1. Saidjon TAVAROV[1], 2. Ziad EL KHATIB[2], 3. Firuz KAMALOV[2], 4. Aleksandr SIDOROV[1], 5. Rustam VALEEV[1], 6. Murodbek SAFARALIEV[3]

South-Ural State University (national research university) (1), Canadian University Dubai (2), Ural Federal University (3)
ORCID: 1. 0000-0002-2875-2752; 3. 0000-0003-3946-0920; 6. 0000-0003-3433-9742

doi:10.15199/48.2024.04.28

Method of forecasting and calculation of electric load of utilities and household consumers under uncertainty

***Abstract**. Our goal in this article is to study the consistency of the actual power consumption with the calculated consumption in distributed electrical networks with a predominance of household consumers in several cities. We analyse the correspondence between the specific electrical load established by regulatory documents and the actual load for a single apartment according to power consumption in several cities. The discrepancy between the actual electrical load on an apartment and its standard value established by the current regulatory documents, which amounted to - negative 48% to 300%. To improve the accuracy of electricity consumption forecast and calculation of electrical loads, a new indicator is proposed - the generalized uncertainty coefficient A_i, the value of which is given for the period under consideration. Thus, using the specified coefficient, methods are proposed for predicting power consumption in electrical distribution networks with a predominance of domestic consumers and calculating electrical loads. When using the developed methods, deviations in forecast calculations in relative terms will not exceed 10%.*

***Streszczenie.** Celem jest zbadanie zgodności rzeczywistego zużycia energii z obliczonym w dystrybucyjnych sieciach elektrycznych z przewagą odbiorców domowych w wielu miastach. Aby zbadać zgodność między określonym obciążeniem elektrycznym ustalonym w dokumentach regulacyjnych a rzeczywistym obciążeniem dla jednego mieszkania w zależności od zużycia energii w wielu miastach. Rozbieżność między faktycznym obciążeniem elektrycznym mieszkania a jego standardową wartością ustaloną w aktualnych dokumentach regulacyjnych, która wyniosła - minus 48 do 300%. Aby poprawić dokładność prognozy zużycia energii elektrycznej i obliczania obciążeń elektrycznych, proponuje się nowy wskaźnik - uogólniony współczynnik niepewności A_i, którego wartość podano dla rozważanego okresu. Tak więc, stosując określony współczynnik, proponuje się metody przewidywania zużycia energii w sieciach dystrybucji energii elektrycznej z przewagą odbiorców krajowych i obliczania obciążeń elektrycznych. Przy stosowaniu opracowanych metod odchylenia w obliczeniach prognoz w kategoriach względnych nie przekroczą 10%. (**Metoda prognozowania i obliczania obciążenia elektrycznego zakładów użyteczności publicznej i odbiorców domowych w warunkach niepewności**)*

Keywords: electrical load, power consumption, generalized uncertainty coefficient, specific load
Słowa kluczowe: obciążenie elektryczne, zużycie energii, uogólniony współczynnik niepewności, obciążenie właściwe

Introduction

It is known that one of the indicators of the reliability of urban power supply is the frequency of failure, which is directly dependent on the electrical load. The efficiency of the distribution electrical network is estimated by the duration of undersupply of electricity, the less, the better, and the loss of electricity [1-2].

In recent years, the consumption of electrical energy in household electrical networks has increased significantly, due to both objective reasons (lack or provision of gas supply, hot heat supply) and subjective (human indifference to the state of household electrical receivers - whether they are turned on or turned off in a timely manner) [3-5]. This situation has led to a discrepancy between the normative value of the specific electrical load on the apartment and the actual one [6-8].

The above factors have led to a decrease in the reliability of elements of distribution electrical networks with a voltage of 6–10 kV, their lower energy efficiency [9-12], and affects the operation of those household electrical receivers that are sensitive to the quality of electrical energy supplied directly to apartments. In addition, the unbalance of loads in electrical networks for domestic purposes accelerates the aging process of the insulation in them, which can cause fires [13-16].

To solve this problem, it is necessary to establish the factors that create uncertainty in the forecasting of electricity consumption, to propose and justify a new method for forecasting and calculating the electrical load, which makes it possible to improve the accuracy of its forecast and calculation. However, first it is necessary to show the discrepancy between the actual and specific electrical load in the apartment [17-19].

We will take the real values of power consumption obtained from electricity meters installed at domestic consumers as the initial parameters.

Research method

To study the correspondence between the specific electrical load established by regulatory documentation and the actual one per apartment, according to power consumption data in several cities, the average annual power consumption by household consumers with a certain number of apartments for 2021-2022 was analysed (Fig. 1). The initial data of the considered consumers is given in Table. 1.

Table 1. Data of the considered domestic consumers

Ownership object	Total apartments
Residential building 1	41
Residential building 2	83
Residential building 3	60
Residential building 4	106
Residential building 5	60
Residential building 6	55
Residential building 7	60
Residential building 8	56
Residential building 9	76
Residential building 10	75
Residential building 11	74
Residential building 12	72
Residential building 13	64
Residential building 14	33
Residential building 15	64
Residential building 16	36

Based on the information received from the Energy Sales Organization, the consumers considered in the study are given in Table 1 which belongs to the category without gas supply. According to the Code of Rules 256.1325800.2016, for one apartment for these consumers, the specific electrical load is 10 kW/apartment.

Fig. 1 shows the values of electricity consumption with averaging per 1 apartment of the considered household consumers given in Table 1.

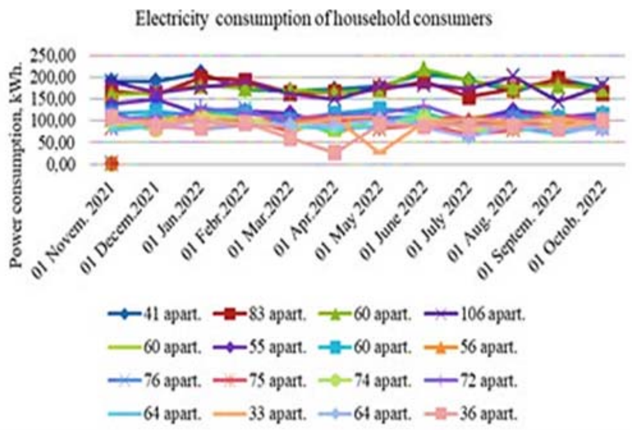

Fig.1. Average annual power consumption with averaging per 1 apartment of considered household consumers

According to formula (1) for Fig. 1, the average power for a certain period of the considered consumers is calculated.

(1) $$P_{\text{кв.}} = \frac{W_{\text{факт.}} \times N_j}{T_{\text{month}.i}},$$

where: W_{actual} – actual average power consumption per apartment, kWh/month; N_j – number of apartments, pcs. (Where j – the serial number of houses in the Table. 1); $T_{\text{month}\ i}$ – number of hours in the *i*-th period.
The results are presented in Fig. 2.

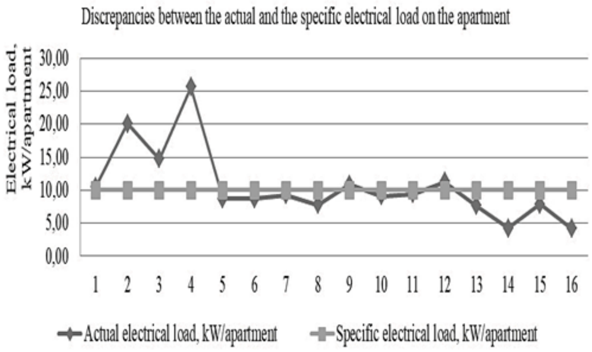

Fig.2. Discrepancy between actual and specific electrical load for an apartment

According to Fig. 2. The discrepancy between the actual and specific loads on the apartment was for $\mathrm{N_j}$ = [1, 2, 3, 4, 14, 16] from – 58% to +155%. The discrepancy arises because these consumers have a factorial feature in terms of the number of connected electrical receivers in apartments. This situation cannot but affect the reliability and efficiency of the supply network of the considered residential buildings ($\mathrm{N_j}$ = [1, 2, 3, 4, 14, 16]).

For other residential facilities (houses) $\mathrm{N_j}$ = [5-13.75 kW /apartment], the nature of power consumption corresponds to the specific power value.

This is due to the fact that for these objects (houses), the actual electrical load does not exceed the established regulatory documentation.

Fig. 3 presents the results of comparing the actual power consumption with the design one for a given specific electrical load on the apartment.

According to Fig. 3 the relative difference between the actual and design electricity consumption, resulting from the values of the specific electrical load on the apartment, is in the range from - 48 to 300% in terms of consumers. But since the development of types of electrical receivers and the demand of consumers for them is growing, such a difference between specific and actual power values will only grow and spread to all types of multi-apartment residential buildings. Thus, it can be argued that the current value of the specific electrical load on the apartment does not correspond to real conditions.

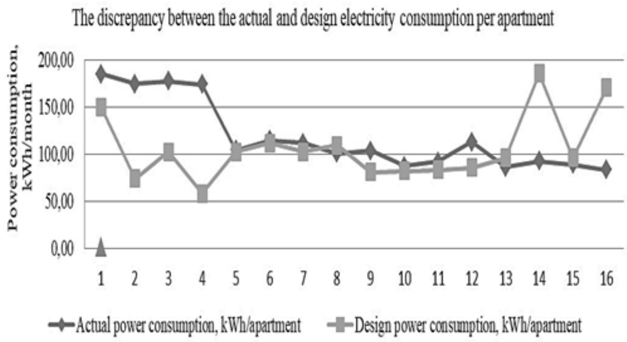

Fig.3. The discrepancy between the results of actual power consumption and the design one for a given specific electrical load on the apartment

Using several mathematical and modeling tools - (statistical and econometric models for collecting and processing data on electricity consumption, models for identifying uncertainty factors, fuzzy set theory, neural network models), factors [20-26] that were not previously taken into account (taking into account the differential heights above sea levels and the financial situation of apartment owners, etc.) when developing the specific electrical load on an apartment, which allowed us to propose a new, so-called generalized uncertainty coefficient A_i. At the same time, it should be noted that when determining A_i, household consumers are taken into account, receiving power from both combined sources (traditional (T)) and single sources (for example, completely on hydropower or renewable energy source (RES) - solar wind, etc.), (E).

(2) $$A_{i(\mathrm{T})} = (t_i\, h + c)/(s + k),$$

(3) $$\mathrm{A}_{i(E)} = (t_i \cdot h \cdot c)/(s \cdot k).$$

Where: t_i – temperature coefficient (taking into account the meteorological factor);

h - Coefficient taking into account the location of consumers above sea level;

c - is a coefficient that takes into account the structural design of a residential building;

s - Is the coefficient of the material (financial) position of the consumer (the welfare of the consumer, an analogue of the income of the Tornquist function);

k - Is a coefficient that takes into account a different number of electrical receivers at the consumer [27].

Given that the electricity consumers we are considering belong to the group (T), we compare using $A_{i(\mathrm{T})}$ the generalized uncertainty coefficient, which is calculated using equation (2).

Using the Internet resource, the average monthly temperatures for the objects under consideration were found - ($\mathrm{t_1}$, $\mathrm{t_2}$ and $\mathrm{t_3}$) where the numbers 1 are the ambient air temperatures at the location of the consumer; 2 - additional temperature, taking into account the temperature difference outside the house and inside the room; 3 – ambient air temperature at point 0 above sea level.

In turn, the coefficients s and k were obtained using the Fisher criterion.

Calculations $A_{i(\mathrm{T})}$ for the considered objects are presented in Fig. 4.

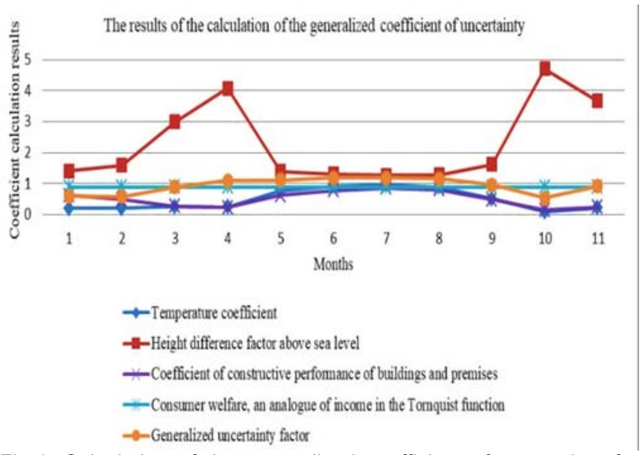

Fig.4. Calculation of the generalized coefficient of uncertainty for the objects under consideration

Using the generalized uncertainty coefficient, we propose forecasting methods based on taking into account the previous power consumption and calculating the electrical loads of household consumers (see expressions 4 and 5).

- Method for calculating the electrical load of apartments, taking into account the generalized coefficient of uncertainty:

(4) $P_{(calc.).apartment} = \frac{W_{previous}}{T_{\text{month}.i}} \times A_{i(\mathrm{T})}$,

where: $W_{previous}$ - data received from the Energy Sales Organization, the previous electricity consumption of household consumers, kWh. (for the same period of the previous year).

- Method for predicting electricity consumption by household consumers, taking into account the generalized uncertainty coefficient:

(5) $W_{forecasted} = \frac{(P_{apartment} \times T_{\text{month}.i} \times N_j)}{A_{i(\mathrm{T})}}$.

where: $P_{apartment}$ - is the calculated value of the electrical load obtained considering the proposed generalized coefficient, kW.

Using formula (4), according to the data of the previous electricity consumption by household consumers, the electrical loads were calculated.

The advantage of the above methods is to consider, using a generalized coefficient, the financial situation of different segments of the population in the objects under consideration, as well as the geographic location of consumers at different levels relative to zero (i.e., sea level).

The importance of taking these two factors into account when predicting and calculating the electrical loads of residential buildings lies in the fact that 1. Not considering the financial situation of the consumer leads to the frequent creation of asymmetries by consumers that exceed the established values, while an increase in the number of electrical receivers sharply increases this problem, 2. Not considering height difference leads to an additional increase in power consumption, due to high humidity above sea level. Thus, again leading to an increase in the first criterion (factor).

The calculation results given in Fig. 5 were compared with the actual values determined earlier and presented in Fig. 2.

When using our proposed method for predicting electricity consumption according to formula (5), the discrepancy between the results is from 8 to 18 kWh/apartment, which in percentage terms does not exceed 10%.

This result allows us to assert a high convergence and thereby ensure an increase in the reliability and efficiency of the distribution electrical network.

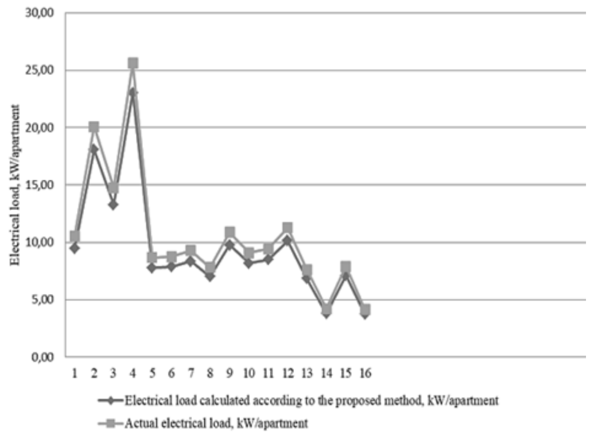

Fig.5. Comparison of the actual electrical load with the load obtained by the proposed method

Load and actual did not exceed 10%.

Further, using formula (5), we will predict the power consumption by household consumers for the objects under consideration and compare these results with the actual one.

The results of the comparison will be presented in the form of a dependence in Fig. 6.

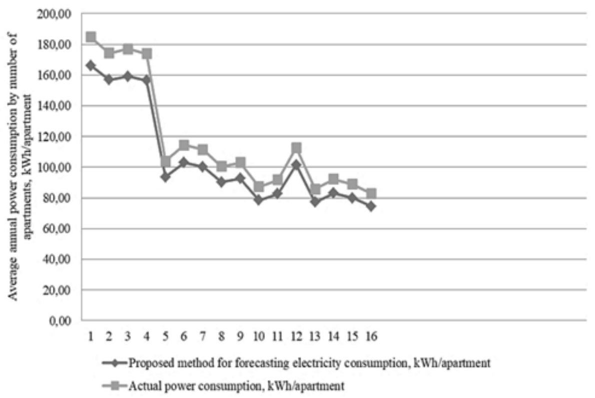

Fig.6. Comparison of actual power consumption with the predicted found one, taking into account the generalized uncertainty coefficient

Conclusions

Based on the study of the actual power consumption by rows of objects with domestic consumers, it is confirmed that the current values of the specific electrical loads for these consumers lead to significant discrepancies with the actual values.

For electrical load from - minus 58 to 155% and for power consumption from - minus 48 to 300%.

To improve the accuracy of the calculation of electrical loads, it is proposed to use a generalized uncertainty coefficient, and on its basis, a method for predicting and calculating electrical loads.

It is shown that when using the proposed methods, the discrepancy between the calculated and actual electrical loads does not exceed 10%, and the error in the predicted power consumption is in the range from 8 to 18 kWh/apartment.

Conflict of Interest

The authors declare no conflict of interest.

Acknowledgment

This research received no external funding.

Authors

PhD Tavarov Saidjon Shiralievich, Department of Life Safety, South-Ural State University (national research university), Prospekt Lenin, 76, Chelyabinsk, 454080, Russian Federation, e-mail: tabarovsaid@mail.ru; PhD Ziad El Khatib, Department of Electrical Engineering, Canadian University Dubai, Dubai 117781, United Arab Emirates, ziad.elkhatib@cud.ac.ae; PhD Firuz Kamalov, Department of Electrical Engineering, Canadian University Dubai, Dubai 117781, United Arab Emirates, firuz@cud.ac.ae; D.Sc Sidorov Aleksandr Ivanovich, Head of the Department of Life Safety, South-Ural State University (national research university), Prospekt Lenin, 76, Chelyabinsk, 454080, Russian Federation, e-mail: sidorovai@mail.ru; PhD Valeev Rustam Galimyanovich, Department of Power Stations, Grids, and Electric Power Systems, South-Ural State University (national research university), Prospekt Lenin, 76, Chelyabinsk, 454080, Russian Federation, e-mail: valeevrustam@mail.ru; PhD Murodbek Kholnazarovich Safaraliev , Department of Automated Electrical Systems, Ural Federal University, 19, Mira Street, Yekaterinburg, 620002, Russian Federation, e-mail: murodbek_03@mail.ru

REFERENCES

[1] Asanova S. et.al., Calculation of power losses at given loads and source voltage in radial networks of 35 kV and above by hier-archical-multilevel structured topology representation, *Przeglad Elektrotechniczny*, (2021), No. 7, 13-18

[2] Asanov M.S. et.al.,The use of Petri computing networks for optimization of the structure of distribution networks to minimize power losses. *Energy Reports,* 6 (2020), 1337-1343

[3] Blazakis K.V, Kapetanakis T.N., Stavrakakis G.S., Effective Electricity Theft Detection in Power Distribution Grids Using an Adaptive Neuro Fuzzy Inference System, *Energies*, (2020), Vol.13, 3110

[4] Jabir H.J., Teh J., Ishak D., Abunima H., Impacts of Demand-Side Management on Electrical Power Systems: A Review, *Energies*, (2018), Vol. 11.,1050

[5] Chan F., Pauwels L.L, Some theoretical results on forecast combinations, *International Journal of Forecasting,* (2018), 34 (1), 64–74

[6] Florian Z., Load Nowcasting: Predicting Actuals with Limited Data, *Energies*, (2020), 13(6), 1443

[7] Khasanzoda N. et al., Use of smart grid based wind resources in isolated power systems, *Energy,* (2022), 253 124188

[8] Ulloa-Vásquez F., García-Santander L., Carrizo D., Heredia-Figueroa F., Intelligent electrical pattern recognition of appliances consumption for home energy management using high resolution measurement, *in IEEE Latin America Transactions*, 20 (2020), no. 2, 326-334

[9] Senyuk M., Safaraliev M., Gulakhmadov A., Ahyoev J.,Application of the Conditional Optimization Synchronous Generator Steam Turbine Operating in a Complex-Closed Configuration Power System, *Mathematics,* (2022), 10, 3979

[10] Bumtsend, U. et al., The unbalanced modes analyze of traction loads network, *In 2020 Ural Symposium on Biomedical Engineering, Radioelectronics and Information Technology (USBEREIT) IEEE*, (2020), 0456-0459

[11] Fezzi C., Mosetti L., Size matters: Estimation sample length and electricity price forecasting accuracy, *The Energy Journal*, 41 (4), (2020)

[12] Goltsos T. E., Syntetos A. A., Van der Laan, Forecasting for remanufacturing: The effects of serialization, *Journal of Operations Management*, 65 (5), (2019), 447–467

[13] Grushka-Cockayne Y, Jose V.R., Combining prediction intervals in the M4 competition, *International Journal of Forecasting,* 36 (1), (2020), 178–185

[14] Hewamalag H, Bergmeir C., Bandara K, Recurrent neural networks for time series forecasting: Current status and future directions, *International Journal of Forecasting,* 37(1), (2021), 388-427

[15] Hong T., Pinson P., Energy forecasting in the big data world, *International Journal of Forecasting*, 35 (4), 2019, 1387–1388

[16] Issi F., Kaplan O., The Determination of Load Profiles and Power Consumptions of Home Appliances, *Energies*, (2018), 11(3), 607

[17] Dzhuraev, S. et al., Computation of the zero-wire current under an asymmetric nonlinear load in a distribution network, *Energy Reports*, 8(2022), 563-573

[18] Sharma S., Majumdar A., Elvira V., Chouzenoux É., Blind kalman filtering for short-term power load forecasting, *IEEE Transactions on Power Systems*, 6(2020), Vol. 35, 4916-4919

[19] Andrea G., Models and Techniques for Electric Load Forecasting in the Presence of Demand Response, IEEE Trans. Con.Sys.Tech., 23(2014), 1087-1097

[20] Deng Z., Wang B., Xu Y., Multi-scale convolutional neural network with time-cognition for multi-step short-term power load forecasting, *IEEE Access,* (2019), Vol. 7., 88058-88071

[21] Kamalov F., Sulieman H., Time series signal recovery methods: comparative study, *In 2021 International Symposium on Networks, Computers and Communications (ISNCC) IEEE*, (2021), 1-5

[22] Kamalov F., Gurrib I., Moussa S., Nazir A., A Comparative Study of Autoregressive and Neural Network Models: Forecasting the GARCH Process, *In International Conference on Intelligent Computing Cham: Springer International Publishing*, (2022), 589-603

[23] Hewamalage H., Bergmeir C., Bandara K., Recurrent neural networks for time series forecasting: Current status and future directions, *International Journal of Forecasting*, 37(1), (2021), 388-427

[24] Hong T., Pinson P., Energy forecasting in the big data world, *International Journal of Forecasting,* 35 (4), (2019), 1387–1388

[25] Tavarov S.S et al., Evaluation of the Operating Modes of the Urban Electric Networks in Dushanbe City, Tajikistan, *Inventions*, (2022), 7, 107

[26] Tavarov S.S, et al., Model and algorithm of electricity consumption management for household consumers in the republic of Tajikistan, *Mathematical Modelling of Engineering Problems*, 7(2020), 520-526

[27] Sidorov A.I., Tavarov S.S, Method for forecasting electric consumption for household users in the conditions of the Republic of Tajikistan, *International Journal of Sustainable Development and Planning*, 15(2020), No. 4, 569-574