Energy economy potential estimation of establishment needs objects of power distribution company

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Abstract. This article describes a systematic approach in assessing the potential of energy saving, based on the universal model of technocenosis. A rank analysis of retrospective data on energy consumption was carried out, a mathematical model of power consumption was obtained. The procedures of interval estimation of the rank parametric distribution are carried out and the objects of establishment needs are determined, which power consumption is not included in the boundaries of statistical norms. With the help of cluster procedures, technocenological norms of power consumption are calculated. Based on the theory of structural and topological dynamics of the rank parametric distribution, the predicted power consumption is determined. The energy saving potential has been calculated and the objects of economic needs have been identified, where the implementation of measures aimed at energy saving is first necessary.

1. Introduction

Establishment needs objects (ENO) – are auxiliary and non-industrial divisions belonging to power plants and electric grid enterprises, which are necessary for servicing the main production, but not directly related to the technological processes of producing heat and electrical energy at power plants, as well as with the transmission and distribution of these types of energy.

The task of servicing the activities of the enterprise of electrical networks is diversified, which determines a wide range and a considerable number of used ENOs. These features do not allow or make it very time-consuming to use traditional methods for determining the standard energy consumption, which are characterized by the general requirement for a detailed analysis of a particular technological process.

To obtain the maximum economic effect from the applying of energy saving measures, it is possible and relevant to consider the totality of objects as a system when determining the potential for energy saving. This requirement is satisfied by the technocenological approach, which takes into account the system properties of the infrastructure object by using the apparatus of non-Gaussian distributions used to describe samples, whose elements are joined by weak links. The main tool of this approach is the rank analysis.

2. Rank analysis

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The initial data for estimating the energy saving potential are retrospective values of energy consumption of objects for the previous few years, arranged in the form of a two-dimensional matrix, each row of which corresponds to a specific time interval (year), and each column corresponds to a specific establishment needs object. Accounting for the influence of all factors on the value of power consumption of a separate establishment needs object complicates the mathematical model.

The two-parameter hyperbolic form of analytical dependence, traditional for the rank analysis, allows to simplify modeling [1, 2, 3]

$$W(r) = \frac{W_1}{r^{\beta}}, \quad (1)$$

It has an undeniable advantage – reduces the task of approximation to the definition of only two parameters W_1 and β. In this regard, an unordered set of source data should be ranked, i. e. arranged in order of decreasing values of the parameter being studied - power consumption (Figure 1, 2), as a result of which each ENO is assigned a rank.

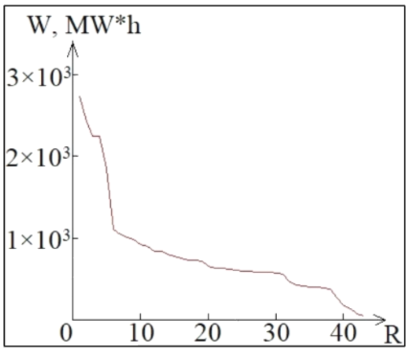

Figure 1 – Rank parametric distribution of technocenosis (for the first year).

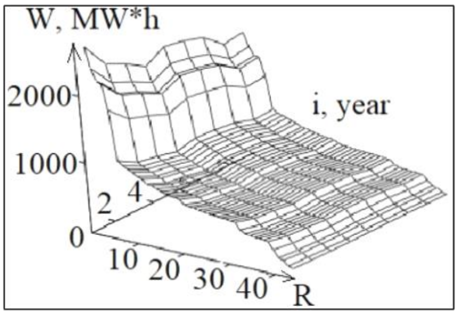

Figure 2 – Three-dimensional rank surface of technocenosis.

As a result of the approximation of the dynamics of power consumption by OHN, the coefficients W_1 and β of the mathematical model (1) of power consumption for each time period of history are obtained.

3. Parametric optimization

3.1. Interval estimation

In order to determine the objects of infrastructure that consume electricity abnormally, the procedure of interval estimation of the rank parametric distribution (RPD) [1, 2] is carried out, within which the confidence interval of the RPD and the location of points, which characterize the ENOs power consumption, are determined.

RPD is divided into a number of plots so that, firstly, at each site there were at least 10-12 points, and secondly, the deviations of the experimental parameters from the corresponding theoretical values determined by the approximation curve were distributed inside the plot along the normal to the law. It is possible to write the equation for each plot:

$$\frac{\Delta}{\sigma(\Delta\theta)} = \Phi^{-1}\left(\frac{p_d}{2}\right), \quad (2)$$

where Δ – width of the confidence interval to one side of the curve;

$\sigma(\Delta\theta)$ – the standard deviation of the experimental points from the theoretical curve (empirically - standard);

p_d – a priori accepted confidence probability;

$\Phi(t) = \dfrac{1}{2\pi}\int\limits_0^t e^{-t^{\frac{3}{2}}} dt$ – Laplace function.

Thus, having solved equation (2), the width of the confidence interval on each of the divisions is determined. If the point on the RPD is included in the confidence interval, then within the limits of the Gaussian spread of parameters, it is possible to state that this ENO consumes electricity normally. If the point is below the confidence interval, this, as a rule, indicates a violation of the normal process of power consumption at the ENO (frequent outages, excessive savings, etc.). If the point is above the interval, then the corresponding ENO has an excessive consumption of electricity.

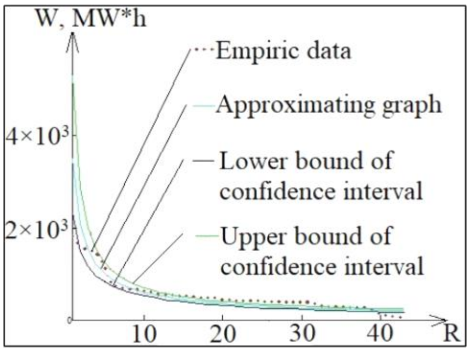

Figure 3 – Confidence interval for the full rank parametric distribution in linear axes.

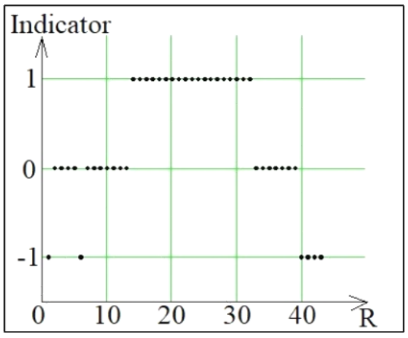

Figure 4 – A graph illustrating how points include in a confidence interval.

3.2. Power consumption forecasting

To evaluate the energy economy potential for the next time step and more accurate planning of measures aimed at energy saving, energy consumption forecasting is carried out. The forecasting method is based on the theory of the structural and topological dynamics of rank parametric distributions [4]. At the same time, the prediction of objects related to the noah, pointer and locust castes of the distribution is carried out separately. The boundaries of castes are determined using the criterion of equal distribution of resources, which is a consequence of the law of optimal construction of technocenosis [1]. In the framework of this method, the total energy resource of the technocenosis for power consumption is calculated, which is then divided into three equal parts:

$$W_{kz} = \frac{\int\limits_0^\infty W(r)dr}{3}, \tag{3}$$

where W_{kz} – a third of the total energy resource of the technocenosis;

$W(r)$ – rank distribution of power consumption.

To predict the power consumption of the noah caste objects (the most energy-intensive), the following polynomials were used:

$$W_j(t) = b_{j0} + \sum_i (b_{ji} t^i), \tag{4}$$

where $W_j(t)$ – power consumption of the object at the *j*-th stage of prehistory;

t – time (years);

b_{ji} – the *i*-th coefficient of the polynomial at the *j*-th stage of prehistory.

The method of forecasting is based on the selection of a polynomial that best describes the trend in the development of the power consumption process [4, 5]. For forecasting, a polynomial [4] is used, which, depending on its degree "*k*", can be a straight, quadratic (etc.) parabola. As a criterion for the optimality of the degree of a polynomial, the minimum of the square deviation of the forecast for the last known year from the actual verification value for the same year is used. Predictive assessment of the power consumption of the object for the next time interval is as follows:

$$W_{t+1} = \frac{1}{n} \cdot \sum_{j=1}^{n} W_j(t+1), \quad (5)$$

where n – number of stages of history.

When predicting the power consumption of objects of the pointer caste, the technocenological properties of the object are taken into account, which ultimately boils down to the concept of stability of hyperbolic distributions [1]. The forecast method [5, 6] in this case is based on the extrapolation of the time series of the regression coefficients of the parameters of the hyperbolic form of the rank distribution (two-parameter form). The forecast of power consumption of the k-th object is defined as follows:

$$W_k = \int_0^\infty \frac{W_0}{r^\beta} dr - \int_0^\infty \frac{W_{0k}}{r^{\beta_k}} dr, \quad (6)$$

where W_0 and W_{0k} – power consumption values for the first distribution point, respectively, with and without the k-th object in the technocenosis;

β and β_k – relevant rank factors;

r – object rank.

To predict the power consumption of objects belonging to the locust caste (with low power consumption) it is very effective to apply the relevant standards, which have remained stable for a number of years. Taking into account the standards that are discussed below, the prediction was made similarly to the prediction of power consumption of the objects of the pointer caste. The general forecast of the infrastructure power consumption (Figure 5) was carried out on the basis of interpolation of the main parameters of the hyperbolic form of the rank parametric distribution according to the following expression:

$$W = \int_0^\infty \frac{W_{0_\Pi}}{r^{\beta_\Pi}} dr, \quad (7)$$

where W_{0_Π} and β_n – forecasting distribution parameters determined on the basis of time series analysis or using secondary rank analysis.

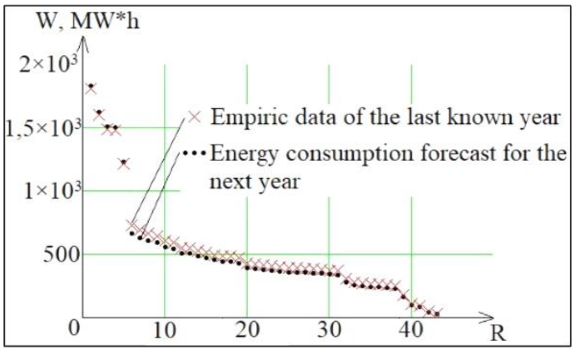

Figure 5 – The graph of the power consumption forecast for the next time interval (2017) and the empirical values of the last period of prehistory.

3.3. *The rationing of power consumption*

In order to determine the reference power consumption of the technocenosis objects, a rationing procedure was applied, consisting in finding the statistical parameters (empirical average and standard) of the technocenosis clusters allocated for the rank parametric distribution over the parameter being studied. Clustering allows to select groups of objects that consume a resource in a similar way at a certain time interval. Statistically, inside the cluster, functional parameters of objects should be distributed according to the normal law [7]. The procedure is implemented on the basis of experimental data on power consumption for each time interval in accordance with the criterion of the quality of splitting into clusters, which looks like this:

$$Q(S) = \sum_{f=1}^{n} \Big(\sum_{(r_i, W_i),(r_j, W_j) \in S_f} (d_E^{\,2}((r_i, W_i),(r_j, W_j))) \to extr \,, \qquad (8)$$

where $d_E\ ((r_i, W_i),(r_j, W_j))$ – weighted Euclidean distance between the points obtained;

$S_f = (S_1, S_2, ..., S_n)$ – fixed *f*-partition of observations $(r_1, W_1),(r_2, W_2),...,(r_k, W_k)$ into a given number of clusters $S_1, S_2, ..., S_n$.

Cluster procedure is supplemented by checking the distance between all clusters S_f and S_m – a combining algorithm was applied based on estimating the distances between points, identifying a pair of points closest to each other and replacing them with the average. In this case, the following criterion is cyclically implemented:

$$\rho_{\min}(S_f, S_m) = \min\left\{ d((r_f, W_f),(r_m, W_m)) \right\} \underset{(r_f, W_f) \in S_f, (r_m, W_m) \in S_m}{\longrightarrow} \max \qquad (9)$$

Power consumption norms for the *S*-group of objects are defined as follows:

$$\overline{W_s} = \frac{\int_{r_{s-1}}^{r_s} \frac{W_0}{r^{\beta}} dr}{r_s - r_{s-1}} \cong \frac{1}{n_s} \sum_{i=1}^{n_s} W_i \,, \qquad (10)$$

where r_{s-1} and r_s – respectively, the left and right rank bounds of the normalized group of objects on the parametric distribution;

n_s – the number of objects in the *S*-group.

The final (predicted) standard of power consumption of the object was determined by extrapolation to the next time interval of the standards obtained for this object at all time intervals of prehistory (Figure 6).

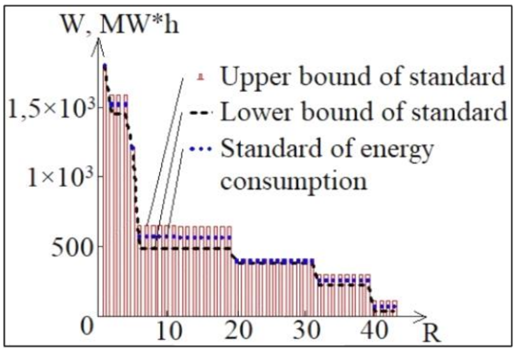

Figure 6 – The graph of ranked forecast energy consumption standard for the next time step.

4. Determination of energy saving potential

After performing operations, described above, it is possible to compare the projected energy consumption of ENOs without implementing energy saving measures and with optimizing of energy consumption, which corresponds to the values of the forecast standards, and calculate the energy saving potential for the next time step. The two assumptions were made while comparing:

1) In the absence of energy saving measures in the system, the corresponding parameters of the norm are taken as the expectation and standard, calculated for the cluster. Otherwise, the expectation is reduced by k1 times, and the standard – by k2 times (k1=k2=0,8);

2) All power consumption results exceeding the standard are replaced by its maximum value for this object. If the power consumption of the object in the simulation is less than the lower limit of the standard, then the minimum value of the standard is taken as the power consumption of the object.

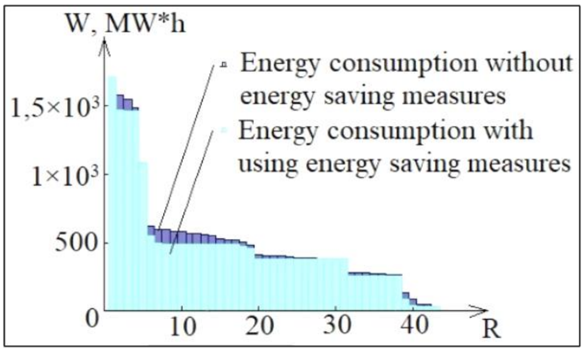

Figure 7 – Power consumption histogram of technocenosis

As a result, the calculated value of the energy saving potential is equal to 1 418 MW·h, which is 6.33% of the total amount of electricity consumed by ENOs in 2017.

Conclusion

Thus, a systematic approach was considered in assessing the potential for energy saving, based on the universal model of technocenosis. At the first stage, a ranking analysis of the retrospective data on energy consumption was carried out, which made it possible to obtain a mathematical model of power consumption. For time intervals (years), where the actual power consumption is known, within the framework of the procedures for the interval estimation of RPD, the ENOs are determined, whose power consumption does not fall within the statistical norms. In order to calculate the potential for energy saving in the coming year, the technocenological norms of energy consumption, calculated using cluster procedures, are compared with the predicted energy consumption determined on the basis of the theory of structural and topological dynamics of RPD. As a result of the assessment of the energy saving potential, ENOs was identified, where the implementation of measures aimed at energy saving is first needed, and the value of the energy saving potential for the next year is calculated.

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