Power Consumption Modeling in Urban Electric Networks of 0.4–10 kV of the Republic of Tajikistan

S. S. Tavarov(✉) and A. I. Sidorov

South-Ural State University (National Research University), 76 Lenina Avenue, 454080 Chelyabinsk, Russian Federation
tavarovss@susu.ru

Abstract. The article is devoted to the establishment of the influence of the geographical location of the cities of the Republic of Tajikistan (RT) on the power consumption of household electrical appliances. A model is proposed for forecasting electricity consumption, taking into account the relief and territorial location of cities in the Republic of Tajikistan, based on data on electricity consumption in previous years. For forecasting, the coefficient of maximum loads was derived with numerical data for large cities of the Republic of Tajikistan, taking into account the climatic and meteorological conditions of their location. This coefficient made it possible to propose a method for predicting the power consumption, with the help of which recommendations on the norms of power consumption were developed. Standards for winter and summer energy consumption are suggested for both maximum hours and during the day. The application of the recommended norms in practice will make it possible to control the parameters of the operation of electrical networks, including networks with a voltage of 0.4 kV. The proposed mathematical model will allow you to monitor compliance with specific electrical loads.

Keywords: Power consumption · Electric load · Terrain conditions · Mathematical model

1 Introduction

Maintaining the operating parameters of electrical networks with 0.4 kV voltages is possible when planning power consumption by household electric receivers.

This will minimize the cost of improving the reliability of power supply, reducing power losses, ensuring the appropriate quality of electricity, reducing the number of failures in the power supply system, which in General will reduce the undersupply of electricity [1–17], which is the main indicator for an energy-saving organization.

Until 2008, the power consumption of enterprises in the Republic of Tajikistan was significantly higher than the power consumption in everyday life. This was due to the presence of heat and hot water supply and gas supply in everyday life during this period.

A. A. Radionov and V. R. Gasiyarov (Eds.): RusAutoConf 2020, LNEE 729, pp. 866–876, 2021.
https://doi.org/10.1007/978-3-030-71119-1_84

Due to the disappearance of these sources of supply and, due to this, the introduction of electric water heaters, electric stoves, as well as the increase in the population of various household electrical receivers, electricity consumption in everyday life has sharply increased.

According to [18], electricity consumers in the Republic of Tajikistan are divided into the following groups:

- Group 1 – industrial, non-industrial, agricultural and equivalent consumers
- Group 2 – consumers of budgetary sphere, the enterprises of the communal services and electric transport
- Group 3 – pumping stations of machine irrigation systems, borehole and reclamation pumping stations
- Group 4 – population, localities, and dormitories

Figure 1 shows the structure of power consumption by these groups in 2010–2015.

From Fig. 1, it follows that the electricity consumption of the population belonging to the 4th group has become higher in recent years than at the enterprises belonging to the 1st group.

It should be noted that according to the mode of power consumption, household consumers belonging to the 4th group have uneven schedules in relation to the 1st group. This, in turn, is the main reason for violating the operating parameters.

It is obvious that the recommendation of power consumption standards for these groups will solve this problem and increase all the above indicators.

Quite a lot of work has been devoted to the problems of constructing mathematical models designed to predict power consumption, for example, [3–12, 17–25]. The mentioned models take into account climatic and meteorological factors, however, it is believed in them that domestic consumers are provided with heat supply, hot water supply, as well as gas supply.

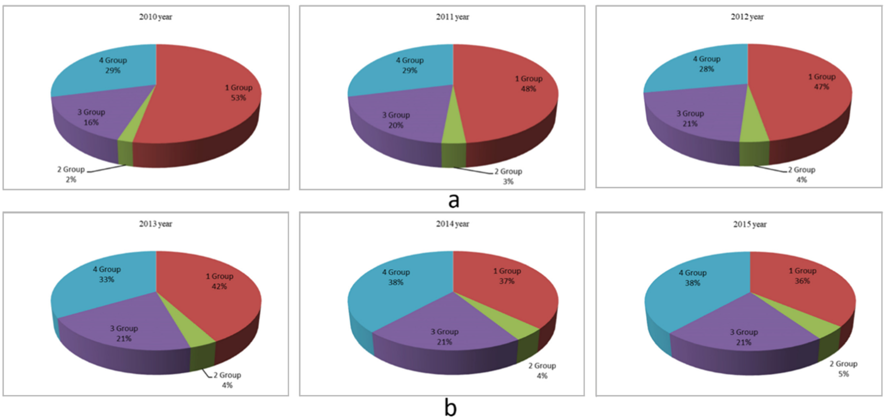

Fig. 1. Structure of power consumption by groups accepted in RT.

In our case, the majority of consumers are deprived of other sources of energy and the entire burden falls on the shoulders of electrical energy.

Due to the lack of specific load standards in the Republic of Tajikistan (RT), the standards developed in the Russian Federation (RF) are applied in the design and reconstruction.

Considering that hydroelectric power stations are the main source of electricity in the Republic of Tajikistan, it is advisable for them to propose such energy consumption standards that would not go beyond the limits established in [26–34].

A well-known factor is that the schedules of electrical loads of household consumers change unevenly during the day and the bulk of the electricity is consumed during the hours of morning and evening highs, while the morning maximum is less than the evening one.

Therefore, due to the lack of energy consumption standards in winter, a discrepancy arises between the planned amount of electricity consumption, determined according to the standards adopted in the Russian Federation, and its actual value. The latter cannot but affect the reliability of power supply.

Thus, when constructing a mathematical model, it is necessary to take into account the factors that affect the power consumption modes as much as possible.

One of the known factors influencing the increase in power consumption is the height of the power supply object above sea level. With an increase in this height, the ambient temperature decreases, which leads to an increase in air humidity. This, in turn, is accompanied by an increase in power consumption, which directly affects the specific electric load.

2 Formulation of the Problem

From the foregoing, it follows that a change in the height of the power supply object relative to sea level leads to an increase in the time of power consumption during hours of maximum loads.

This is due to the fact that the sunrise and sunset in cities with a higher location relative to sea level varies in the range from 30 to 60 min in the direction of decrease. It is known that when the level increases by 100 m, the temperature drops by 0.6 °C.

Therefore, with a known elevation difference, the average temperature difference can be derived, for example, between years. Dushanbe and Khorog. Dushanbe is located at an altitude of 706 m above sea level, while Khorog is located at an altitude of 2123 m. The difference in elevation between the cities of Khorog and Dushanbe is 1418 m. In this case, the temperature difference will be 8.5 °C.

3 Theoretical Part

To simulate the power consumption modes of urban electric networks of the Republic of Tajikistan, it is necessary to take into account climatic and meteorological factors, as well as the geographical location of cities.

To determine the dependence of the specific load from the previous daily and monthly electricity consumption, taking into account the climatic and meteorological characteristics of the cities of the Republic of Tajikistan, the maximum load time coefficient $\alpha_{maximum\ load\ time}$, was derived, which has a functional relationship:

$$\alpha_{maximum\ load\ time} = F(X_i), \tag{1}$$

$$X_i = X_1; X_2; X_3; X_4; X_5, \tag{2}$$

where: x_1 – temperature; x_2 – design features of houses; x_3 – height difference of cities; x_4 – air humidity: x_5 – wind speed.

Given the interdependence of the factors given in (2), the final expression of the maximum load time coefficient takes the form:

$$\alpha_{max.\ l.\ t.} = \alpha_{maximum\ day} \cdot \alpha_{max.\ mon.}, \tag{3}$$

where: $\alpha_{maximum\ day}$ – coefficient characterizing the length of time maximum loads during the day; $\alpha_{max.\ mon.}$ – coefficient characterizing the period of time of maximum loads during the month.

Using the coefficient $\alpha_{maximum\ load\ time}$, taking into account climatic and meteorological factors and the geographical location of the cities of the Republic of Tajikistan, it is possible to determine the specific norms of power consumption during peak hours for winter and summertime:

$$W_{maximum\ load\ time} = P_{all.} \cdot t_{max.\ t.\ p.\ d.} \cdot \alpha_{max.\ l.\ t.}, \tag{4}$$

$$W_{remaining\ consum\ t} = P_{av.} \cdot t_{res.} \cdot \alpha_{res.}, \tag{5}$$

$$W_{tot} = W_{maximum\ load\ time} + W_{remaining\ consum\ t}, \tag{6}$$

where: $P_{all.}$ – permitted power provided by the electricity supply organization 4–5 kW, $t_{max.\ t.\ p.\ d.}$ – maximum load time during the day, hours, $\alpha_{max.\ l.\ t.}$ – maximum load time factor.

4 Practical Relevance and Suggestions

To predict power consumption, the obtained mathematical model was used, expressed in terms of the coefficient of maximum loads and daily power consumption data.

In Fig. 2 and 3 show the daily electricity consumption versus the number of subscribers connected to city transformer substations for May 28, 2019.

According to power consumption data for previous years, taking into account climatic and meteorological factors [25–29], the times of maximum power consumption of evening winter and summer maximums were established:

- years Dushanbe and Bokhtar (winter) - 3.5 h and (summer) - 2.5 h
- Khorog, the time of evening maximums of loads - 4.5 h (winter) and - 3.5 h (summer)

The difference in maximum loads between Dushanbe and Khorog is explained by their different position relative to sea level.

Using the obtained maximum load time coefficient α (maximum load time) for Fig. 2, 3, specific electrical loads at maximum hours were determined. The results are shown in Fig. 4, 5.

Fig. 2. Dependence of daily electricity consumption on the number of subscribers receiving power from transformer substation 568, T-1

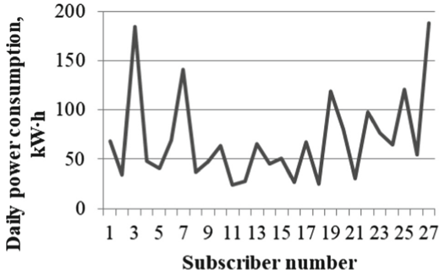

Fig. 3. Dependence of daily electricity consumption on the number of subscribers receiving power from transformer substation 583, T-1

Fig. 4. Electrical loads during maximum hours for subscribers powered by transformer substation-568, T-1.

From the obtained dependences (Fig. 4, 5), it can be seen that the electric load during maximum hours in the main part of subscribers exceeds normalized values. The excess is due to the fact that the considered subscribers do not have other sources of energy besides electric.

Fig. 5. Electrical loads during maximum hours for subscribers powered by transformer substation 583, T-1.

To comply with the allowable specific electric loads, depending on the daily and monthly electricity consumption, time factors for maximum loads were proposed, which, in our opinion, allow us to control the excess of specific electric loads.

According to power consumption data for previous years [26–29], numerical values of the maximum load time factors for cities of the Republic of Tajikistan with various conditions were derived:

$$\text{- c. Dushanbe city: } \alpha_{maximum\ load\ time} = 0{,}145;$$

$$\text{- c. Khorog: } \alpha_{maximum\ load\ time} = 0{,}188;$$

$$\text{- c. Khojent: } \alpha_{maximum\ load\ time} = 0{,}167.$$

To establish specific norms of power consumption, depending on the coefficient of time of maximum loads, it is recommended to use dependencies 1 and 2.

Therefore, in the presence of previous data on the maximum monthly power consumption, using the obtained maximum load time coefficient, it is possible to determine such power consumption rates during the day or month that will correspond to specific electric loads [26–29] and will not exceed the allowed power for typical residential buildings installed power supply organizations.

I rely on the maximum load time coefficient (3) and the obtained numerical data using expressions (4–6), we determine the maximum daily and monthly power consumption rates in time:

for Dushanbe:

$$W_{maximum\ load\ time} = 4 \cdot 24 \cdot 0{,}145 = 13{,}93\ \text{kW} \cdot \text{h};$$

$$W_{remaining\ consum\ t} = 2 \cdot 24 \cdot \left(\frac{20{,}5}{24}\right) = 41\ \text{kW} \cdot \text{h};$$

$$W_{tot} = 13,93 + 41 = 54,92\ \text{kW} \cdot \text{h}.$$

for Khorog:

$$W_{maximum\ load\ time} = 4 \cdot 24 \cdot 0,188 = 18,05\ \text{kW} \cdot \text{h};$$

$$W_{remaining\ consum\ t} = 2,5 \cdot 24 \cdot \left(\frac{20,5}{24}\right) = 51,25\ \text{kW} \cdot \text{h};$$

$$W_{tot} = 18,05 + 51,25 = 69,3\ \text{kW} \cdot \text{h}.$$

for Khojent:

$$W_{maximum\ load\ time} = 4 \cdot 24 \cdot 0,167 = 16,032\ \text{kW} \cdot \text{h};$$

$$W_{remaining\ consum\ t} = 2,5 \cdot 24 \cdot \left(\frac{20,5}{24}\right) = 41\ \text{kW} \cdot \text{h};$$

$$W_{tot} = 16,032 + 41 = 57,032\ \text{kW} \cdot \text{h}.$$

The relative difference in power consumption in hours of maximum loads will be: between the city of Khorog and Dushanbe:

$$\delta = \frac{18,05 - 13,93}{18,05} \cdot 100\% = 22,83\%$$

between Khojent and Dushanbe:

$$\delta = \frac{16,032 - 13,93}{18,05} \cdot 100\% = 13,11\%.$$

between Khorog and Khojent.

$$\delta = \frac{18,05 - 16,032}{18,05} \cdot 100\% = 11,18\%.$$

The resulting relative difference in power consumption during peak hours of Khorog in relation to other cities of the Republic of Tajikistan under consideration is much larger.

This once again confirms the validity of our research and proves the influence of climatic, meteorological and geographical locations of the cities of the Republic of Tajikistan.

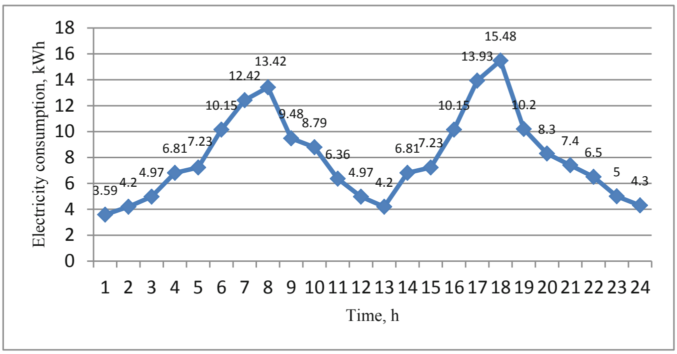

Fig. 6. Winter hourly schedule of electricity consumption in Dushanbe.

The obtained expressions (3–5), as well as the maximum load time coefficients, make it possible to predict power consumption in the summer and winter months. Present forecast data in the form of graphs for the winter and summer months.

In Fig. 6, 7, 8 and 9 show the forecasted electricity consumption schedules for the winter and summer months of some cities in the Republic of Tajikistan.

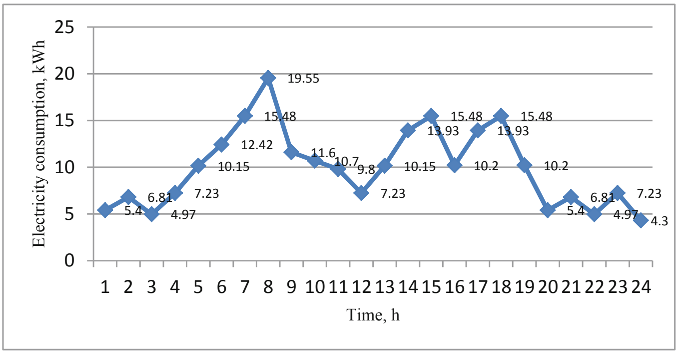

Fig. 7. Winter hourly electricity consumption schedule of Khorog.

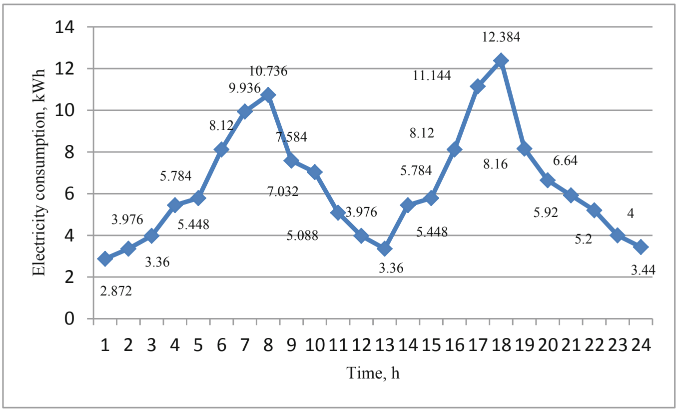

Fig. 8. Summer hourly energy consumption schedule in Dushanbe.

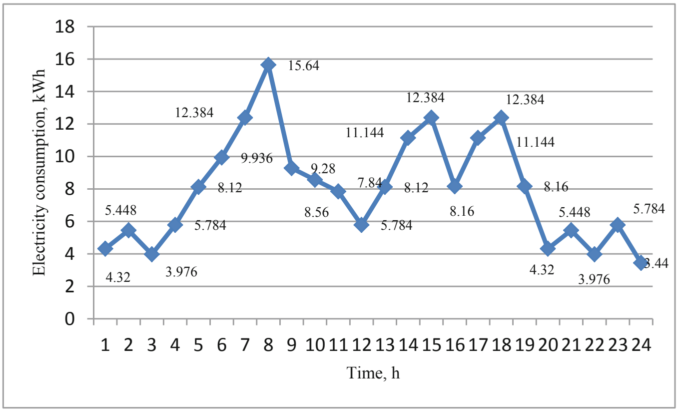

Fig. 9. Summer hourly electricity consumption schedule of Khorog.

5 Conclusions

The graphs of power consumption during the day allow you to control the power consumption during peak hours. If these power consumption standards are exceeded, notification of electricity consumers exceeding these standards will be required. From the obtained graphs Fig. 6, 7, 8 and 9 show that the relative difference in power consumption during winter and summer highs is 20%. The relatively small difference between summer highs and winter highs is associated with the use of air conditioners, which greatly affect the power consumption in residential buildings.

It should be noted that for cooling residential premises in Dushanbe, the energy consumption is much higher than in Khorog. This factor is due to the different geographical location of these cities.

References

1. Zakaria, Y., Anup, P.: An optimal load schedule of household appliances with leveled load profile and consumer's preferences. DUE (2018). https://doi.org/10.23919/DUE.2018.8384382
2. Zakaria, Y., Pule, Kh.: A binary integer programming model for optimal load scheduling of household appliances with consumer's preferences. DUE (2018). https://doi.org/10.23919/DUE.2018.8384381
3. Gheorghe, G., Florina, S.: Processing of smart meters data for peak load estimation of consumers. ATEE (2015). https://doi.org/10.1109/ATEE.2015.7133922
4. Hussein, S., Boonruang, M.: Intelligent algorithm for optimal load management in smart home appliance scheduling in distribution system. In: iEECON (2018). https://doi.org/10.1109/IEECON.2018.8712166
5. Jangkyum, K.: Analysis of power usage at household and proper energy management. In: International Conference on Information and Communication Technology Convergence (ICTC), pp. 450–456 (2018)
6. Fatih, I., Kaplan, K.O.: The determination of load profiles and power consumptions of home appliances. Energies, 607–621 (2018). https://doi.org/10.3390/en11030607

7. Leopoldo, A., Francesco, B., Annalisa, L., et al.: Smart power meters in augmented reality environment for electricity consumption awareness. Energies, 2303–2313 (2018). https://doi.org/10.3390/en11092303
8. Ke, Y., Xudong, W., Yang, D., et al.: Multi-step short-term power consumption forecasting with a hybrid deep learning strategy. Energies, 3089–3110 (2018). https://doi.org/10.3390/en11113089
9. Sergej, V., Alina, S., Rima, K.: The Impact of socio-economic indicators on sustainable consumption of domestic electricity in Lithuania. Sustainability, 162–176 (2018). https://doi.org/10.3390/su10020162
10. Florian, Z., Load, N.: Predicting actuals with limited data. Energies, 1443–1453 (2020). https://doi.org/10.3390/en13061443
11. Aqdas, N., Muhammad, U.J., Nadeem, J., et al.: Short-term electric load and price forecasting using enhanced extreme learning machine optimization in smart grids. Energies, 866–880 (2019). https://doi.org/10.3390/en12050866
12. Wai-Ming, T., Peter, K., Chun, L., et al.: Modeling of monthly residential and commercial electricity consumption using nonlinear seasonal models—The Case of Hong Kong. Energies, 885–899 (2017). https://doi.org/10.3390/en10070885.
13. Seunghyoung, R., Jaekoo, N., Hongseok, K.: Deep neural network-based demand side short term load forecasting. Energies, 3–17 (2017). https://doi.org/10.3390/en10010003
14. Makokluev, B.I., Kostikov, V.: Modeling of electric loads of electric power systems. Electrical Tech. Russia, 6–18 (1994)
15. Makokluev, B.I., Pavlikov, V., Vladimirov, A.: Influence of fluctuations of meteorological factors on power consumption of power units. Ind. Power Eng., 11–23 (2003)
16. Makokluev, B.I.: Trend of electricity consumption of UES of Russia. Sci. Tech. J. Energy Unified Netw., 6–64 (2019)
17. Makokluev, B.I., Polizharov, A.S., Basov, A.A., et al.: Short-term forecasting of power consumption of power systems. Power Technol. Eng., 24–35 (2018)
18. Makokluev, B.I., Polizharov, A.S., Antonov, A.V., et al.: Operational correction of schedules of electric power consumption in the planning cycle of the balancing market. Power Technol. Eng., 36–44 (2019)
19. Repkina, N.G.: Research of factors affecting the accuracy prediction daily power consumption. Russian Electromech., 41–43 (2015). https://doi.org/10.17213/0136-3360-2015-2-41-43
20. Zubakin, V.A., Kovshov, N.M.: Methods and models for analyzing the volatility of electricity consumption taking into account cyclicality and stochasticity. Anal. Forecast Manag., 6–12 (2015)
21. Komornik, S., Kalichets, E.: Requirements for energy consumption forecasting systems. Energo. Market, 5–7 (2008)
22. Vorotnitsky, V.E., Morzhin, Y.: Digital transformation of energy in Russia -a system task of the fourth industrial revolution. Sci. Tech. J. Energy Unified Netw., 12–21 (2018)
23. Vorotnitsky, V.E.: The Solution to the problems of the Russian electric power industry should be systematic, qualified and customer-oriented. Ind. Power Eng., 14–21 (2018)
24. Vorotnitsky, V.E.: On digitalization in the economy and electric power industry. Power Technol. Eng., 6–14 (2019)
25. Valeev, G.S., Dzyuba, M.A., Valeev, R.G.: Modeling of daily load schedules of 6–10 kV distribution network sections in cities and localities under conditions of limited initial information. Bull. SUSU. A Series Energy, 23–29 (2016). https://doi.org/10.14529/power160203
26. Sidorov, A.I., Tavarov, S.S.: Method for forecasting electric consumption for household users in the conditions of the Republic of Tajikistan. Int. J. Sustain. Dev. Plan., 569–574. https://doi.org/10.18280/ijsdp.150417

27. Sidorov, A.I., Khanzhina, O.A., Tavarov, S.S.: Ensuring the efficiency of distribution networks C. Dushanbe and Republic of Tajikistan. FarEastCon (2019). https://doi.org/10.1109/FarEastCon.2019.8934377
28. Sidorov, A.I., Tavarov, S.S.: Normalization of power consumption in the Republic of Tajikistan taking into account the climatic features of the region. Sci. Tech. J. E. U. N., 70–75 (2019)
29. Tavarov, S.Sh.: Specific power consumption of the domestic sector taking into account the ambient air temperature and the territorial location of the Republic of Tajikistan. Ind. Power Eng., 19–22 (2019)
30. BR 256. 1325800.2016. Electrical installations of residential and public buildings rules of design and installation. https://files.stroyinf.ru/Data2/1/4293751/4293751598.htm. Accessed 11 Jul 2017
31. BR-2696-01: Interim instruction for calculating electrical loads of residential buildings. Moscow. Publishing house GUP "NIAC" (2001)
32. Vatin, N.I., Gorshkov, A.S., Nemova, D.V.: Energy efficiency of envelopes at major repairs. Cons. Univ. Build. Struct., 1–11 (2013). https://doi.org/10.18720/CUBS.8.1
33. SS 30494-2011: Residential and public buildings. The parameters of the microclimate in the premises (2011)
34. Boguslavsky, L.D.: Reducing energy consumption when working with heating and ventilation systems. Moscow, Stroizdat (1985)