DEFINITION OF CAPACITY AND ENERGY OF DISTORTION IN THE SYSTEMS OF ELECTROSUPPLY WITH NONLINEAR POWER

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ABSTRACT

One of the basic integrated parameters describing quality of electrical energy in energy-systems is presence nonlinear power of distortion energy. The principal advantage of this parameter is opportunity of quality management by electrical energy on the base of the tariff's mechanism. The results of analyze of rightness of the calculation methods and measurement of energy of distortion are given.

Keywords: definition, capacity, energy of distortion, electrosupply, nonlinear power.

I. INTRODUCTION

Increase of sensitivities of the modern technology to distortion of sinusoidal character of change of voltage and current demands perfection of the mechanism of responsibility for reduction of quality of electrical energy. Actuality of the date problem causes very mach number of the scientific publications, where the various methods of calculation and measurement of capacity and energy in the systems of electro-supply (SES) with nonlinear power (NP) are proffered.

In that case, the specify of energetic processes in circuits of variable current is not enough full taken into account, and also not using the date factor some authors really use some separate recommendations proffered in the literature on the theoretical bases of the electrotechnical the specify of energetic processes without general research. And as on the basis of these methods the measure devices occupied the world market are created, the problem of reduction of the methodical error of measurement of power and energy in SES gets the large urgency. The difficulties of the decision of this problem in many respects are caused by application of the methods of calculation based on averaging of energetically processes, simplification of concept of power of network of not constant current.

Averaging real process results carries to not only in loss of some information about features of generation and consumption of electrical energy, but it also results in the parities deprived of physical sense [1].

II. MAIN PART

From the theoretical bases of electro-technique it is known, that in circuits of non constant current the instant parameter of power of the basic harmonic of voltage and current can be calculated under the formula

$$S_{1,1}(t) = u_1(t)\cdot i_1(t) = P_{1,1}(1-\cos 2\omega t) + Q_{1,1}\sin 2\omega t$$

Let's present this formula as follows:

$$S_{1,1}(t) = P_1 - \left[P_{1,1}\sin\left(2\omega t - 90^0\right) - Q_{1,1}\sin 2\omega t\right] \quad (2)$$

From mathematics also it is known, that the sum (difference) of two sinusoidal functions with amplitudes À1 and À2 and corners of shift 1 and 2 is as sinusoidal function, i.e.

$$A_1\sin(k\omega t + \psi_1) + A_2(\sin k\omega t + \psi_2) = A_\Sigma \sin(k\omega t + \psi_\Sigma)$$

where

$$A_\Sigma = \sqrt{A_1^2 + A_2^2 + 2A_1A_2\cos(\psi_2 - \psi_1)}$$

$$tg\psi_\Sigma = \frac{A_1\sin\psi_1 + A_2\sin\psi_2}{A_1\cos\psi_1 + A_2\cos\psi_2}$$

At $A_1 = P_{1,1}, A_2 = -Q_{1,1}, \psi_1 = -90^0, \psi_2 = 0$ и $A_\Sigma = G_{1,1}$

$$S_{1,1}(t) = P_1 - G_{1,1}\sin(z\omega t + \psi_\Sigma) = P_1 - G_{1,1}(t) \quad (2)$$

where

$$G_{1,1} = \sqrt{P_{1,1}^2 + Q_{1,1}^2 + 2P_{1,1}Q_{1,1}\cos 90^0} = \sqrt{P_{1,1}^2 + Q_{1,1}^2} \quad (3)$$

$$tg\psi_\Sigma = \frac{P_{1,1}}{Q_{1,1}} = ctg\varphi \quad (4)$$

φ- the corner of shift between vectors of voltage and current.

$$S_{1,1\max} = P_1 + G_{1,1} \quad (5)$$

$$S_{1,1\min} = P_1 - G_{1,1} \quad (6)$$

Thus:

1. The power in circuits of non constant current in the any moment of time S1,1 (t) is equal of the sum of two components:

1.1. Constant (on interval of the basic harmonic T_1) positive active power P_1.

1.2. Sinusoidal changing complete power.

2. The quadratic dependence is between $G_{1,1}, P_{1,1}$ and $Q_{1,1}$ (see the formula 3).

3. According to the p. 1. the generated (consumed) electrical energy also can be submitted by the sum of two components:

3.1 Active energy. Quantitatively it is completely characterized by parameter

$$W_P(t) = \int_0^t P_I(\tau)d\tau = T_I \sum_{i=1}^{t/T_I} P_I$$

This energy will be transformed in power to other kinds of energy (for example, in thermal or mechanical).

3.2. The second component of energy WG, 1 (t) is not less important and specific. It provides necessary conditions of transformation of active energy in power, characterizes non-uniformity of generation (consumption) of electrical energy, depends on jet resistance of circuit of non constant current. It summing parameter on an interval T_1 is equal to zero. The multi-measure of this energy causes expediency of its differentiation on active and jet components.

The active component characterizes only non-uniformity of generation (consumption) of active energy. On each quarter of the period T_1 the active energy periodically changes as.

$$W_{P,1}^{(+)}(T_1/2) = W_{P,1}^{(-)}(T_1/2) = \frac{2P_{1,1}}{\omega_2} = \frac{P_{1,1} \cdot T_1}{2\pi} = W_{P,1}(T_1/2) = \frac{W_P(T_1)}{2\pi}$$

As the jet resistance in circuits of non constant current SES carries inductive character, then the jet component of energy $W_{G,\ 1\ (t)}$ in the moment t in SES characterizes energy of magnetic field of inductive resistance. On an interval T_1 the summing parameter of jet energy is equal to zero and consequently its summation by analogy to active energy is useless. Thus, the electro-supply by jet energy on purpose differs of electro-supply by active energy. If the active energy is used for transformation to other kinds of energy, then the jet energy is necessary for creation of a magnetic field in elements of circuit SЭS.

The features of change of jet energy on an interval T_1 allow to present it «generated (consumed)» by a part of $W_{Q,1}^{(+)}(T_1/2)$, which is equal area of a positive half-wave of sinusoid $Q_{1,1}(t) = Q_{1,1}\sin(2\omega t + \varphi)$ and equal it on parameter and opposite on a mark and «returned» part, $W_{Q,1}^{(-)}(T_1/2)$,

$$W_{Q,1}^{(+)}(T_1/2) = W_{Q,1}^{(-)}(T_1/2) = \frac{Q_{1,1} \cdot T_1}{2\pi} = W_{Q,1}(T_1/2)$$

Thus

$$W_{G,1}(T_1/2) = \sqrt{W_{P,1}^2(T_1/2) + W_{Q,1}^2(T_1/2)} \qquad (7)$$

and completely will be coordinated with (3).

4. For quantitative characterize of energetic process in SЭS at solution of practical problems, the some number of parameters executed control of efficiency of electro-supply is used. An evident example is factor of capacity carrying out current control of demanded throughput on a condition of heating of elements of a network. The increase of efficiency is achieved by measurement of an integrated parameter-jet energy and subsequent application to this parameter of the mechanism of the tariffs. And though it is well known, that the summing parameter of jet energy on each interval T_1 is equal to zero. The principle of summation of a generated part of jet energy has shown the serviceability and will be used by us for calculation of the total energy of maximum harmonics.

In a non sinusoidal regime the energetic processes in electrical circuits of non constant current SЭS have own features. These features are caused by change of sinusoidal character of voltage on the switching devices (SD) and current in circuits of power. High-voltage SЭS are mainly three-phases. In the present paper the problems of measurement of capacity and energy of distortion for symmetric power are considered, when the electrical phenomena in each phase are similar to the phenomena in one-phase circuits. Non symmetry of power presents own features to course of electrical process (dependence on character of change of power, non-uniformity of distortion sinusoidal on phases, increase of losses and other). However the recommended ways of an estimation ÌÈ and ЭИ remain constant. For quantitative characteristic of the allowable parameter of distortion of sinusoidal ÃÎÑÒ 13109-97 factor of distortion of sinusoidal form of voltage and factors of harmonics regulates, where their number exceed tens and is defined by number of taken into account harmonics (nm = 40). If to take into account expediency, repeatedly marked in the literature necessaries of application (are successfully used in the specifications of some the international standards of quality of electro-energy) of parameters of distortion sinusoidal current in circuits, and also normally allowable and limiting allowable parameters, then number of parameters for the quantitative characteristic of one of versions of quality by the electro-energy SЭS – non sinusoidal form, exceeds 10^2. Moreover, they are not always objective, as the effect of mutual partial compensation of current (voltage) of various harmonics (MPCH), limiting their influence does not take into account. For example, it is well known, that the sum of amplitudes of voltage (currents) of separate harmonics is much higher than the maximal parameter of non sinusoidal voltage on lines of the substation (current in circuits). Or else, the factors of n-th harmonic of voltage insufficiently full characterize distortion sinusoidal curves u(t), and effect from compensation of one of most harmonics of voltage can be insufficient, as influences adjacent (odd) and multiple by it harmonics grows. The maximal effect can be received only by the analysis of change of total energy of maximum harmonics and corresponds to the maximal reduction of parameter of this energy. MPCH does not mark factor of distortion of sinusoidal power. In this connection, aspiration of transformation to parameters, which more full and integrally characterizes energetic process of non sinusoidal regime SES-to the parameters of capacity and energy. By analogy to parameters factor of capacity and jet energy for electrical energy of the basic harmonic, parameters of non sinusoidal on ÃÎÑÒ 13109-97 and the parameters of capacity and energy of maximum harmonics mutually supplementing each other should be used for control (first) and managements (second) quality of electro-energy in SES.

To distinguish $G_{1,1}$ and $W_{G,1}(T_1)$ from the appropriate capacity and energy of maximum harmonics (we shall designate them through D_G and $W_{D,G}(T_1)$), let's name D_G- by capacity of distortion (CD), and $W_{D,G}(T_1)$- by energy of distortion (ED). These terms correspond also to physical essence of consequences of influence CD, deforming sinusoidal character, $G_{1,1}(t)$.

The character of change of energetic process of non sinusoidal regime, first of all, is defined by a type of a source of harmonics. The elementary structural schemes of electro-supply with various sources of harmonics, with indication of settlement points of measurement of capacity and energy (lines РУ-ш) and features of distribution of flows of energy appropriate to the active capacity Ð1, variable of the capacity parameter of the basic harmonic $G_{1,1}(t)$ and the capacities of the maximum harmonics DG (t), are given on figure.1a-e.

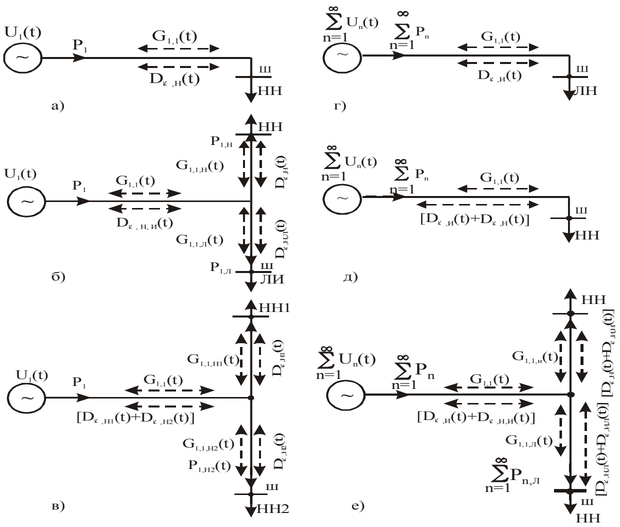

Рис.1.

Fig.1. The typical structural scheme of electro-supply with sources of maximum harmonics

As sources of harmonics are considered ÍÍ (electro-technological installation with nonlinear voltage-ampere characteristic) and source of active energy. The schemes a, b, v are characteristic for SES of the large power systems, and schemes g, d, e - for independent energy-systems of special purpose (separate sea gas-oil fundament, ship transport etc.).

The scheme of a fig. 1g is analogy to the circuit fig.1a, since between ÍÍ1 and ÍÍ2 the maximum harmonics of current do not process practically, that is explained by essential excess of internal resistance ÍÍ for maximum harmonics of resistance in circuits of a source of active capacity.

Measurement of capacity and energy in the settlement points includes: measurement of active capacity P_1 (energy – $W_{P,1}(t)$); measurement of jet capacity – Q_{11} (energy – $W_{Q,1}(t)$); measurement of total МИ- $D_{G,\Sigma}$(ЭИ- $W_{D,\Sigma,G}(t)$).

Taking into account, that e.m.f. of sources of active capacity (generators of power stations) practically sinusoidal, the measurement of consumed energy of active capacity (in the settlement points of the circuits 1a, b, v) should be carried out on current parameter and voltage of the basic harmonic. Measurement of energy of active capacity on the data of instant parameters of voltage u(t) on lines ÐÓ and current in circuits (i (t)) HH under the formula

$$W^*_{P,1}(T_1) = \int_0^{T_1} u(t)\cdot i(t)dt = T_1 \cdot \sum_{n=1}^{\infty} U_n I_n \cos\varphi_n = T_1 \cdot \sum_{n=1}^{\infty} P_n \quad (8)$$

results to systematic methodical error of measurement, as U_n with $n=\overline{2,\infty}$ characterize not a voltage causing current In, and voltage caused by a power lowing on internal resistance HH Zn, at course of a current In, that is natural not same [2]. The parameter of this error is equal

$$\delta W_{P,1}(T_1) = \frac{1}{P_1}\sum_{n=2}^{\infty} P_n \quad (9)$$

and a consumer in addition pays for unused electric power, which is equal

$$\Delta W_{P,1}(T_1) = T_1 \sum_{n=2}^{\infty} P_n$$

and that large, than stronger is the distortion sinusoidal voltage and current. Thus, the consumer with linear power does not only receives the poor-quality electrical energy, but owes also pay more. In that case methodical error does not only essentially exceed accuracy of measurement. Such offers, as «expediency of the analysis of a direction of flows and their parameter) on each harmonic» follow from this erroneous representation. Moreover, the devices for measurement of these flow are ordered and made.

If e.m.f. of a source of active capacity is not sinusoidal, then measurement WP, 1 under the formula (8) can be carried out only for the scheme 1g [3]. In the schemes 1g and 1e voltage on lines and current in circuits are geometrical sum of vectors of the same harmonics of both sources of maximum harmonics and the application of the formula (8) brings a special methodical error.

The measurement of consumed jet energy in settlement points for all the schemes. fig. 1 should be resulted on parameters of the working voltage and current of the basic harmonic and corner of shift between these parameters. Measurement of jet energy under the formula

$$W^*_{Q,1}(T_1) = T_1 \cdot \sum_{n=1}^{\infty} U_n I_n \sin\varphi_n = T_1 \cdot \sum_{n=1}^{\infty} Q_n \quad (10)$$

contains four components of methodical errors:

1. Actually, the jet energy, consumed by power, is equal not to product of jet capacity on time, and in π1= 3,14 times are less [4];
2. It is caused by the marked above features of occurrence of non sinusoidal voltage on line ÐÓ with connected HH. This error also conducts to increase of consumed jet energy and numerically is equal

$$\delta W_{Q,1}(T_1) = \frac{1}{Q_{1,1}}\sum_{n=2}^{\infty} Q_n \quad (11)$$

and the consumer in addition pays for jet energy $\Delta W_{Q,1} = T_1 \sum_{n=2}^{\infty} Q_n$.

3. It is caused by inadmissibility of addition of peak parameters of jet capacity, as these parameters differ with corners of shift concerning amplitude of the basic harmonic and a symbol [2,3].

4. The jet capacities parameters of maximum harmonics concern to a jet component МИ, causing distortion of sinusoidal character of jet capacity of the basic harmonic $Q_{1,1\,(t)}$.

If to take into account these errors and parameters of the tariffs on active and jet energy, then that cost 1 mVap-o really consumed jet energy is approached the cost 1 mVap-o of active energy.

The experimental researches, carried out by the authors, [2-5] have allowed to conclude:

- HH in SES will transform a part of consumed energy WG, 1 (t) in ЭИ of maximum harmonics WD, G (t);
- Generated HH ÌÈ, not changing parameter of consumed active capacity, deforms sinusoidal character G1,1 (t)

III. CONCLUSIONS

1. The algorithms of account and measurement of active and jet capacity (energy) both for the basic harmonic, and for maximum harmonics should be based on features of power processes in circuits of non constant current of the systems of electro-supply with nonlinear power. Significant methodical errors of account otherwise are inevitable.

2. Nonlinear power in the systems of electro-supply will transform a part of consumed energy of variable capacity of the basic harmonic to energy of maximum harmonics. This energy:

- not changing parameter of active capacity consumed nonlinear power, deforms sinusoidal character of variable capacity of the basic harmonic and is called as energy of distortion;
- the total parameter of energy of distortion on an interval of the basic harmonic is equal to zero and by analogy to jet energy of the basic harmonic consists from «generated» and equal to it «consumed» of parts;
- the principle of summation of numerical parameter of a generated part of energy of distortion calculated on each interval of the basic harmonic, allows to define a part of the deformed energy of variable capacity of the basic harmonic on an any interval of time;
- the deformed part of energy should be paid by the consumer on established for active and jet energy by the tariff.

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