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A GRAPHIC METHOD FOR THE RESEARCH INTO ELECTRICAL LOAD DYNAMICS IN RESIDENTIAL APPARTMENTS

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Abstract. The paper reports the results of research into forming the dynamics of electrical load in the flats equipped with gas cookers (evidence from town houses). A feature of the research consists in employing a graphic method, which uses the data of the quality analyzer G4500 BLACKBOX Portable and Automated Commercial Electricity Accounting System (ACEAS) as a basis for load dynamics modelling. Unlike the calculations done by valid standards, this method significantly increases the accuracy of calculation due to modelling the loads of flats, and their synthesis. The application of this method ensures savings in capital expenditures on the construction and operation of electricity supply systems.

Key words: block of flats, electrical load, graphic method, graph modelling, accuracy of calculation

1. Introduction. Relevance of the subject

The task of precision computation of electrical loads in residential houses requires new approaches to their measurement, taking into account characteristics of household electrical appliances. The use of valid normative documents leads to a 1,5–3,5 times excess of the actual load, which significantly affects the capital costs for the construction and operation of power supply systems, the chosen subject of research is relevant therefore.

2. Analysis of scientific publications. Statement of the problem

The overview of scientific publications shows that the dynamics of daily residential power consumption has been the focus of the researchers' attention for a long time now for the purpose of its forecasting, responding to power demand, and reducing the load [1, 2]. The load conditions of residential areas are modelled at 15-minute intervals [3]. The systems architectures are developed to control the load in smart buildings by smart grids able to integrate different energy sources [4]. The algorithms for regulation of electric energy in residential houses are developed based on statistical data on the forecasting of power demand, taking into account self-controlled electrical appliances [5], etc.

However, the publications mentioned above, as well as some other related researches do not study the problem by modelling electrical loads of household appliances with a dynamics discreteness at the level of ms, and synthesizing their graphs at different levels of power supply systems, which would greatly increase the computational accuracy of the calculated load.

The purpose of the work is to model the load dynamics in residential houses, synthesize their curves and compare the obtained results with the load determined by valid normative documents.

3. Objectives of the research

a) to study technical characteristics of the major household electrical appliances by using modern measuring instruments and information technologies;

b) to model the dynamics of electrical loads of individual household appliances, and synthesize them at the entrances to flats on the basis of the data obtained from previous measurements of their parameters;

c) to compare the calculated load errors obtained in line with the valid normative documents and by the graphic method of computation with the actual data obtained by measuring the electrical loads of flats using the G4500, ACEAS.

4. Presentation of the main research material

4.1. Experimental research base

The technical characteristics of household appliances were studied by using the Electricity Quality Analyzer Elspec G4500 produced by Elspec Technologies (Israel) (Fig. 1).

The PQSCADA Investigator software produced by Elspec Technologies (Israel) processes effectively a large number of parameters that are instantly displayed on the PC monitor. The information coming from the measurement points is instantly converted into a graphical interpretation of complex processes occurring on the network in one synchronized time axis or in digital form.

Fig. 1. A Set of instruments for measuring the dynamics parameters of electrical loads of household appliances:
a – a portable device G4500 BLACKBOX Portable;
b – a notebook for monitoring processes on the network;
c – PQSCADA software; d – AC wires; e – DC wires;
f – a flexible AC clamp meter.

The information stored in the device regarding the measured parameters of an electric network can be presented on the monitor either as curves or in digital form in Excel.

4.2. Essence of the graphic method for calculating residential electrical loads

The information received by G4500 BLACKBOX Portable, makes it possible to model the electrical load dynamics of major household appliances [6]. For example, the dynamics of a resistive electrical load of PC when turning it on, opening a file, typing, and shutting it down, received by using G4500 are shown in Fig. 2.

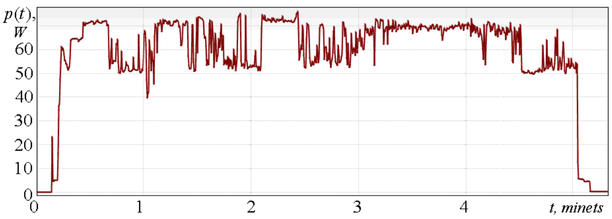

Fig. 2. Dynamics of the resistive electrical load of PC when turning it on, opening a file, typing, and shutting it down.

A half-hour maximum equal to the mathematical expectation of the average maximum load over a 30-minute time interval is accepted as the calculated electrical load of household electrical appliances brought to the flats entrance and to the riser line, respectively.

When there is a graph illustrating the electrical loads of household appliances over a certain period, the calculated resistive load p_c is determined as the maximum of average electrical loads obtained over half an hour by the following formula:

$$p_c = \frac{\int_{t_i}^{t_i+0.5} p(t)dt}{0.5} \to \max . \qquad (1)$$

The calculated reactive load q_c of electrical appliances is determined as follows:

$$q_c = p_c \mathrm{tg}\varphi \text{ , kvar.} \qquad (2)$$

The calculated full load of electrical appliances

$$s_c = \sqrt{p_c^2 + q_c^2} \text{ , kVA.} \qquad (3)$$

Modelling the dynamics of electrical loads consumed by household appliances used in 12 flats of a multi-flat building is carried out according to the developed program using the “cspline (x, y)” function embedded in MathCAD with the continuation of interpolation curve with a cubic parabola as [6, 9–11]:

$n = 25 \quad TO := (0\ 1\ 2 \ldots 22\ 23\ 24)$

$P10 := (P_{1.0}\ P_{1.1}\ P_{1.2} \ldots P_{1.22}\ P_{1.23}\ P_{1.24})$

$P20 := (P_{2.0}\ P_{2.1}\ P_{2.2} \ldots P_{2.22}\ P_{2.23}\ P_{2.24})$

...

$P110 := (P_{11.0}\ P_{11.1}\ P_{11.2} \ldots P_{11.22}\ P_{11.23}\ P_{11.24})$

$P120 := (P_{12.0}\ P_{12.1}\ P_{12.2} \ldots P_{12.22}\ P_{12.23}\ P_{12.24})$

$T := T0^T \quad P1 := P10^T \quad P2 := P20^T \ldots P11 := P110^T \quad P12 := P120^T$

$s11 := \mathrm{cspline}(T,P1) \quad p1(t) := \mathrm{interp}(s11,T,P1,t)$

$s12 := \mathrm{cspline}(T,P2) \quad p2(t) := \mathrm{interp}(s12,T,P2,t)$

...

$s111 := \mathrm{cspline}(T,P11) \quad p11(t) := \mathrm{interp}(s111,T,P11,t)$

$s112 := \mathrm{cspline}(T,P12) \quad p12(t) := \mathrm{interp}(s112,T,P12,t)$

$t := \min(T) - 0.1 - 0.01, \min(T) - 0.1 .. \max(T) + 0.1 \; i := 0..n$

The resulting models of electrical load dynamics make it possible to measure, with sufficiently high accuracy, the amount of electricity consumed by electrical appliences over a certain period, as well as starting, peak currents, etc.

For example, the amount of electricity consumed by the households during the operation time T is defined as follows:

$$W_a = \int_0^T p(t)dt = p_m T . \qquad (4)$$

The synthesis of dynamics of electrical load of standard household appliances used in a flat equipped with a gas cooker determines its specific curve during the week that is given in Fig. 3.

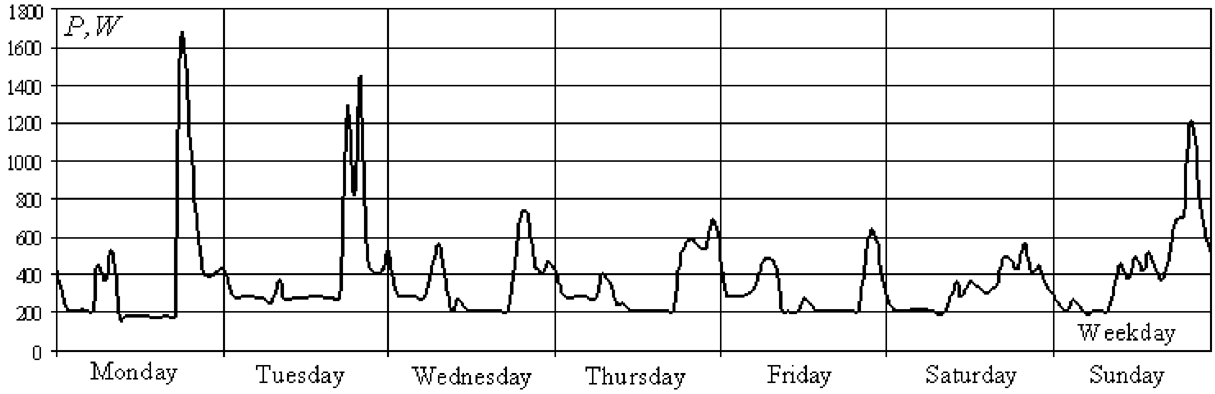

Fig. 3. Result of modelling the dynamics of a weekly electrical load of the flat equipped with a gas cooker.

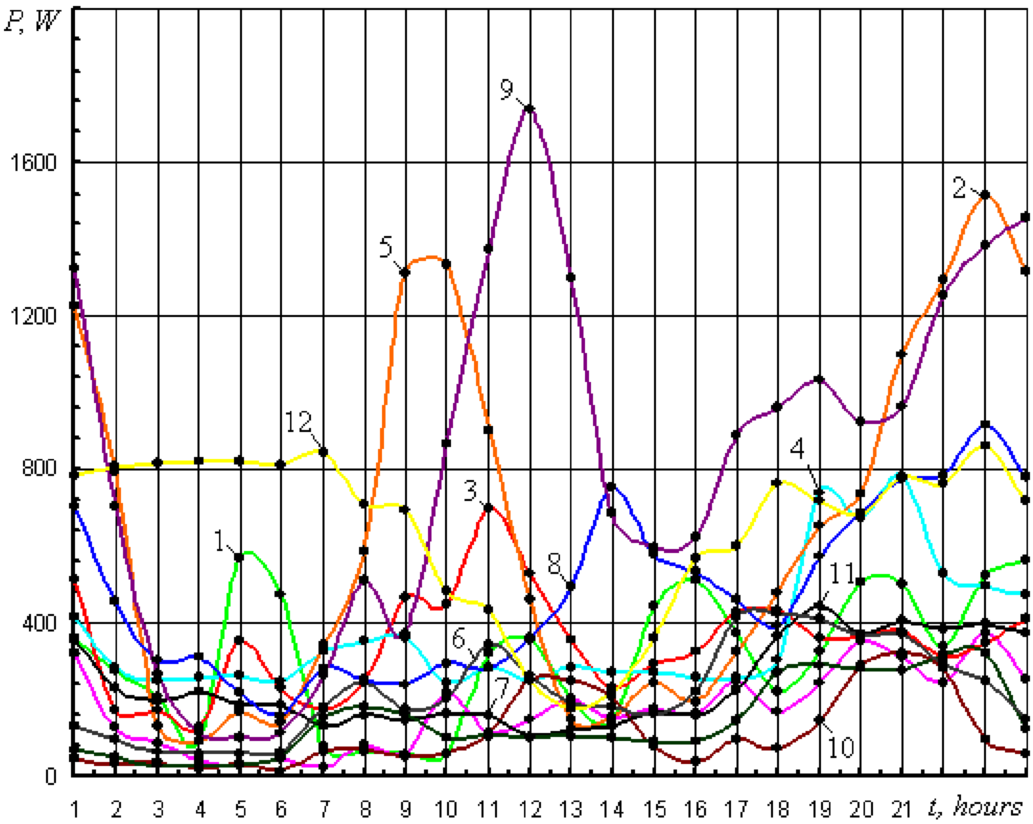

Fig. 4. Example of daily hourly-based electrical loads of 12 flats, the numbers of which coincide with their curve numbers.

According to Fig. 3, the maximum electrical load of this flat during the week does not exceed 1.7 kW, the minimum – 0.2 kW, according to ACEAS.

The example of daily hourly-based electrical loads of 12 flats, the numbers of which coincide with their curve numbers is shown in Fig. 4.

It is proved that the distribution of electrical load brought to the entrances of residential houses corresponds to the normal law, it follows that

$$P_{max} = \bar{P}_{max} + t\sigma , \qquad (5)$$

The value of normalized deviation for interior electrical networks of residential houses is established at $t_a = 3$ (corresponding to the probability of 99,7 %).

The calculated load of a group of flats with the same specific electrical load at the entrance to the flat is defined as follows [7, 8]:

$$p_{c.f} = p_{sp.c.f} N , \qquad (6)$$

where $p_{sp.c.f}$ – the specific calculated electrical load of a single flat, which is selected depending on the level of electrification accepted and the number of flats connected to this area of electrical network, kW/flat; N – the number of flats connected to the line, service entrance.

The calculated electrical loads of 12 flats of a residential house according to the normative documents and formula (6):

$$P_{c.12f} = 2.36 \cdot 12 = 28.3 \text{ kW}.$$

The calculated electrical loads of 12 flats of a residential house according to the graph parameters (see Fig. 5) and formula (1):

$$P_c = \int_{19.75}^{20.25} P(t)\,dt \Big/ 0.5 = 8.2 \text{ kW}.$$

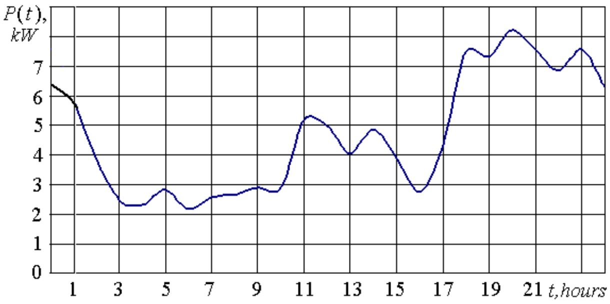

Fig. 5. Final curve of a daily electrical load of 12 flats over Sunday.

Consequently, Sunday's calculated load of 12 flats, which is computed by the curve in Fig. 5, is 3.45 times less than the load determined according to the data of the State Building Code (SBC) B. 2.5-23: 2010.

According to the data of the State Building Code (SBC) (p_{c1}) and calculated by the graph (p_{c2}), according to the data of ACEAS, G4500 BLACKBOX, trends in the calculated electrical loads of the flats p_c are constructed by a power-function approximation of the data (Fig. 6)

$$P_{c1} = 5.1447\,N^{0.6532}\text{, kW};$$

$$P_{c2} = 1.5616\,N^{0.7359}\text{, kW}.$$

According to the State Building Code (SBC) (p_{p1}) and calculated by the graph (p_{p2}), trends in the calculated electrical loads of the flats p_p and adequacy of R^2 samples approximation are constructed by:

a linear function

$$P_{c.l1} = 0.8758\,N + 11.885\text{, kW}; \quad R_{l1}^2 = 0.9906;$$

$$P_{c.l2} = 0.4311\,N + 2.9657\text{, }kW; \quad R_{l1}^2 = 0.9928;$$

a power function having the form shown in Fig. 6

$$P_{c.s1} = 5.1447\,N^{0.6532}\text{kW}; \quad R_{s1}^2 = 0.9981;$$

$$P_{c.s2} = 1.5616\,N^{0.7359}\,kW; \quad R_{s1}^2 = 0.9955.$$

The highest adequacy of the approximation of calculated load samples for 1, 12, 64, 120, and 144 flats of a residential 144-flat building is determined by the power function, that is 0.9981 and 0.9955, respectively.

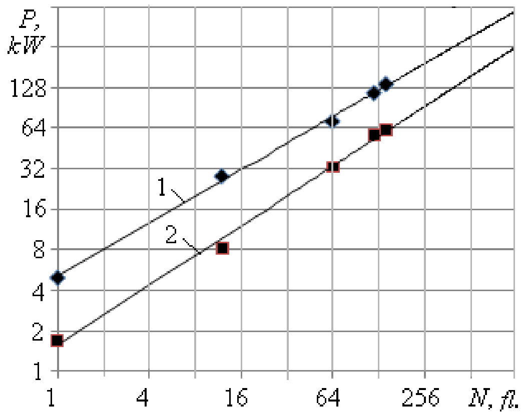

Fig. 6. Approximation results of the calculated electrical load values depending on the number of flats according to the State Building Code (1), and by using the graphic method (2).

According to Fig. 6, the greatest difference between the calculated loads obtained by different computational methods occurs at the interval of fewer flats.

5. Conclusion

The research is devoted to the development of a method for computing the calculated electrical load of flats using the curves for its variance. The application of the method allows a more precise measurement of the load, which leads to energy and material resources savings due to the refinement of normative calculation parameters when designing residential power systems.

The technical characteristics of major household appliances are investigated through the use of modern measuring instruments and information technologies. They can serve as the basis for creating a modern information database. The dynamics of electrical loads of individual household appliances at the flats entrances is modelled. This helps to obtain refined data of the calculated loads in buildings as a whole. It is shown that the errors when determining the calculated capacities using the electrical loads dynamics, received from the data of ACEAS and G4500 BLACKBOX, are much lower than when using the data of valid normative documents. Therefore, it is advisable to accumulate data on the real electrical loads of flats and houses, and create a database of residential electrical loads dynamics for the purpose of its further application to similar objects.

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ГРАФІЧНИЙ МЕТОД ДОСЛІДЖЕННЯ ДИНАМІКИ ЕЛЕКТРИЧНОГО НАВАНТАЖЕННЯ КВАРТИР ЖИТЛОВИХ БУДИНКІВ

Анатолій Бондарчук, Петро Лежнюк

Продано метод обчислення електричного навантаження житлових будинків з використанням їх графіків зміни, новизна якого, на відміну від визначення за чинними нормативами, полягає в підвищенні точності його визначення. Досягається це за рахунок моделювання динаміки навантажень електроприймачів, їх синтезу на вводах житлових будинків.

Вихідну інформацію для моделювання попередньо отримується вимірюванням пристроєм G4500 BLACKBOX Portable та АСКОЕ параметрів систем електропостачання.

Розроблено математичні моделі динаміки електричного навантаження жител за допомогою вбудованої в MathCAD функції “cspline (x,y)” із продовженням інтерполяційної кривої кубічною параболою.

Оцінено похибки обчисленого за нормативами та графічним методом щодо реального електричного навантаження квартир житлових будинків міста. Точність обчислення електричного навантаження завдяки використання графоаналітичного методу підвищується в 1,5–3 рази порівняно з визначенням за нормативами. Це економить енергетичні ресурси, капітальні витрати на спорудження та експлуатацію систем електропостачання.

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