SHS Web of Conferences 35, 01096 (2017) DOI: 10.1051/shsconf/20173501096
ICIE-2017

Modeling prices of wholesale market of electric energy and power by the example of the UPS of the Ural

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Abstract. The article oversees forecasting model for deviations of the balancing market index and day-ahead market index according to the maximum similarity sample for different levels of approximation in the context of positive and negative time-series value. The model was being tested on the factual data of the Integrated Power system of the Ural, Wholesale market for electricity and power of Russian Federation. Describes the price formation on the day-ahead market and the balancing market index. The necessity to use accurate forecasting methods consumption and prices of electrical energy and power to reduce penalties when the electric power industry entities on the energy exchange. The testing of mathematical models to predict the balancing market index deviations and day-ahead market based on a sample of maximum similarity with certain approximation equations for positive and negative values gave the prediction error of 3.3%.

1 Introduction

Electric power industry is currently one of the leading sectors of the Russian economy. According to the results of electric power production in the year 2013 Russia took the 3d place. Almost 10% of country's GDP falls to the share of electric power.

The obvious question is whether the electricity is a commodity? Or does it refer to a different object of civil rights? Currently, in the Russian Federation, according to the Civil Code of the Russian Federation, the contract power - a kind of contract of sale [1].

Such a wide distribution of electric energy, and its specificity as a commodity has led to the need for accurate regulation of tariffs.

The market, which allows developing competitive relationship inside the industry, is acknowledged to be the most effective for building relations in electric energy. All the stated above is confirmed by the before-reform state of the electric power market in Russia, when the monopoly energy production conditions and state tariff regulation has led to unsolvable economic contradictions, among of which are the following ones:

- non-payments crisis;
- imbalance between tariffs and production/sales cost;
- quicker growth of the prices on materials and fuel, than on sold electric power;
- cross-subsidization.

Ultimate retail consumer purchases electric energy on competitive electric energy market, alongside with the product itself he is compelled to compensate the associated costs as well [2]. These costs exist because electrical power supply is not possible without supplementary services. These services with time has been formed into the separate markets:

- capacity market;
- derivatives market;
- ancillary services market;
- financial transmission rights market [3].

In today's existing view WMEP operates from September 1, 2006, when the Government of Russian Federation introduced new rules of functioning of the wholesale market. At present, the Russian wholesale electricity market is the youngest in the world and least explored.

In the electricity market, the planned consumption volumes are formed on the basis of bilateral agreements. In reality, the actual amount of electricity is almost always different from the routine. Deviations from targets are sold on the balancing market (BM), and the System Operator of the Unified Energy System of Russia (SO) regularly conducts a competitive selection of applications providers, based on the current forecast electricity consumption.

The causes of deviations are different and qualified own and external initiatives. Own initiative arises because a market participant actions (customer or supplier), external is a result of the command with or accident that led to the forced change in the mode of production and consumption of electricity [4].

Despite the fact that since the beginning of the 50s of the last century is not disproved the concept of information efficiency of stock market [5], a practice encourages researchers to find the direction of the most variable models to predict stock market prices. In Russian conditions, the task of forecasting of the basic parameters of the electricity market is one of the

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most urgent and practical importance of the fundamental challenges of financial planning subjects of electric power and to optimize their activity on the wholesale market.

Today, developed a large number of time series forecasting models, accumulated data base of real values. Ongoing work on the development of new models and improve the computing platforms and systems. At the same time requirements for the accuracy of forecasting and economic governance are becoming more stringent, so the task of forecasting time series is not only improved, but also more complicated with each passing day [6].

The urgency posed obvious problems, because due to the lack of precision of forecasting models energy consumers are losing their competitive edge, which leads to a deterioration in financial and economic performance of electricity market participants and even crises.

In this paper will propose a mathematical model for predicting the deviation index balancing market (BMI), the market rate on the day-ahead market (DAM) on a sample of maximum similarity with different equations approximations for positive and negative values.

2 The aim and objectives of the research

As mentioned above the aim of this study is to develop a mathematical model predicting deviations from BMI to DAM.

Research objectives:

• research method of formation of the market rate on the day ahead;
• research method of formation of tariffs for the balancing market;
• development of mathematical prediction models;
• testing model, confirmation or refutation of its effectiveness.

In this paper we will consider the formation of tariffs in the current competitive market of electric power industry of the Russian Federation.

3 Formation of prices on the day-ahead market

On the wholesale market of an organized system of agreements between the subjects of the wholesale market. In the electricity market, there are several types of commercial transactions:

• central planning regimes, in which prices are determined based on the result of the auction bids submitted by suppliers and buyers, as this type is called "day-ahead" market or spot market (the DAM market);
• bilateral agreement for the supply between generating companies and buyers of electricity wholesale market entities are free to choose the counterparties to such contracts, but for such a contract, suppliers are required to provide, and buyers purchase amount stated in the contract;
• combined commercial transactions in which generating companies may enter into a tripartite agreement and to participate in centralized planning, submitting price bids.

Wholesale electricity market should include providing sufficient power to cover the electricity demand with regard to the necessary provision of electric power using the most effective resource-saving technologies [7]. Thus, providers are required to maintain power generation equipment in a state of readiness for electric energy production. Monitoring the timely and proper implementation of the investment programs of generating companies formed as a result of the power of trade is carried out by the system operator. Selection of power also provides by the system operator.

The “day-ahead” market is organized in form of bidding auction. The main goal of this auction is to establish prices and volumes of electric energy with maximum mutual advantage. Each pricing application contains 24 of the planned appointment of electricity and 24 values of the price at which the participant is willing to buy/sell a specified amount.

Price bids submitted to the auction organizer for the day. Sellers indicate in the application the minimum price at which they are willing to sell a specified amount of electricity, and the buyers, respectively, the maximum price at which they are willing to buy.

In addition to the application with the specified price, spot price acceptance bids exist, they mean that the buyer is ready to purchase a specified amount of power at any price. Similar applications exist for suppliers, where they are willing to sell a specified amount at any price, even zero.

After the adoption of all applications from the buyers of the auction organizer ranks them in descending order. This means that the buyer is always ready to buy a specified amount at a price lower than he indicated in the application. Thus, a demand curve, which has a stepped form and includes milestones applications. Application vendors are sorted in ascending order of price, thereby forming the supply curve. And the demand curve and the supply curve will undergo spot price acceptance in the first place.

The intersection of demand and supply curves gives the equilibrium price and quantity [8]. Participants of the auction price in applications which coincided with the equilibrium, called pricing. Applications buyers who have the right of the equilibrium price can not buy anything at a cheaper price, as well as suppliers have nothing to sell at a higher price. Scheme of the equilibrium price is shown in Fig. 1.

This auction is closed, as neither buyers nor sellers are not aware of the content of the price submitted by other parties, and can not predict prices and volumes in the past the market. Pricing in this auction is a margin that is the most effective way of organizing the bidding in a competitive environment.

From the foregoing it follows the importance of the accuracy of prediction of consumption and production of electricity. It is clear that errors in forecasting the volume values occur regularly, so in addition to the day-ahead market there is a balancing market, which represents a market of deviations of actual hourly production and consumption of electricity from the planned trading schedule [9]. The volumes on the balancing market are regulated by the System Operator by reducing or increasing the production of electricity. Market participants who have made mistakes in planning can buy or sell electricity on the balancing market, but the price it is very disadvantageous. Fig. 2 shows the deviation of the market price of the day ahead and balancing market index on the example in December 2014, the data are taken from the official website of the wholesale electricity and capacity market (http://br.so-ups.ru/).

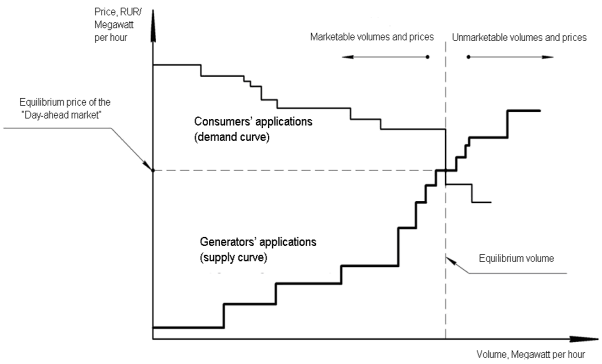

Fig. 1. Forming the equilibrium price of the day-ahead market.

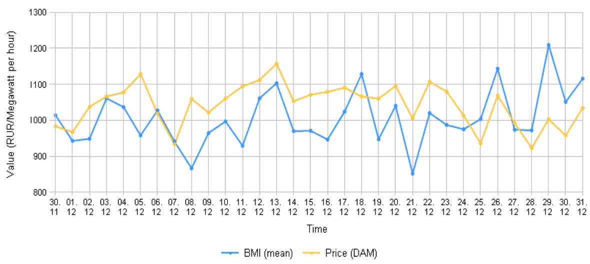

Fig. 2. Price deviation of BMI (Balancing Market Index) and DAM (Day-ahead market) from 30.11.2014 till 31.12.2014 by the example of the UPS (Unified Power System) of the Ural.

4 Formation of prices on the balancing market

Balancing market prices are formed on the basis of market supply and demand curves, in the event of changes in demand, if you need more or less electricity. If the actual power consumption of the power grid has exceeded the plan, the system operator turns considers applications of generators, starting with the immediate right of the equilibrium price. Application generators are joining is not satisfied buyers need electricity (Fig. 3). Price of the balancing market in this case is equal to the point of intersection of the required volume of customers with the supply curve.

If there is a reverse situation and the actual power consumption of the power system was below the plan, the system operator in turn reduces the load power plants, starting with the immediate left of the equilibrium price. Price of the balancing market, in this case will be determined by the price of an application generator, whose stage was at the intersection with the required volume of customers (Fig. 4).

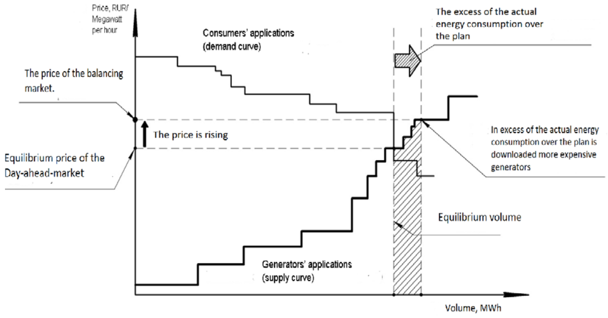

Fig. 3. Pricing on the balancing market in excess of the actual consumption of the power grid on the plan.

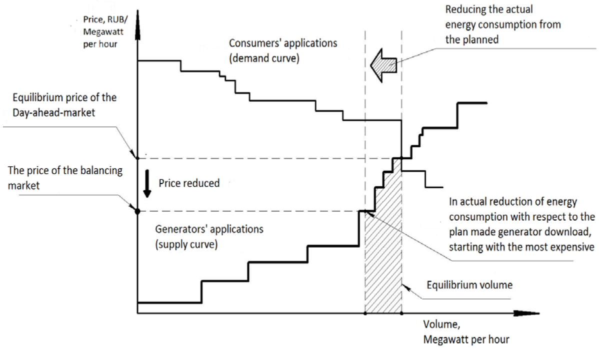

Fig. 4. Pricing of the balancing market with a decrease of actual consumption from the power grid plan.

If any deviations from the target values of energy price becomes unfavorable, compared to the price on the day-ahead market. That is, when errors in planning for consumers, they buy electricity at a higher price and return situation when mistakes in the planning of the suppliers when they sell electricity at a lower price [10]. Thus, the importance of the accuracy of the prediction comes to the fore, as the plan with the smallest errors lead to a reduction in costs and, consequently, to increase profits. Below is a mathematical model for predicting deviations from BMI to DAM sample of maximum similarity.

A large number of studies in the field of forecasting tariffs directly WMEP, but the foregoing should be the importance of forecasting not only tariffs DAM, but deviations BMI from the DAM. With a negative deviation, that is, the BMI is less than the DAM, there is a discharge of expensive generators will work cheaper, so if the electricity supplier wants to participate in the auction, then, knowing the predicted deviation, he applies for SO with valuable lower than forecast DAM. Consumers with a negative deviation to guarantee the participation in the auction may submit the application on a target price below the DAM on the value not exceeding the forecast deviations [11]. With a positive deviation occurs loading more expensive generators to participate in the auction generators may apply to the price above the value of a target DAM forecast deviations.

Thus, the prediction of the BMI deviations from the DAM in tandem with the projected values of DAM rate and volume of consumption will increase economic benefits and efficiency of both producers and consumers.

Thus, the prediction of the BMI deviations from the DAM in tandem with the projected values of DAM rate and volume of consumption will increase economic benefits and efficiency of both producers and consumers [12].

Studies to evaluate the effectiveness of existing prediction models have shown that the most adequate model to show maximum similarity the sample, which was taken as a basis for the proposed model below [13].

5 Mathematical model

Finally, complete content and organizational editing before formatting. Please take note of the following items when proofreading spelling and grammar:

The result of the study was the mathematical model for predicting time series deviations based on a sample of maximum similarity with different equations approximations for positive and negative values, which is presented below [14].

Small scale integration is often used for prognozing the time series [15], that is to say predicting not the series itself or the process, but its change or accession. In other words we get the series $\tilde{Z}(t)=Z(t)-Z(t-1)$, where $Z(t)$ is an original time series, and $\tilde{Z}(t)$ is a series of increase or difference of the adjacent indexes [16]. In this model it is offered to modify first order integration method and use the deviations of BMI and DAM time series (Fig. 2). This method would help to predict the predict the possible electric power cross-pickings and, therefore, to enhance the accuracy of the already existing methods of forecast.

Now we get to the formal description of the model. Let's introduce all the necessary nomenclature:

$Z(t)=Z(1),Z(2),...,Z(T)$ is a time series that represents the volume of consumed energy in the moment of time T.

$Z_t^M=Z(t),...,Z(t=M-1)$ is a piece of the time series Z(t), where M is the length of the sample, considering that $M\in\{1,2,...,T\}$.

The length of the sample is defined as the maximum value from the stable range MAE for prediction value of each of $M\in[P,\frac{0,3Z_t}{P}]$, where P is the length of prognosis. The prognosis is built upon the model, described below. MAE (mean absolute error) is calculated through the following formula:

$$MAE=\frac{1}{n}\sum_{i=1}^{n}\left|y(i)-\hat{y}(i)\right|,$$

where t is a moment of time, a datum point in the sample, besides $t\in\{1,2,...,T-M+1\}$

Modeling of the time series with the help of samples is based on the supposition that a time series is a sequence of samples [17]. Grounding on this supposition, we assume 2 samples of the equal length and belonging to one and the same time series with difference in datum points of sequences k [18].

$$Z_t^M=Z(t),...,Z(t+M-1)$$
$$Z_{t-k}^M=Z(t-k),...,Z(t-k+M-1)$$
$$k\in\{1,2,...,t-1\}$$

Let's consider the prognosis algorithm.

Defining the new history sample:

Z_{T-M+1}^M is a sample of a time series, which values are preceding the moment of prognosis T.

Defining the maximum similarity sample:

For each value of time delay from diapason $k\in\{1,2,...,T-M-1\}$ the task of approximation of the sample given is solved $Z_{T-M+1-k}^M$, in other words the sample is being sequentially compared to all other values of time sequence with shift to unitary vector.

Calculating the approximation through classic linear model would be improper, because the values of time series can be either positive or negative. The acquired sample is divided into 2 rows: $Z_{T-M+1-k}^+\geq 0$ - for positive values of the sample and $Z_{T-M+1-k}^-<0$ for the negative.

Than we calculate the approximate value of the sample for positive values of the sample and separately for negative using the following formula:

$$Z_t^M=\alpha_1 Z_{t-k}^M+\alpha_0 I^M,$$

where α_1 and α_0 are coefficients, I^M is a unitary vector.

It is necessary to define the values of coefficients in order to:

$$\sigma^2=\sum_{t=0}^{M-1}(Z(t+i)-\hat{Z}(t+i))^2\rightarrow min$$

in other words in order for the square of deviations of model values from the real ones to be minimal [8].

Function of approximate error looks like this:

$$S_k^M(\alpha_1,\alpha_0)=\sum_{t=0}^{M-1}\sigma_i^2=\sum_{t=0}^{M-1}(Z(t+i)-\alpha_1 Z(t-k+i)-\alpha_0)^2$$

Its value can be calculated with least-squares method [19].

$$Z_X \cdot A = Z_Y \text{, where } A = \begin{bmatrix} \alpha_1 \\ \alpha_0 \end{bmatrix}$$

$$Z_X = \begin{bmatrix} \sum_{i=0}^{M-1} Z^2(k+i) & \sum_{i=0}^{M-1} Z(k+i) \\ \sum_{i=0}^{M-1} Z(k+i) & M \end{bmatrix}$$

$$Z_Y = \begin{bmatrix} \sum_{i=0}^{M-1} Z(k+i) \cdot Z(T-M+1+i) \\ \sum_{i=0}^{M-1} Z(T-M+1\_i) \end{bmatrix}$$

On the basis of the set task we get 2 sets of matrices A:

$$A^+ = \begin{bmatrix} \alpha_1 \\ \alpha_0 \end{bmatrix} \quad A^- = \begin{bmatrix} \alpha_3 \\ \alpha_2 \end{bmatrix}$$

Then coefficients are defined and then approximate values of the sample. After this the values of the correlation module is calculated with the formula:

$$\rho_k^M = \left|\rho(\widehat{Z}_t^M, Z_t^M)\right| =$$

$$= \frac{\left|\sum_{i=1}^{M}(\widehat{Z}(t+i)-\overline{Z})(Z(t+i)-\overline{Z})\right|}{\sqrt{\sum_{i=1}^{M}(\widehat{Z}(t+i)-\overline{Z})^2 \sum_{i=1}^{M}(Z(t+i)-\overline{Z})^2}} \in [0,1]$$

From the gathered values the highest possible is picked and its coherence to the time delay is found [20].

With consideration of the maximum value of the time delay, coefficients and the sample length, 2 equations of approximation can be written, which are applied according to positive and negative values of the sample:

$\widehat{Z}_t^{+M} = \alpha_1 Z_{t-k}^M + \alpha_0 I^M$ - for positive values

$\widehat{Z}_t^{-M} = \alpha_3 Z_{t-k}^M + \alpha_2 I^M$ - for negative values

For the researched series the parametre M=142.

Sample from the new history and sample of maximum similarity from history is represented in the Fig.5, where Sample means sample that precedes the prognosis, SML – sample of maximum similarity (likehood).

The offered model is based on the sample of maximum similarity of the daily digressions from DAM from the history data of 2009-2014 that was acquired for official site of the wholesale electric power market (http://br.so-ups.ru/).

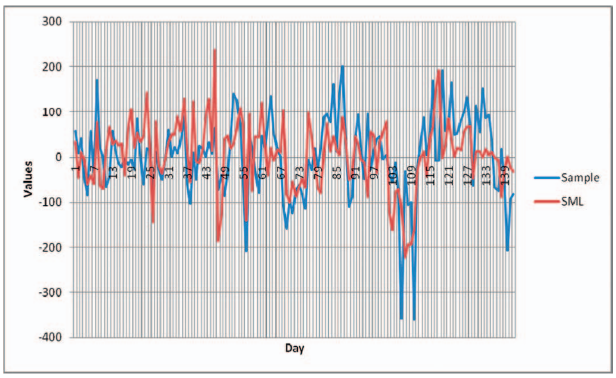

Fig. 5. Comparing the sample of maximum similarity from history and sample of the new history.

The results of prognosis are represented on the Fig. 6, where History means the sample that follows the sample of maximum similarity, values of which approximate while composing the prognosis, Forecast – predicted values, Control – real values.

The forecast error for the aquired results is 3, 3%

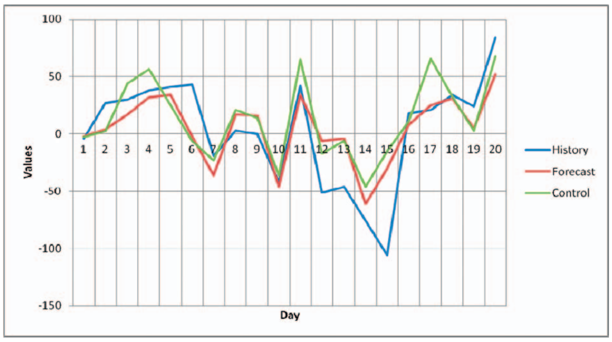

Fig. 6. Prediction 20 deviation values IDB and RSV sample maximum similarity with certain approximation equations for positive and negative values.

6 Conclusion

In the wholesale market, buyers and sellers are generating companies, export/import electricity operators, sales organizations, distribution companies (in terms of electricity purchase for covering transmission losses), large consumers. The subjects of the wholesale market may act as, both sellers and buyers of electricity and capacity. For the wholesale market participant status an organization must satisfy the requirements set out in the approved resolution of the Government of the Russian Federation of December 27, 2010 № 1172 Rules of the wholesale electricity (capacity) market and in the Treaty of Accession to the trading system of the wholesale market. All subjects of the wholesale market are included in Non-Commercial Partnership "Market Council" [21].

In terms of trade, energy is a commodity, and the energy supply contract - a kind of contract of sale.

In a competitive electricity market, the retail price is formed taking into account the cost of additional capacity services markets, derivative financial instruments, financial transmission rights, ancillary services. Commercial transactions in the DAM market are:

- central planning regimes,
- bilateral agreements,
- combined trade deals.

To determine the value of the deviations for different types of initiatives used formulas (cutting), calculated for each hour of the day for each node of the computational model. Cutting is defined as the maximum (minimum) value of the indicator BR and market prices for day-ahead market (DAM), thereby stimulating a more accurate execution of the planned consumption and production of electricity. On the basis of the cost of deviations defined prerequisites and preliminary commitments BR, the difference between which generates imbalance BR. Negative imbalance is distributed among the participants in proportion to their own initiatives. Positive imbalance is distributed between suppliers, proportional to the execution of external initiatives, and consumers, as accurately as possible adhering to the planned consumption. Thus, the BM "fine" participants of the market, allowing the greatest deviations of actual consumption and production of the planned, on its own initiative, and "rewarded" the participants adhering to the planned consumption and as accurately execute commands from [12]. Consequently, the equilibrium market price for a day is formed at the intersection of the curve and the supply curve stprosa received by the auction filed by suppliers and customers applications peresorty electricity sold on the balancing market, but the price formed on it is disadvantageous to both sides of the bargain. There is a need for methods of predicting which give the least prediction error.

In the current formulation, the problem has already become the subject of a large-scale study. Written by a large number of theses and monographs on the electricity market forecasting, both foreign and domestic authors. Works compatriots in this area can be divided into three stages: the Soviet period, the transition period in Russia and the modern period. Among the most active explorers of the modern period of relevant work Sedov AV, Nadtoka II, Chuchueva IA As part of the research Chuchueva IA performed an in-depth analysis of time series forecasting model based on a sample of maximum similarity to approximate WMEP parameters [22].

Currently, the company carried out the accumulation of historical values of economic and physical parameters in the database, which significantly increases the volume of input to solve the problems of forecasting. Consequently, the widespread methods of maximal similarity samples from history that in its different variations show a high prediction accuracy.

The article was discussed in detail the model of forecasting of the balancing market index deviations from the market rate on the day-ahead sample maximum likelihood using a variety of approximation equations for positive and negative values of the time series. prediction error was 3.3%, indicating a high efficiency model. As it has been the model of forecasting of electricity consumption of the sample maximum similarity three time series (source obtained through the integration of first and second order). The highest efficiency demonstrated a method of forecasting time series with the integration of the first order.

From the above we can conclude about the effectiveness of the use of not only individual methods of forecasting in electricity consumption, rates of DAM and the BMI deviations from DAM, but the use of them in combination. Since knowing the predicted values of these three parameters can be adjusted by prices and volumes specified in the application, thereby reducing their risks in participating in the auction.

Subjects with established rules of the electricity power market works economically interested in improving the working methods and improving the accuracy of prediction of its basic parameters.

The work was supported by Act 211 Government of the Russian Federation, contract № 02.A03.21.0011.

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