Mathematic simulation of mining company's power demand forecast (by example of "Neryungri" coal strip mine)

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Abstract. The article covers the aspects of forecasting and consideration of the wholesale market environment in generating the power demand forecast. Major mining companies that operate in conditions of the present day power market have to provide a reliable energy demand request for a certain time period ahead, thus ensuring sufficient reduction of financial losses associated with deviations of the actual power demand from the expected figures. Normally, under the power supply agreement, the consumer is bound to provide a per-month and per-hour request annually. It means that the consumer has to generate one-month-ahead short-term and medium-term hourly forecasts. The authors discovered that empiric distributions of "Yakutugol", Holding Joint Stock Company, power demand belong to the sustainable rank parameter H-distribution type used for generating forecasts based on extrapolation of such distribution parameters. For this reason they justify the need to apply the mathematic rank analysis in short-term forecasting of the contracted power demand of "Neryungri" coal strip mine being a component of the technocenosis-type system of the mining company "Yakutugol", Holding JSC.

1. Introduction

"Yakutugol", Holding JSC, is the largest coal mining company in the Sakha Republic (Yakutia) and the Far East Federal District that operates in coal mining and trade for more than 40 years. "Yakutugol" is the major coal supplier to the Asian-Pacific market. Over 50% of the total coal production is exported to Japan, South Korea and China. Trial cargos were delivered to India and Brazil [1]. Metallurgic and power companies of Russia, Japan, South Korea, India and Taiwan are among its major consumers. The region’s climate is severely continental, the above-zero temperature period lasts for 137 days, the below-zero temperature holds up for 228 days. The range of absolute elevations in the field area is 600…1200 m [2].

Overburden recovery is carried out by using the mining transportation system that includes sturdy excavator power shovels and drag-lines WE-11/50 (walking excavator) that load large dump trucks with the capacity of 120-218 tons. Mining activities in a mining unit shall be carried out by horizontal
layers. The bench height must be 10.0 m. Excavator power shovels ECC-10 (ECC the Excavator is Career Caterpillar) and ECC -8I are mainly used for stripping, while in so called "sink holes" where underlying rock elevations leap, they use excavator drag-lines ESH-11/50 and «KOMATSU» diesel excavators PC-3000 with 8.5 m³ shovel size.

The actual mining fleet comprises 25 excavators, including:
- strip-mining – 16 excavators, of which PC-5500 – 2 pcs, 301-M – 2 pcs, PC-8000 – 3 pcs, 201-M – 1 pc, ECC -20 – 6 pcs, ECC -15 – 2 pcs;
- production mining – 9 excavators, of which ECC -10 – 1 pc, ECC -8I – 6 pcs, WE-11/50 – 2 pcs.

Besides the expected strip-mining and production mining activities, they consider other types of activities currently carried out at "Neryungri" coal strip mine (that is about 10% of the total annual mining volume): construction of service roadways in mine floors and access points from the coal seam to seam tops; mucking; ice and snow cleaning, crushed stone removal; work at temporary coal storages, etc. For these purposes they use excavator power shovels ECC-5A and ECC-8I.

Though power demand differs from site to site, purchase costs, evidently, constitute a substantial part of the total expenses. An alternative way for a mining company to reduce costs is to become a participant of the wholesale electrical energy and power market.

Major companies that entry the wholesale market of electrical energy aim to save costs associated with its purchase. If energy demand is great, the benefit gained reaches several million RUR annually.

For the majority of companies the main constraint is day-ahead hourly forecast with max. 5% acceptable variance.

A faulty forecast turns to economical losses of the company: underestimation of the expected load (exceed of the maximum load requested) leads to penalties; if the actual hourly load is less than the contracted one, they have to pay for the contracted capacity.

2. State-of-the-Art Methods of Power Demand Forecast Simulation

To reduce power consumption expenses the coal mining companies enter the wholesale electrical energy and power market, i.e. conclude the agreement on purchasing the electrical energy with a market operator, not with Energo, JSC. Among the functions of the wholesale electrical energy and power market are management of the wholesale market activities, generation of electrical energy and power balances, management of contractual relations between subjects, etc.

Today a lot of methods and models of power demand forecasting are available [3-6], and their number tends to increase constantly. According to [7], there are above 150 forecast methods known. Let's consider the basic forecast methods that are most frequently used in other industrial sectors.

Power demand calculations by general specific power requirements, product electrical capacitance and process parameter multiple regression equation belong to the group of multifactor methods. These methods should be only used for defining the expected values of power demand, but not of power consumption rates at a certain production area. In case the majority of parameters cannot be evaluated precisely, they use the fuzzy-set theory for power demand estimation [8-10].

The main disadvantage of regression models is the need to know precise values of independent (explanatory) variables in the forecast interval, what is not, however, always possible.

To forecast daily and hourly volumes of power demand and loads they consider the random component of the time sequence, using autoregression methods [11], probabilistic simulation [12]. As we talk about separation and forecasting of the random component, the process of defining the deterministic component takes on particular significance. The Box-Jenkins method used in [13] is applied for co-forecasting of trend and random components, thus combining autoregression and moving average methods. The Box-Jenkins model is based on handling autoregression sequences that do not contain any priori assumptions concerning discount factors. This model is only used for building trends by transition to sequence differences, it tolerates excesses and presents them as moving average random numbers.

In time sequence-based forecast methods they use only the retrospective data on company's power consumption, that is both - advantage and disadvantage of such methods. These data are always
available and can be presented in any time interval required. However, the main disadvantage centers around the key idea that the expected variable value depends exclusively on its previous values, what is actually wrong.

A promising trend in power demand forecasting is application of the rank analysis method based on stable hyperbolic H-distribution. To apply the method based on ranked H-distributions it is required that a system belongs to the new object type - technocenosis [14].

3. Application of Rank Analysis Method Based on Stable Hyperbolic H-distribution

Though affiliates (departments) reporting to "Yakutugol", Holding JSC, carry out different activities, they all focus on coal mining and preparation.

To define trends in company's power demand, they have studied the consumption structure of "Yakutugol", Holding JSC, affiliates (departments). Analysis of power demand dynamics in time presupposes definition of the model. They choose the rank model to carry out such analysis.

The key idea of the rank analysis is to build up and to approximate rank distributions for their further application in forecasting. The rank distribution is a decreasing sequence of parameter (e.g., power demand) values, that is ordered the way that every following number is less than the previous one and is associated with the rank (the number in order in such ordered sequence) [14].

The rank distribution is, actually, a Zipf distribution in the rank differential form [14], that is a result of approximation of a non-increasing parameter value sequence obtained in the process of technocenosis type ordering. Here the rank is a sequential type number. If they use a speciation parameter (power demand), the distribution is called the rank parametric H-distribution.

Building graphic rank parametric distributions is done by every speciation parameter. It is peculiar for ranking subjects.

The analysis procedure is as follows:
1. Select elements (subjects) in the cenosis ("Yakutugol", Holding JSC) and define the parameter to study - subject's hourly power demand, Wi;
2. Rank companies: assign Rank i to integer numbers in the order of decreasing of parameter Wi. Rank 1 is assigned to subjects with the biggest power demand, the subject with the lowest power demand will be assigned the rank equal to the total number of companies i=n. Finally, they obtain the rank distribution of subjects based on the power demand value [15].

Electrical facilities of "Yakutugol", Holding JSC, includes 36 subjects. The most energy-consuming companies are "Neryungri" coal strip mine, Washhouse, Machinery and repair works. On results of sequential rank H-distributions the most energy-consuming department is assigned to a new distribution caste. Similarly they define departments belonging to pointer and grasshopper castes.

In power demand forecasting they use rank parametric distributions of power demand [14]. The obtained distributions are described by the mathematic relation. Formally the aim of rank distribution approximation is to define the analytic relation that describes the aggregate of points the best possible way.

To define regression factors, they most frequently use the classical two-parameter model of H-distribution [14, 16, 17]:

\[
W_i = \frac{W_1}{r_i^\beta},
\]  

(1)

where: \(W_i\) – power demand expected value vector; \(r_i\) – technocenosis object rank vector; \(W_1\) – max. power demand value that corresponds to first rank (first point); \(\beta\) – rank factor that defines form and gradient of approximating curve.

Regression factors \(W_1\) and \(\beta\) are defined by the least square method (LS); it provides most accurate results [18, 19].

On the other hand, the relation should contain the least possible number of parameters. The two-parameter hyperbolic relation [14] - the Zipf law - fits both contradictory requirements.
Sequential rank distribution approximation results in two time sequences that reflect regression factor variation dynamics.

Approximation of time sequences $W_1$ and $\beta$ is carried out by LS method by expressions:

$$W_1(t) = a_1 + b_1 \cdot t,$$

$$\beta(t) = a_2 + b_2 \cdot t.$$  (2)

where: $t$ – time; $a_1,a_2,b_1,b_2$ – regression factors.

Hyperbolic relation containing only two parameters - $\beta$ parameter and dynamics of power demand in first point $W_1$ of rank H-distribution - is used to forecast power demand of technocenosis, see figure 1.

The obtained rank surface parameter relations reveal correlation between these electrical parameters of the system and enable long-term forecasting of "Yakutugol", Holding JSC, power demand.

To obtain reliable forecasts and verify company's forecasts (second obligatory side of dynamics) they should use the structural-topological dynamics - H-distribution synthesis by forecasting company's power demand curve [20, 21]. The forecast of power demand curves is more reliable and accurate than that of the rank, as the rank prediction is limited by the only model of approximation of the time sequence while the power demand curve forecast is not limited in choosing forecast parameters.

The 3D rank surface shown in figure 2 is essential for empiric rank distribution approximation in the context of the following static data processing. Its objective is to select the analytical relation that describes the aggregate of points the best possible way. The two-parameter hyperbolic model is used on default. Approximation was carried out by LS method.

The technocenosis object power demand forecast procedure is implemented in two related steps [14]. The data obtained during all investigation hours except the last several days is used as the base for generating the forecast at the first step. Static comparison of the obtained results with the corresponding data acquired in the last hours helps to define the most efficient method to be applied for each object. The second step is generation of the final power demand forecast based on the data acquired in all hours of investigation.
Figure 2. 3D rank surface of technocenosis: X-axis - object rank; Y-axis - time interval (number of investigation hours); Z-axis - power demand, kWh.

Expected power demand values correspond to the following expression:

\[ W_{i}^{t+1} = W_{i}^{t} R_{i} \]

(3)

where \( i = 1, 2, \ldots, n \); \( W_{i}^{t+1} \) – forecast for the \( i \)th object; \( W_{i}^{t} R_{i} \) – vector of expected values of a rank parametric distribution in the time interval \( t+1 \); \( R_{i} \) – value of the \( i \)th component of the rank matrix.

Using the above obtained results, they get the final power demand forecast for the following time intervals (hours) (see figure 3).

Figure 3. Power demand forecast diagrams: a – X-axis - object rank; Y-axis - power demand, kWh; b – time parameter forecast.

Compared with other forecast methods, the power demand forecast requires only two parameters (\( W_{1} \) and \( \beta \)) of hyperbolic relation to be predicted (1). Object power demand is simply restored from previous values of the stable-in time rank matrix (3).

4. Conclusion

Hereinbefore it is shown that power demand of "Neryungri" coal strip mine is a component of "Yakutugol", Holding JSC, technocenosis; therefore, it is essential to use the technocenosis-based approach in short-term forecasting of the contractual value of the coal strip mine power demand. It is stated that empiric distributions of "Yakutugol", Holding JSC, power demand belong to the type of
stable rank parametric H-distributions used for generation of forecasts based on extrapolation of such distribution parameters. Application of the rank analysis-based short-term daily power demand forecast algorithm helps to consider management peculiarities of a mining company as a cenosis-type object. Compared with the actually used "intuitive" forecasting, the rank analysis-based forecast contains much less errors in declared power demand. Alongside with that, the average accuracy of hourly forecast results is 4.1% (for the strip mine); significant deviations constrain one to look for other ways of improving the accuracy of the rank analysis method.

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