqrt{\frac{1}{T}\int_{t_0}^{t_0+T}p_{nc}^2dt}}{\|p\|}=\sqrt{\frac{\sum_s\left(P_{a.nc.s}^2+P_{b.nc.s}^2\right)}{2\|p\|^2}}.$$

Using the above equations for active and reactive power, based on the data in Table 1, we will perform a numerical calculation of the degrees for previously indicated experiments. The calculation results are summarized in Table 3.

Thus, the power degrees obtained by the ratio of power components with its RMS norm are different. We perform a comparative analysis of the results obtained (Table 3.) for power at the end of the cable transmission line. First, we should note the difference in the RMS power values at the end

Table 3

The calculation results of degrees of the power component at the end and beginning of the cable transmission line

Parameter	Exp1		Exp2	
	p_{fin1}	p_{beg1}	p_{fin2}	p_{beg2}
P, [kW]	361.50	374.00	361.50	371.30
Q, [kvar]	–285.80	–320.60	–285.80	–313.70
$\|p\|$,[kVA]	458.90	480.80	511.30	529.30
$P_{RMS.C}$, [kVA]	482.80	507.40	483.80	505.50
$P_{RMS.PC}$, [kVA]	232.90	240.90	235.40	239.0
$P_{RMS.NC}$, [kVA]	2.12	3.35	2.11	3.65
q_P, [pu]	0.788	0.778	0.707	0.701
q_Q, [pu]	–0.623	–0.667	–0.559	–0.593
q_C, [pu]	0.697	0.713	0.629	0.648
q_{PC}, [pu]	0.508	0.501	0.460	0.452
q_{NC}, [pu]	0.005	0.007	0.004	0.007

of the cable transmission line – $\Delta\|p\|$ = 511.3 – 458.9 = = 52.4 [kVA] ≙ 10.24 %. As a result, with the same active power value, the active power degree values (q_P) are different 0.788 > 0.707. Among other things, the non-canonical power degree value (q_C) and pseudo-canonical power degree value (q_{PC}) are 0.697 > 0.629; 0.508 > 0.460, respectively, for the first and second experiments. The numerical values of the proposed indicators obtained from the experiment results, create prerequisites for their further use in assessing degrees and reasons of electrical power distortion.

Conclusions.

1. According to the analysis results of existing methods for calculating power components, it has been established that the diversity of these indicators, regulated by existing standards, ineffectively reflects instantaneous power characteristics. This is proved by the numerical experiment conducted for the cable transmission line presented by PI-shaped equivalent circuit, for which the active resistance change under the skin effect is taken into account. In this case, at the end of the cable transmission line, the voltage and current with the same RMS and THD value act.

2. It is noted that the different distortion mode of instantaneous power at the end of the cable transmission line, corresponds to the identical integral power indicators, calculated by known methods. However, this leads to different power indices calculated by the same methods at the beginning of the cable transmission line and different values in line power losses.

3. The alternative power indicators calculated relative to its RMS value are proposed. Their effectiveness in reflecting the power distortion is shown, using the alternative method for determining the power components depending on the harmonics frequency combination of current and voltage. It is noted that for the conditions of the conducted numerical experiments, the pseudo-canonical power and non-canonical power degrees differ.

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Інноваційна методика оцінки спотворення електричної потужності кабельної лінії електропередачі

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Мета. Обґрунтування використання компонент електричної потужності, утворених гармоніками струму й напруги різної частоти, для оцінки її впливу на процес передачі електричної енергії.

Методика. Використана П-образна схема заміщення кабельної лінії електропередачі. Провідність ізоляції прийнята нескінченно малою. Із використанням результатів відомих досліджень урахована зміна активного опору з підвищенням частоти струму. Кабельна лінія електропередачі представлена чотириполюсником, рівняння якого записані в А-формі. При незмінному характері напруги в кінці лінії, для двох випадків змінного несинусоїдального струму в кінці лінії, однаковому його діючому значенні й коефіцієнті нелінійних спотворень, виконано розрахунок параметрів режиму чотириполюсника. На підставі отриманих параметрів режиму лінії, за існуючих методик визначення складових потужності, виконано їх чисельний розрахунок. За результатами аналізу отриманих складових потужності для двох випадків відзначено їх збіг на початку лінії та розбіжність у кінці лінії. На підставі цього зроблено висновок щодо низької інформативності складових потужності розрахованих за відомою методикою.

Результати. Із використанням альтернативної методики визначення компонент миттєвої потужності, у залежності від поєднання частот гармонік струму й напруги, запропоновано ряд показників спотворення потужності. При цьому традиційно використані активна й реактивна потужності. На базі чисельних розрахунків зазначених показників потужності для ліній електропередач, в умовах двох раніше зазначених експериментів, продемонстрована їх ефективність. Відзначено, що для умов проведених чисельних експериментів істотно відрізняються показники частки псевдоканонічної та неканонічної компонент у залежності від розподілу амплітуд гармонік струму при одному й тому ж діючому його значенні та коефіцієнті нелінійних спотворень.

Наукова новизна. Отримала розвиток теорія миттєвої електричної потужності в частині показників спотворення потужності, що визначаються з урахуванням комбінації частот полігармонічного струму й напруги однофазних електричних систем.

Практична значимість. Інноваційні показники спотворення електричної потужності, отримані на основі аналізу складу миттєвої потужності, відображають неякісність електричної енергії. Додаткове введення запропонованих показників до процедури обліку електричної енергії є передумовою для мотивації учасників процесу до підвищення якості.

Ключові слова: *кабельна лінія електропередачі, гармоніки струму й напруги, компоненти потужності, норма потужності*

Инновационная методика оценки искажения электрической мощности кабельной линии электропередачи

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Цель. Обоснование использования компонент электрической мощности, образованных гармониками тока и напряжения разной частоты, для оценки ее влияния на процесс передачи электрической энергии.

Методика. Использована П-образная схема замещения кабельной линии электропередачи. Проводимость изоляции принята бесконечно малой. С использованием результатов известных исследований учтено изменение активного сопротивления с повышением частоты тока. Кабельная линия электропередачи представлена четырехполюсником, уравнения которого записаны в А-форме. При неизменном характере напряжения в конце линии, для двух случаев переменного несинусоидального тока в конце линии, одинаковом его действующем значении и коэффициенте нелинейных искажений, выполнен расчет параметров режима четырехполюсника. На основании полученных параметров режима линии, по существующим методикам определения составляющих мощности, выполнен их численный расчет. По результатам анализа полученных составляющих мощности для двух случаев отмечено их совпадение в начале линии и несовпадение в конце линии. На основании этого сделан вывод о низкой информативности составляющих мощности, рассчитанных по известной методике.

Результаты. С использованием альтернативной методики определения компонент мгновенной мощности, в зависимости от сочетания частот гармоник тока и напряжения, предложен ряд показателей искажения мощности. При этом традиционно использованы активная и реактивная мощности. Выполнив численный расчет указанных показателей мощности для линии электропередачи, в условиях двух ранее оговоренных экспериментов, продемонстрирована их эффективность. Отмечено, что для условий проведенных численных экспериментов существенным образом отличаются показатели доли псевдоканонической и неканонической компонент в зависимости от распределения амплитуд гармоник тока при одном и том же действующем его значении и коэффициенте нелинейных искажений

Научная новизна. Получила развитие теория мгновенной электрической мощности в части показателей искажения мощности, определяемых с учетом комбинации частот полигармонического тока и напряжения однофазных электрических систем.

Практическая значимость. Инновационные показатели искажения электрической мощности, полученные на основе анализа состава мгновенной мощности, отражают некачественность электрической энергии. Дополнительное введение предложенных показателей в процедуру учета электрической энергии является предпосылкой для мотивации участников процесса к повышению качества.

Ключевые слова: *кабельная линия электропередачи, гармоники тока и напряжения, компоненты мощности, норма мощности*

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