Dynamics appraisal of electrical energy consumption process of iron ore mines in conditions of indeterminacy and insufficiency of information

Roman Parkhomenko

Senior teacher
State Higher Educational Institution
"Kryvyi Rih National University", Ukraine

Abstract
In this paper, the process state of electrical energy consumption in conditions of indeterminacy and insufficiency of information with the applying of data-compression methods such as Karhunen-Loeve expansion (KLE) and Principle Component Analysis (PCA) was appraised. As the result, the mathematical model of electric energy consumption process was introduced. This model was developed using statistical classification when nonuniform operating mode of electric loads. The mathematical model, which was obtained, allows considering parameters (factors) of mine production team and others, which have an impact on electro-energy intensity of production.
Key words: ELECTRIC LOADS, DATA-COMPRESSION, IRON-ORE MINES.

Introduction

The efficiency upgrading of electric energy use in iron-ore companies is inextricably connected with the problem of valuation level reasonability of electrical energy consumption conditions, this is particularly topical by virtue of mining conditions specification.

Mining companies energy consumption depends on many factors. The factors impact on energy consumption (EC) process is of complicated and multivarious nature. The description of this nature under deterministic as well as classical static methods is not always possible due to unpredictability of conditions determining factors effect. In this regard, we can state that electric energy consumption (EEC) of iron-ore companies is formed by the impact of factors, which cannot be predicted for sure. A large number of various factors present certain valuation difficulties of their impact on EEC in methodological as well as technical-and-economic terms.

Simulation status analysis of electric energy consumption process of mine networks electric loads power-consuming units shows that the information on EEC process consists of empirical data varieties and characterises it by multivariate random features. Features considerable number makes it difficult to find out the connections between them. In such a case, it is necessary to describe EC process by the less number of summarized characteristics reflecting internal objectively existing regularities, which are not within direct observation.

These particularities lead to necessity of using the special methods while appraisal of EEC conditions state of mine companies. These methods allow obtaining the solution in conditions of insufficient information when reducing of initial data dimension (data-compression) on the process under investigation [1]. In this case, EC data analysis tasks, which are solved by the factor analysis methods, appear.

Considerable number of mine companies processing electric loads, while in operation, form energy conditions, which are nonuniform (from the standpoint of probability distribution) [1]. In these circumstances, probability distributions of initial statistical information characteristic value and reduced (compressed) information in EEC processes are of polymodal nature. This circumstance introduces some difficulties while modeling of EEC processes.

Purpose and objectives of research

The purpose of the paper is the development of electric energy consumption mathematical model using statistical classification method when nonuniform operating mode of electric loads.

The material and results of researches

The process state of electrical energy consumption in conditions of indeterminacy and insufficiency of information with the applying of data-compression KLE and PCA methods supposes detection of essential features determining the nature of energy consumption conditions. The principle of above-noted methods [2] lies in the fact that best possible projection of the observation points totality of space with smaller dimension is found out using orthogonal transformations. At that, newly received vectors are distributed in reduced space: in PCA they are distributed by the measure of maximum dispersion while in KLE - by the measure of minimum mean-square error. As can be seen from the above, KLE allows introducing the steadiest system state, to which minimum mean-square error conforms, and PCA allows to describe maximum system dispersion by less number of vectors, h.e. to obtain the most probable variation limits of initial experimental matrix.

For implying of the compression methods, initial information on EC should be presented in the form of matrix:

$$X = [Xj] = \begin{bmatrix} X_{11}\dots & X_{1j}\dots & X_{1m} \\ X_{i1}\dots & X_{ij}\dots & X_{im} \\ \dots & \dots & \dots \\ X_{n1} & X_{nj} & X_{nm} \end{bmatrix}, \qquad (1)$$

where [*Xj*] - row-vector reflecting the information on electrical energy consumption when i-th characteristic value;

Xij - value of the electrical energy consumption quantity of *i*-th characteristic and *j* -th dimension (object).

$i = \overline{1,n}$ - number of characteristic values;

$j = \overline{1,m}$ - number of dimensions (objects).

In this case, the electrical energy consumption may be characterized as n-dimensional vector.

During EEC modeling with the use of KLE the main transformations are the following.

In real EEC process, the characteristic orthogonal (independent) components (representative vectors), which describe the electrical energy consumption in the space with smaller dimension when extracting of maximum information from the observation results, are segregated. This procedure is performed by the coordinates system linear transformation of initial n-dimensional vector of electrical energy consumption X in accordance with the following equation:

$$X = A \cdot Y, \qquad (2)$$

where A - transformation matrix, $A = \{a_{ij}\}$, $i, j = \overline{1,n}$;

Y – representative n-dimensional vector, which describes EC process in the new variables space. $Y = \{Y_{ij}\}, i = \overline{1,n}, \quad j = \overline{1,m}$.

The transformation matrix A is located on initial matrix X and has the form of n-eigenvectors of the covariance matrix K_x

$$K_x = \begin{bmatrix} K_{11}\dots & K_{1j}\dots & K_{1m} \\ K_{i1}\dots & K_{ij}\dots & K_{im} \\ \dots & \dots & \dots \\ K_{n1} & K_{nj} & K_{nm} \end{bmatrix}, \qquad (3)$$

where *Kij* - sample unbiased estimates of covariance matrix elements, which are determined by formula:

$$K_{ij} = \frac{1}{m-1}\sum_{j=1}^{m}(X_{ij} - \overline{X}_j)(X_{lj} - \overline{X}_l), \qquad (4)$$

where $\overline{X}_j, \overline{X}_l$ - secondary average of *i*-th and *l*-th component of n-dimensional vector of electrical energy consumption *X*.

Eigenvectors U_i of matrix K_x are found out by eigenvalues λ_{Ki} from the equation

$$K_x \cdot U_i = \lambda_{Ki} \cdot U_i , \qquad (5)$$

Eigenvalues λ_{Ki} are obtained by the solution of the equation:

$$K_x - \lambda_{Ki} \cdot I = 0 , \qquad (6)$$

where *I* - unity matrix.

For observance of orthonormalization condition, eigenvectors normalizing must be fulfilled, upon which we obtain transformation matrix:

$$A = [A] = \begin{bmatrix} A_{11} \dots & A_{1r} \dots & A_{1n} \\ X_{i1} \dots & X_{ir} \dots & X_{in} \\ \dots & \dots & \dots \\ X_{n1} & X_{nr} & X_{nn} \end{bmatrix}, \qquad (7)$$

When orthonormality observing, in the new variables space

$$M\{(Y_{ij} - \overline{Y}_i) \cdot (Y_{ij} - \overline{Y}_l)\} = \begin{cases} \lambda_i & \text{where } \_ l = i \\ 0 & \text{where } \_ l \neq i \end{cases}$$

representative vector is determined by matrix equation:

$$Y = A^T X , \qquad (8)$$

In these circumstances, the following conditions are fulfilled:

$$M\{(Y_{ij} - \overline{Y}_i) \cdot (Y_{ij} - \overline{Y}_l)\} = \begin{cases} \lambda_i & \text{where } \_ l = i \\ 0 & \text{where } \_ l \neq i \end{cases}$$

Representative vectors Y_i are uncorrelated, h.e. the condition

(9)

is fulfilled;

The mean-square error is minimal when using only N first representative vectors Y_i *(N<n)* for introduction of vector X

$$\overline{\varepsilon}^2(N)_{\min} = \sum_{i=N+1}^{n} \lambda_{Ki} , \qquad (10)$$

From there, for EEC process under investigation the model of compressed information is as follows:

$$X_{ij} = \sum_{r=0}^{n} a_{ir} \cdot Y_{rj} , \qquad (11)$$

While modeling of EEC process by PCA, the main transformations are the following:

The matrix values of initial data on EEC process are standardized and we obtain the standardized matrix

$$Z = \{Z_{ij}\}, \qquad (12)$$

The values of standardized matrix:

$$Z_{ij} = \frac{X_{ij} - \overline{X}_j}{\overline{\sigma}_j} , \qquad (13)$$

where $\overline{X}_j$ - the average value of the column *j ;*

σ_j - mean-square deviation of value X in column *j*

The new variables are found out as uncorrelated normalized linear combinations of initial features. In matrix form we have:

$$F = B^T \cdot Z , \qquad (14)$$

where *F* – matrix of new variables (main component),

$F = \{f_{ij}\}$, $i = \overline{1,n}$; $j = \overline{1,m}$;

B – transformation matrix.

Transformation matrix

$$B = A \cdot \lambda^{1/2} ; \qquad (15)$$

where A - orthogonal matrix where *r*-th column is *r*-th eigenvector, which conforms to *r*-th eigenvalue of correlation matrix R_x*;*

λ - diagonal matrix. On this matrix diagonal λ_r, eigenvalues of correlation matrix R_x of vector X are located.

The matrix λ are ranged in decreasing order:

$$\lambda_1 \geq \lambda_2 \geq \lambda_3 \geq \dots \geq \lambda_n \geq 0 , \qquad (16)$$

The new variables are ranged in decreasing order of their dispersion in space of features, h.e.

$$\sigma^2(f_1) \geq \sigma^2(f_2) \geq \dots \geq \sigma^2(f_n), \qquad (17)$$

where f_1, $f_2 \dots$ f_n - first, second, n-th main components respectively.

For the EC process under investigation the model of compressed information has the form

$$X_{ij} = \sum_{r=1}^{n} b_{ir} \cdot f_{rj} , \qquad (18)$$

where *n* – number of main components f_{rj} ensuring contribution to the total dispersion with sufficient given reliability.

While approximation of transformation vectors (A_r, B_r) and representative vectors Y_r (main components f_r), adequate models of EC process are obtained by analytical functions:

$$F_{Xij}(\gamma_a, \varphi_Y) = \sum_{r=1}^{n} \gamma_a, r_i(T) \cdot Y_{Y,rj} , \qquad (19)$$

where γ_a, φ_Y - analytical functions, approximated vectors A_r and Y_r included in matrix A and Y respectively; $i = \overline{1,n}$; $j = \overline{1,m}$.

Conclusions

The above-mentioned procedures allow more complete using of initial statistical information for appraisals, which describe EC condition properly, in conditions of indeterminacy and small informative value of observable features determining EC process.

References

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