The long-term forecasting of specific fuel consumption by the power system of Uzbekistan

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Abstract. The article considers the possibility of using the least squares method (LSM) for long-term forecasting of the parameters of the regime of electric power systems. There is presented least squares method for predicting the parameters of the regime of electric power systems. It is shown that, based on the least-squares method, it is possible to obtain prognostic equations, as well as coefficients of approximating functions necessary for the formation of these equations. The results of the analysis of the comparison of linear, hyperbolic, logarithmic, exponential and quadratic functions on the use of LSMs to predict specific fuel consumption are presented. The criterion of the least squares method, which is according for using the statistical data of the control sample in the obtained prognostic functions, the standard deviations are found.

1 Introduction

The long-term forecasting of the specific fuel consumption for the entire electric power system, the level and nature of consumption is required in order to identify quantitative indicators of the development of energy indicators, the development of the electric network and power transmission networks, and to determine the fuel strategy.

2 About the long-term forecasting of specific fuel consumption

The main task of managing the regimes of electric power systems (EPS) is to satisfy the needs of economic sectors and the population with high-quality electric energy and heat in the short and long term at minimum cost, ensuring energy efficiency of their production and consumption [1, 6-10].

However, in a transition economy, due to insufficient investment and imperfect technical means of monitoring and accounting for the production and consumption of energy resources, including electricity, this requirement is not always feasible. In this context, the issues of predicting operational parameters, as well as specific consumption for supplied electricity, and in particular, increasing their accuracy, are becoming paramount. Moreover, well-known forecasting models that do not take into account the market, random nature

of relationships, in practice, often turn out to be unsuitable for planning and managing EPS modes. In such a situation, for the analysis, modeling and forecasting of operating parameters and characteristics of the electrical system, it is advisable to apply methods of direct construction of models from observational data (statistics). Such methods make it possible to identify implicit cause-effect relationships and patterns hidden in retrospective data and to present them in explicit form of mathematical models [3-4, 10-12].

As we know, the management of EPS on the basis of planning (forecasting) is divided into four time levels: long-term (prospective), short-term planning (forecasting), operational and automatic control. At each level, it is necessary to ensure an appropriate balance of energy production and consumption, which requires maximum forecast accuracy.

Long-term forecasting is the first stage of system research and substantiation of the prospects for the development of energy. It calls to outline the area of acceptable and effective development of the country's fuel-energy complex (FEC), can identify possible problems of the situation and bottlenecks in this development, provide targets, a base and the necessary information to deepen and specify studies in developing the energy strategy, general schemes and development programs for regional industrial energy systems, as well as strategic plans for energy

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companies. Long-term forecasts play an important role in the modern preparation of the fundamental scientific section in a wide area of knowledge related to the development of energy [2, 13-15].

Long-term forecasting of specific fuel consumption in the whole electric power system, the level and nature of annual electricity consumption is required in order to identify quantitative indicators of the development of energy capacities, the development of the electric network and power transmission networks, as well as the determination of the fuel strategy.

Specific fuel consumption per kW·h of electric energy supplied is one of the main indicators of energy efficiency in the functioning of the electric power industry in Uzbekistan. This parameter refers to the parameters characterizing the long-term (perspective) forecasting, the period of which is from 1-5 to 20 years. In case of expectation of commissioning of capacities by EPS or design and design changes in the network in the near future, a long-term forecast is made for the cycle "months-quarters-years".

For long-term forecasting based on statistical methods, retrospective statistical information about the parameters and modes of loading of EPS is used. It is based on the apparatus of statistical analysis and forecasting of time series. It should also be noted that in the process of short-term planning of electrical modes, the results obtained from their long-term planning are used, while the solutions are adjusted taking into account the specified circuit-mode conditions. The results of solving the problems of short-term planning of electric modes are transferred to the level of long-term mode control as planned values [5, 15-19].

3 The results of calculation experiments

Consider the results of long-term forecasting of specific fuel consumption in the electric power system of Uzbekistan using the least squares method (least squares) and compare its computational efficiency. Table 1 shows the values of specific fuel consumption for a number of years for JSC «Uzbekenergo», with the help of which a training sample was compiled (data from 1990-2011) to derive approximating functions and a control sample (data from 2012-2016) that allows checking approximating functions.

Table 1. The values of specific fuel consumption for a number of years for JSC «Uzbekenergo»

	the data of training sample								
Years	1990	1991	1992	1993	1994	1995	1996	1997	1998
x_i	1	2	3	4	5	6	7	8	9
y_i	361,5	368,4	368,6	362,5	361,2	362,7	363,4	367,7	369,8
	the data of training sample								
Years	1999	2000	2001	2002	2003	2004	2005	2006	2007
x_i	10	11	12	13	14	15	16	17	18
y_i	377,1	379,5	381,9	383,3	384,5	387,7	381,0	377,6	375,0
	the data of training sample				the data of control sample				
Years	2008	2009	2010	2011	2012	2013	2014	2015	2016
x_i	19	20	21	22	23	24	25	26	27
y_i	380,8	383,6	379,8	378,9	379,9	374,2	375,6	374,8	375,0

In order to determine approximating coefficients of prognostic equations from systems of equations obtained for [6]:

- linear function (LSM-1),
- hyperbolic function (LSM-2),
- logarithmic function (LSM-3),
- exponential function (LSM-4),
- quadratic functions (LSM-5).

We will make the necessary calculations and, according to the criterion of the least squares method (LSM) (1), we determine an approximating function whose sum of the squared deviations is the smallest:

$$\sum_{i=1}^{n} e_i^2 = \sum_{i=1}^{n} (y_i - f(x_i))^2 \to \min. \qquad (1)$$

Assume all points M1(x1,y1), M2(x2,y2),…, Mn(xn,yn) tend to be in a straight line and there is every reason to believe the presence of a linear relationship:

$$y=f(x)=ax+b. \qquad (2)$$

Find the coefficients a and b so that the sum of the squared deviations

$$F(a,b) = \sum_{i=1}^{n} e_i^2 = \sum_{i=1}^{n} (y_i - (ax_i + b))^2$$

was the smallest. To do this, we find partial derivatives of the first order. According to the rule of linearity, you can differentiate directly under the sum icon:

$$\frac{\partial F}{\partial a} = \left(\sum_{i=1}^{n} (y_i - (ax_i + b))^2 \right)_a^{'} =$$

$$\sum_{i=1}^{n} [2(y_i - (ax_i + b)) \cdot (y_i - (ax_i + b))_a^{'}] =$$

$$2\sum_{i=1}^{n} [(y_i - ax_i - b)) \cdot (0 - (x_i + 0))] =$$

$$2\sum_{i=1}^{n} [(y_i - ax_i - b)) \cdot (-x_i)] =$$

$$2\sum_{i=1}^{n} [(ax_i^2 + bx_i - y_ix_i)] \qquad (3)$$

$$\frac{\partial F}{\partial b} = \left(\sum_{i=1}^{n} (y_i - (ax_i + b))^2 \right)_b^{'} =$$

$$\sum_{i=1}^{n} [2(y_i - (ax_i + b)) \cdot (y_i - (ax_i + b))_b^{'}] =$$

$$2\sum_{i=1}^{n} [(y_i - ax_i - b)) \cdot (0 - (0 + 1))] =$$

$$2\sum_{i=1}^{n} [(ax_i^2 + b - y_i)] \qquad (4)$$

We compose a standard system of equations:

$$\begin{cases} \dfrac{\partial F}{\partial a} = 0 \\ \dfrac{\partial F}{\partial b} = 0 \end{cases} \Rightarrow \begin{cases} 2\sum_{i=1}^{n} [(ax_i^2 + bx_i - y_ix_i)] = 0 \\ 2\sum_{i=1}^{n} (ax_i^2 + x_i - y_i) = 0 \end{cases} \qquad (5)$$

After simplification, the system of equations will have the following form:

$$\begin{cases} a\sum_{i=1}^{n} x_i^2 + b\sum_{i=1}^{n} x_i - \sum_{i=1}^{n} y_ix_i = 0 \\ a\sum_{i=1}^{n} x_i + \sum_{i=1}^{n} b - \sum_{i=1}^{n} y_i = 0 \end{cases} \Rightarrow$$

$$\begin{cases} a\sum_{i=1}^{n} x_i^2 + b\sum_{i=1}^{n} x_i - \sum_{i=1}^{n} y_ix_i = 0 \\ a\sum_{i=1}^{n} x_i + \underbrace{\sum_{i=1}^{n} b + b + 4 \cdot 3}_{n.pa3} b - \sum_{i=1}^{n} y_i = 0 \end{cases} \qquad (6)$$

We rewrite the system in the "applied" form:

$$\begin{cases} a\sum_{i=1}^{n} x_i^2 + b\sum_{i=1}^{n} x_i = \sum_{i=1}^{n} y_ix_i \\ a\sum_{i=1}^{n} x_i + bn = \sum_{i=1}^{n} y_i \end{cases} \qquad (7)$$

If a function is assumed in the form of hyperbolic (8), logarithmic (9), exponential (10) and quadratic (11), having performed similar calculations (3-7), the system of equations will have the following form:

$$\begin{cases} \dfrac{\partial F}{\partial a} = 0 \\ \dfrac{\partial F}{\partial b} = 0 \end{cases} \Rightarrow \begin{cases} a\sum_{i=1}^{n} \dfrac{1}{x_i^2} + b\sum_{i=1}^{n} \dfrac{1}{x_i} = \sum_{i=1}^{n} \dfrac{y_i}{x_i} \\ a\sum_{i=1}^{n} \dfrac{1}{x_i} + bn = \sum_{i=1}^{n} y_i \end{cases} \qquad (8)$$

$$\begin{cases} \dfrac{\partial F}{\partial a} = 0 \\ \dfrac{\partial F}{\partial b} = 0 \end{cases} \Rightarrow \begin{cases} a\sum_{i=1}^{n} \ln(x_i)^2 + b\sum_{i=1}^{n} \ln(x_i) = \sum_{i=1}^{n} y_i \ln(x_i) \\ a\sum_{i=1}^{n} \ln x_i + bn = \sum_{i=1}^{n} y_i \end{cases} \qquad (9)$$

$$\begin{cases} \dfrac{\partial F}{\partial a} = 0 \\ \dfrac{\partial F}{\partial b} = 0 \end{cases} \Rightarrow \begin{cases} a\sum_{i=1}^{n} x_i^2 + b\sum_{i=1}^{n} x_i = \sum_{i=1}^{n} x_i \ln(y_i) \\ a\sum_{i=1}^{n} x_i + bn = \sum_{i=1}^{n} \ln(y_i) \end{cases} \qquad (10)$$

$$\begin{cases} \dfrac{\partial F}{\partial a} = 0 \\[2mm] \dfrac{\partial F}{\partial b} = 0 \\[2mm] \dfrac{\partial F}{\partial c} = 0 \end{cases} \Rightarrow \begin{cases} a\sum_{i=1}^{n} x_i^4 + b\sum_{i=1}^{n} x_i^3 + c\sum_{i=1}^{n} x_i^2 = \sum_{i=1}^{n} x_i^2 y_i \\[2mm] a\sum_{i=1}^{n} x_i^3 + b\sum_{i=1}^{n} x_i^2 + c\sum_{i=1}^{n} x_i = \sum_{i=1}^{n} x_i y_i \\[2mm] a\sum_{i=1}^{n} x_i^2 + b\sum_{i=1}^{n} x_i + cn = \sum_{i=1}^{n} y_i \end{cases} \quad (11)$$

Based on the data of the training sample, solving the system of equations (7-11) we determine the coefficients with which we will form the following prognostic functions (12-16) LSM-1, LSM-2, LSM-3, LSM-4 and LSM-5, respectively:

$y=f(x)=1{,}040373x+362{,}4039$ (12)
$y=f(x)=-23{,}1112/x+378{,}2454$ (13)
$y=f(x)=-6{,}35941*\ln(x)+389{,}3322$ (14)
$y=f(x)=366{,}12*e0{,}0016x$ (15)
$y=f(x)=-0{,}0624x2+2{,}4745x+356{,}67$ (16)

Based on the control sample, using (12-16), we predict the specific consumption from 2012 to 2016.

Table 2. The calculation results (in ton of standard fuel).

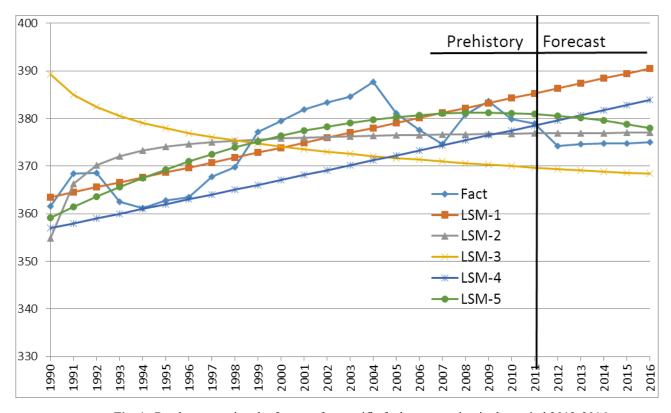| Years	Fact	LSM-1	LSM-2	LSM-3	LSM-4	LSM-5
2012	379,9	386,33	376,9	369,39	379,6	380,57
2013	374,2	387,37	376,9	369,12	380,6	380,12
2014	375,6	388,41	377,0	368,86	381,7	379,53
2015	374,8	389,45	377,0	368,61	382,8	378,82
2016	375,0	390,49	377,0	370,35	383,8	377,99

Fig. 1. Graphs comparing the forecast for specific fuel consumption in the period 2012-2016
(in ton of standard fuel).

4 Conclusion

According to the least squares least squares criterion, the least sum of squared deviations was obtained when predicting the quadratic function (LSM-5):

$$\sum_{i=1}^{n} e_{i\ LSM-3}^2 \phi \sum_{i=1}^{n} e_{i\ LSM-2}^2 \phi \sum_{i=1}^{n} e_{i\ LSM-4}^2 \phi \sum_{i=1}^{n} e_{i\ LSM-1}^2 \phi \sum_{i=1}^{n} e_{i\ LSM-5}^2$$

$$3619,7 \phi 1031,1 \phi 825,4 \phi 593,9 \phi 483,7$$

Thus, in conclusion, it should be noted that from the analyzed functions according to the LSM criterion, the least sum of squared deviations was obtained when predicting specific fuel consumption using a polynomial 2-degree function.

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