The Methods, Models and Algorithms of Electrical Loads Estimation for Different Type's Electricity Consumers in the Residential and Public Buildings

A.Sh.Arifjanov[1], Z.E.Yusupov*[2] , A.G.Saidkhodjaev**[3]
[1]Institute of Power Engineering and Automation, Academy of Sciences of Uzbekistan
*[2]Karabuk University, Turkey
**[3] Tashkent State Technical University, Uzbekistan

Abstract

Problems of environmental protection, energy security and economic development, referred to as the "three E» (Environment, Energy, Economics), are interlinked global challenges of the modern era. Nowadays it is becoming clear that the challenges facing the energy sector are becoming more cuter. People's desire to improve the living standards dictates the increasing the energy capacity, and especially electric power and its reliability. Urban distribution, as well as internal electrical networks of residential, municipal and public buildings, is essential elements of electricity supply system. The estimated electrical load is one of the main parameters that determine the design and construction of the electrical network elements. Therefore, the correct estimation problem of electricity consumption and a maximum electrical load of enterprises, homes have always been important in their design and operation. A reliable determination of the residential and public buildings loads is difficult because of the random nature of changes in electrical loads due to continuous population growth and an increase in the number of used electrical appliances. In this paper are considered an issue of the development of methods, models and algorithms for the estimation of electrical loads for the various types of electricity customers in the residential and public buildings.

Keywords: method, model, electrical loads estimation, daily schedule load.

1. Introduction

Urban distribution networks, as well as the internal network of residential, municipal and public buildings, are integral elements of the overall power system. One of the main parameters that determine the design and construction of the network elements is estimated electrical load. Therefore, the problem of correct estimation of power consumption and maximum electrical load of enterprises, organizations, institutions, homes have always been important in their design and operation [1].

Calculation of the urban network load includes determining the load of individual consumers (residential buildings, public buildings, municipal services, etc.) and electrical elements of the system (distribution lines, transformer substations, distribution centers, power centers, etc.).
At design, it is necessary to estimate correctly the maximum settlement loads as in general on object (for accession to a power supply system) and at the different levels of system of internal power supply (transformer substations, distributing devices, separate cable lines). On these loadings choose all electric equipment, therefore, they shouldn't be exceeded in use. At the same time, unjustified overestimate of settlement loadings leads to increase in cost of electric equipment. Therefore, loading has to be calculated as much as possible precisely.

In connection with the appearance of part of the population the possibility of use in the home of a wide range of modern household appliances and equipment, as well as in connection with the construction of urban and rural buildings on individual projects with luxury apartments, new specific standards of electrical loads should be determined based on the actual measurements

*Corresponding author: Address: [1]Institute of Power Engineering and Automation, Academy of Sciences of Uzbekistan

electrical loads, taking into account their probabilistic nature and features of modern luxury apartments in new buildings of the city, analysis of electrical appliances market development and technology, the degree of saturation of apartments, both now and in the future.

In the cities, the problem of reliable determination of residential and public buildings loads, and provide energy savings is especially difficult, because of population growth and an increase the number of used electrical appliances. Along with the increasing number of electrical appliances used by the population grows and their installed capacity.

Modern residential buildings have a lot of different power consumers which include lighting, household appliances and power equipment. There is an ongoing process of improving housing comfort, and this process increases the amount of domestic power consumers and increased domestic electricity consumption. Increasing the number of floor's homes tightens the requirements for reliability and continuity of supply of electric networks. The same features are proper for public buildings. The public buildings include a variety of institutions and the organization of management, finance, education; pre-schools, libraries, enterprises of trade, restaurants, consumer services; hotels, hospitals, museums, entertainment and sports facilities.

In this regard, the reliable definition of electric loadings of residential and public buildings in the cities became very actual problem on which solution the end results of actions for energy saving in many respects depend. The normative document "The electric facilities of residential and public buildings. Construction norms and rules" using to calculate of loadings of residential buildings doesn't solve the designated problem, because the specific norms of electric loadings given in this document for various types of consumers of energy have been defined in the 80s last century and don't correspond to today's condition of power consumption in residential and public buildings. In many cases the calculated values of electric loadings of residential and public buildings defined according to this normative document with use of various correction coefficients aren't true [2].

2. The problem statement

Analysis of the existing regimes of power consumption in the urban electric network shows the need to develop new accounting standards specific to electrical loads for different types of residential and public buildings consumers, taking into account the current realities of power consumption in the residential and public sector.

Estimated electrical loads and dynamics of their growth in the future is the foundation that determines the nature of construction and the development of urban electrical networks. The electrical loads of houses and public buildings are random and depend on some of factors: the way of life of the various families, the number of power consumers and power and others. Therefore, the basis for determining the load is used the probabilistic and statistical approach to the load as a non-stationary random variable. Hence, the estimated electrical load or network element assumes to be probable maximum load value for an interval of 30 minutes.

To obtain reliable data while a design of standard charts and determine their numerical characteristics it is necessary correctly handle the experimental results, based on the position of mathematical statistics and probability theory. It should be borne in mind that, according to the law of large numbers and the theory of probability, the results determine the average aggregate will be valid when the number of tests or, in other words, the number of surveyed members together will be quite large. On the other hand, with an increase in the number of aggregate members, their examination is a huge work, and we have a problem of determining a sufficient number of members in the aggregate, that allow to obtain mean values with sufficient accuracy.

Therefore, for an assessment of this loading very often used some generalized indicators, coefficients, specific loadings and specific expenses of the electric power.

The existing algorithms of load calculation of the industrial power systems, determination of the maximum loads and the choice of electric equipment don't consider dynamics of growth and character of household loading, laws of its functioning, do not allow to take into account in calculating of the actual loading the relationship of load changes on a day of the week, time of day. Despite the large number of works on the subject, the daily schedule load model of residential and public buildings and their practical implementation are not well developed. There is not a program that gives to specify the load calculation data of residential and public buildings on the current state of the loads.

The method widely used for determining the maximum electrical load of electrical networks are based on the measurement of the average load of electrical consumers over a given time period t (t = 8 hours or 0.5 hours) with variable initial measuring point. The total number of electrical consumers, on which measurements are made should not be less than 20% of the total number of electrical consumers connected to the electric network (but not less than 15). Measurements should be carried out repeatedly and for a long time [2, 3]. All these methods are characterized by a long time and a low accuracy of measurements; by a significant difference from the actual loads, especially the total; by significant errors in calculation (do not include the probabilistic nature of the electrical loads in the urban network). These methods also do not take into account the time factor of maximum electric load of each customer. In addition, these techniques are designed for installations with a regular operating mode and require large amounts of additional measurements and not possible to determine the desired value for a predetermined time period including at least three units.

The way of definition of the maximum load of electric consumers [4] according to which measure once individual loadings in various technological operating modes, total time of each technological mode for basic time and calculate the load group with a probability of exceeding no more than the required conditions of the problem.

However, this method does not provide sufficient accuracy while determining the estimated load for a group of different types of electric consumers, in particular, if even in the same technological modes individual electrical loads are not constant.

3. A new method of solving the problem

A method for determining the maximum electrical load of electrical networks and individual electrical consumers patented by one of author of this paper [5].
This method significantly reduces the numbers and time of measurements and improve the accuracy and reliability of determining the maximum electrical load of consumers.
The essence of a way is electric loads of the certain consumers are measured in various technological operating modes for basic time. Then from set of the measured loads the maximum size of load of the certain consumers is determined. The maximum value of the electric load is defined as the highest value for all of the measured periods of typical daily schedules, with a maximum electrical load in a time interval 15-minute and 30-minute. Further calculation of loads of a network is conducted in a general view on a formula.

Let's us consider the essence and use of this new method. The essence of the new method for calculating the load of 0.4 kV and 6 - 10 kV electrical networks is to determine estimated load for each time period of the day according to the on typical daily schedule of customer load. It is found by summing of the mathematical expectations and the mean square deviations of all consumers. For the calculated maximum value of the total load is accepted its greatest value from all the calculating for hour or half-hour periods of the daily schedule.

The mathematical expectation for the construction of a typical load graph of homogeneous consumers will be equal [6]:

$$\overline{P_{cpi}} = \frac{\sum_{\beta=1}^{m} \sum_{\gamma=1}^{l} \sum_{j=1}^{n} Y_{ij\gamma\beta}}{m \ln}$$

where:

P_{cpi} - mathematical expectation of the random load;

Y_{ij} - matrix of initial values of the loads daily schedule;

n - the number of points measured value of the daily schedule for a half-hour or hour interval;

l - the number of load measurements (in days) in each point at electrical network;

m - the number of homogeneous consumers, accepted as experimental.

So, the root-mean-square deviation equals:

$$\sigma_{\overline{pi}} = \sqrt{D_i} = \sqrt{\frac{\sum_{\beta=1}^{m} \sum_{\gamma=1}^{l} \sum_{j=1}^{n} Y_{ij\gamma\beta}^2}{m \ln} - \left(\frac{\sum_{\beta=1}^{m} \sum_{\gamma=1}^{l} \sum_{j=1}^{n} Y_{ij\gamma\beta}^2}{m \ln}\right)^2}$$

The value of measured daily schedule load can be given as a matrix Y_{ij} – current or power, where

i - rows (at half-hour intervals i = 48 per day, at hourly intervals i = 24);

j - columns of the matrix (at 5-minute increments of the load curve in a half-hour interval j = 7, j = 13 in an hour interval).

Investigation of the electrical load of public buildings has its own peculiarity. Average maximum values of different groups of public buildings cannot be subjected to similar statistical processing as the load of residential buildings, so there are large variations in the average value of apartments load. Because absolute values of electrical loads for different by construction and character of public building have a very large variation of average values and do not provide sufficient accuracy of calculations. Therefore, it is necessary to conduct processing of public buildings statistical data for homogeneous consumers.

4. The Algorithm of a New Method Implementation

The algorithm of the new method is as follows [6]:

1. The experimental investigations of urban power consumers and electrical loads conduct.
2. Using the mathematical apparatus of the theory of probability and mathematical statistics are being built characteristic (model) daily schedules of electrical loads for all types of urban power consumers and the electrical load.

3. On the basis of these daily schedule characteristic, using Lagrange, Newton, Stirling, Bessel, Chebyshev and others methods are determined analytical functions (equations, formulas) of curves (daily schedules) of mode changes each consumer.

4. Next, by functions (equations, formulas), which are describes curve of the daily schedule load, analytically are defined of maximum coefficients Km.

In general, the equation describing the daily schedule of electric load has the form:

$$S(x) = U_{i=1,24}\, S_i(x)$$

$$\text{or}\quad S_3(x) = \frac{M_{i-1}}{6h_i}(x_i^3 - 3x_i^2 x + 3x_i x^2 - x^3) + \frac{M_i}{6h_i}(x^3 - 3x^2 x_{i-1} + 3x x_{i-1}^2 - x_{i-1}^3) +$$

$$+\frac{f_{i-1}}{h_i}x_i - \frac{M_{i-1}\cdot h_i^2}{6h_i}x_i - \frac{f_{i-1}}{h_i}x + \frac{M_{i-1}\cdot h_i^2}{6h_i}x + \frac{f_i}{h_i}x - \frac{f_i}{h_i}x_{i-1} - \frac{M_i\cdot h_i^2}{6h_i}x + \frac{M_i\cdot h_i^2}{6h_i}x_{i-1} =$$

$$= (M_i - M_{i-1})\cdot\frac{x^3}{6h_i} + \frac{3}{6h_i}\cdot(M_i x_i - M_{i-1}x_{i-1})x^2 + (M_i\cdot x^2{}_{i-1} - M_{i-1}\cdot x^2{}_i - 2f_{i-1} + M_{i-1}\cdot h^2{}_i -$$

$$- M_i\cdot h^2{}_i + 2f_i)x + (M_{i-1}\cdot x^3{}_i - M_i\cdot x^3{}_{i-1} + 6f_{i-1}\cdot x_i - 6f_i\cdot x_{i-1} - M_{i-1}\cdot h_i^2\cdot x_i +$$

$$+ M_i\cdot h_i^2\cdot x_{i-1})\frac{1}{6h_i} = a_{i0}\cdot x^3 + a_{i1}\cdot x^2 + a_{i2}\cdot x + a_{i3}$$

where:

$$a_0 = \frac{M_i - M_{i-1}}{6h_i}$$

$$a_1 = \frac{1}{2h_i}(M_{i-1}x_i - M_i\cdot x_{i-1})$$

$$a_2 = \frac{1}{2h_i}(M_i\cdot x^2{}_{i-1} - M_{i-1}\cdot x^2{}_i + M_{i-1}\cdot h^2{}_i - M_i\cdot h^2{}_i - 2f_{i-1} + 2f_i)$$

$$a_3 = \frac{1}{6h_i}(M_{i-1}\cdot x^3{}_i - M_i\cdot x^3{}_{i-1} + 6f_{i-1}\cdot x_i - 6f_i\cdot x_{i-1} + M_i\cdot h_i^2\cdot x_{i-1} - M_{i-1}\cdot h_i^2\cdot x_i)$$

On the base of this algorithm, substituting the values M_i, f_i, h_i, x_i from the table, we obtain a system from 24 equations in 3rd order.

As a result, for the curve of the daily schedule load we obtain a system of equations, which has the following general form:

$$S_3(x) = a_{i0}\, x^3 + a_{i1}\, x^2 + a_{i2}\, x + a_{i3},$$

where a_{i0}, ai_1, a_{i2}, a_{i3} - coefficients of each equation.

Substituting the data from the daily schedule in these equations, we can obtain the curve segments of the daily schedule, and combining all of the 24 segments, as a result, get the curve of daily schedule, that is almost completely coinciding with the characteristic of daily schedule of consumer loads.

For each electrical consumer or appliances construct its equation of the curve and own formula for the maximum electrical load.

As a result, the calculation is obtained precise and more authentic and closer to the actual load, taking into account the peculiarities of load conditions change, the time factor for each appliance and consumer included in the city's power system.

Example 1. The characteristic daily schedule electrical load of the hospital, built using the Lagrange polynomial for $x_0 = 1$, $x_1 = 10$, $x_2 = 16$, $x_3 = 22$; $y_0 = 10$, $y_1 = 54$, $y_2 = 98$, $y_3 = 10$ is as follows (fig.1) [6]:

$$P(t) = 21.95057 - 15.91852\, t + 2.72962\, t^2 - 0.26084\, t^3$$

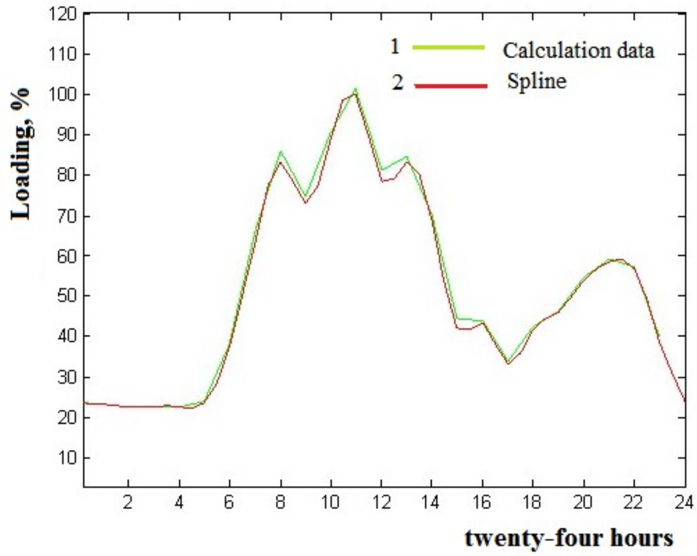

Fig.1. The characteristic of daily schedule hospital's electric load:
1- constructed from experimental data, 2- built by Lagrange polynomial.

Conclusions

1. Developed an improved method for determining the estimated electrical loads in residential and public buildings with using characteristic of daily load curves of the same type of consumers, constructed from experimental measurements of the characteristics of the typical power consumption of residential and public buildings consumers.
2. The use of the developed methods, models and algorithms allow more reliably determine the electrical loads in modern residential and public buildings taking into account peculiarities the load condition change each electrical consumer and load, included in the city's power supply system.

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