Montenegrin Journal of Economics

Vol. 11, No. 2 (2015), 125-135

The Day-ahead Energy Market Forecasting in Russian Federation: a Case Study of Siberia

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ARTICLE INFO

Received September 12, 2015
Received in revised from -
Accepted December 04, 2015
Available online December 07, 2015

JEL classification:
C02; Q40; Q43

DOI:

10.14254/1800-5845.2015/11-2/8

Keywords:

Energy,
Wholesale electricity market,
Power,
Day-ahead energy market,
Marginal pricing,
Generator strategy
Time series,
Russian Federation

ABSTRACT

Recent reforms in Russian power industry and the wholesale electric power and capacity market construction put energy companies into the new competitive conditions. Due to these reforms, the issues of price and quantity forecasting at the day-ahead market (DAM) gain special importance. Particularly, the extrapolated values of the prices and quantities at DAM are necessary for the regulator, and also for energy companies to work out the best market strategy.

The current Russian wholesale electricity market represents a fundamentally new model of the electric power industry that functions on a competitive basis. The key role in the structure of the wholesale energy trading sector is played by the day-ahead electricity sector that provides up to the 80% of total electricity sales in the country. As a result of the auction clearing, the market price for all points in the supply of electricity is formed and the volume of the market is determined. There is also a need for forecasting the equilibrium price and quantity of electricity sales, which largely determine the strategies of generation companies from the perspective of the use of free electric powers. This paper proposes a method of construction of medium and long-term forecasting of the DAM’s main characteristics. Our results that stem from the mathematical model and statistical data reveal the most significant factors and quantified their nature, their extent as well as their effect on the energy market of Siberia.

1. INTRODUCTION

Currently, Russia’s wholesale electricity and power market (formally known as OREM) comprises a totally new framework of business transactions in the electric utilities industry, with a competitive environment that shares many properties of “perfectly contestable markets”.

The OREM model follows the rules of deregulated electricity markets while paying heed to specific Russian nuances and incorporates the experience of PJM Interconnection, one of the world's first deregulated electricity markets that has brought together transmission networks operated by utility companies in the states of Pennsylvania, New Jersey, Maryland, Delaware, Virginia, and Ohio (see e.g. Borenstein, 2002; or Pittman, 2007).

The emergence of electricity markets in US and most-advanced European countries in late 20th century was driven by the growing discontent with the quality of services provided by a number of natural-monopoly industries as well as accelerating globalization trends and the birth of unified global markets. The wholesale electricity and power market is comprised by three electricity trading sectors:

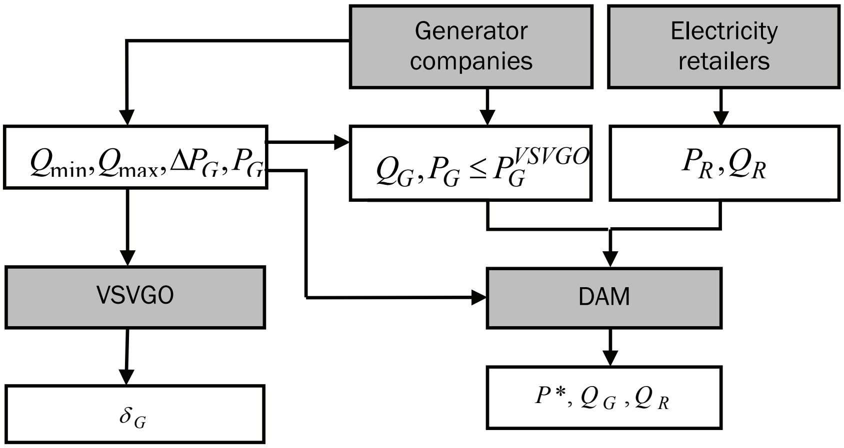
- Bilateral contract market (BCM)
- Day-ahead market (DAM)
- Balancing market (BM).

At the bilateral contract market electricity is traded under regulated and free bilateral contracts. In the regulated sector, rates for electricity supplied to and bought at the wholesale market are set by the Federal Tariff Service of Russia.

The day-ahead market is used to sell/buy excess/lacking amounts of electricity to complement quantities traded in bilateral contracts. Electricity is traded at DAM at prices influenced by supply and demand.

The balancing market accommodates deviations of actual hourly output/consumption figures from the scheduled electricity trading quantities and serves to balance supply against demand in real time. Rewards are paid to generators who adjust their electricity output in response to System Operator's (SO) initiative; at the same time, generators reducing their output unilaterally as well as load-increasing consumers are penalized with extra charges (Lisin, Grigoryeva, 2012); Lisin et al,2014; Makarenko, Streimikiene, 2014).

Figure 1. Offer submission flowchart for VSVGO and DAM



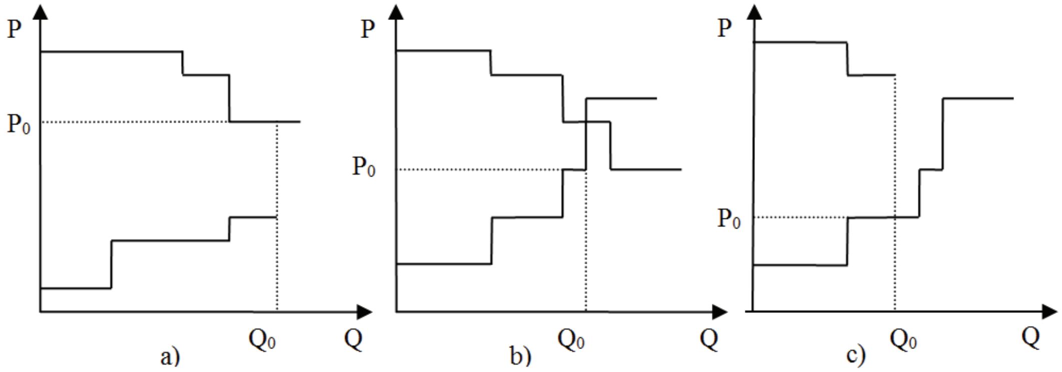
Note: P_G, P_R, Q_G, Q_R – are the prices and quantities of generator and retailer companies, $Q_{\min}$ and $Q_{\max}$ are technically feasible minimum and maximum power outputs, P^* is the equilibrium price, δ_G is a Boolean variable (1 or 0 for the online/offline output condition of generating unit of generator G taking part in VSVGO, at the end of the period in question)

Source: Own results

Sales at DAM are preceded by a bidding procedure for selecting generator plant to be brought online, known as VSVGO and carried out a week ahead of the trading day. Prices from offers submitted by generators for VSVGO then serve as ceiling prices for offers submitted to DAM and BM markets throughout the following week. The diagram above (Figure 1) illustrates the influence VSVGO bidding has on DAM trading outcome.

Figure 2 shows a graphical interpretation of the price discovery model for the day-ahead market. Only in a single potential situation may the consumer act as a price-setter when bidding for electricity (Figure 2a). In all other instances (Figures 2b, 2c), a generator's offer sets the price (see Stoft, 2002; Lisin and Strielkowski, 2014; Nicolaisen et al, 2001; or Melnik and Mustafina, 2013).

Figure 2. Price discovery at the day-ahead market



Source: Own results

Typically, generating companies begin with the marginal strategy, submitting their offers at prices equal to electricity generation cost that only includes variable costs. The marginal strategy calls for submitting offers based on marginal costs i.e. the relative increase in production cost per megawatt-hour output. It is known that the optimum utilization of power plant has no relation to its semi-fixed costs. For that reason, variable costs are included in the expense function. A generator may benefit from submitting offers using the marginal cost strategy only when all market players follow the same strategy. Power plant will be loaded most efficiently in this case while the market price and volume will be close to the competitive equilibrium point.

Generating companies can also use market power, based on physical and financial withdrawal of power plant generating capacity. Physical and financial withdrawal are two market strategies that seek to remove a part of low-priced offers from the market either by raising price or by minimizing underpriced supply. Table 1 shows the potential value that may be obtained by applying them.

The prices and quantities forecasting at DAM allows generation companies work out more effective strategies in order to sell electric power ate a reasonable price and to obtain profit even in situation of the high price volatility (Borenstein, 2000; Simionescu, 2013). Also among the main objectives of the construction of medium and long-term forecasting at DAM procedure we can mention the following:

- Providing the effective regimes of the power plants work.
- Improvement of the business planning at generation companies.
- Improvement of the generation companies behavior at the wholesale market on the base of the best option choice between trade operations at DAM, long-term bilateral contracts, and forward contracts that allow risk hedging.

Table 1. Basic strategies available to generators for exercising market power

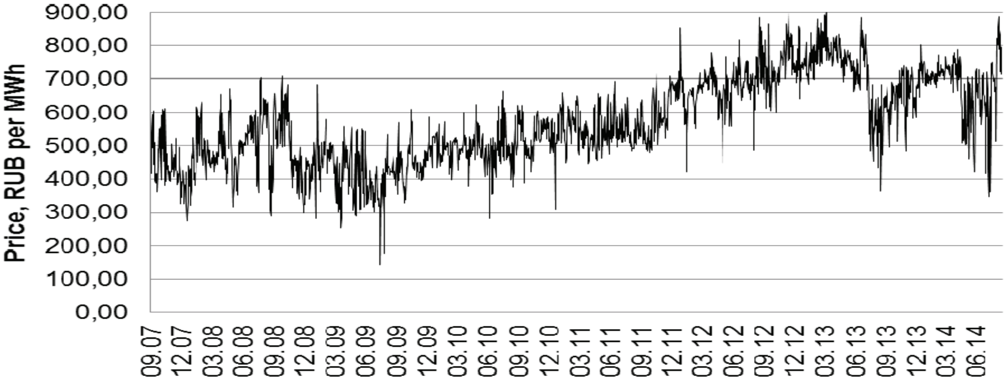
Strategy name	*Application mechanism*	*Outcome*
Financial withdrawal	Place electricity supply offers at a higher price (exceeding marginal electricity production costs in particular).	In a demand-dominated market (with demand becoming inelastic) this should increase the equilibrium market price and potential generator's revenue as a consequence.
Physical withdrawal	Offer reduced amounts of electricity at the market relative to the full output capacity of company's generator plant.	A part of the supplied power is taken away from the market causing the equilibrium price to go up.
Physical withdrawal by means of free bilateral contracts	Make free bilateral contracts aiming to reduce the amount of cheap product offered at the market.	This will make the equilibrium market price go higher if electricity consumption increases.

Source: Own results based on (Stoft, 2002; Nicolaisen et al, 2001; Melnik and Mustafina, 2013)

2. THE DAILY EQUILIBRIUM PRICE FORECASTING AT DAM

The daily price forecast is based on statistical data about adjusted by CPI (Rosstat, 2015) electricity prices at DAM (second price zone – Siberia) for 7 years (09.2007–08.2014) provided by (Russian Trading System Administrator of the Wholesale Electricity Market, 2015) (see Figure 3).

Figure 3. Dynamics of adjusted by CPI electricity prices at DAM (09.2007-08.2014)



Source: Own results based on (Russian Trading System Administrator, 2015)

We included into the model the following regressors (Davidson et al, 2009): trend (*t*), dummies for the days of week ($z^{(1)}$–$z^{(6)}$) and holidays ($z^{(7)}$), the share of working turbines at Sayano-Shushenskaya power station (essential due to the 2009 year catastrophic accident) ($z^{(8)}$), average day temperature ($x^{(1)}$) and light day duration ($x^{(2)}$) (The Weather Schedule, 2015), adjusted oil ($x^{(3)}$) and natural gas ($x^{(4)}$) prices (Market and analytics "Finam", 2015), dollar ($x^{(5)}$) and euro ($x^{(6)}$) exchange rates (Central Bank of Russian Federation, 2015), Russian GDP ($x^{(7)}$) (Rosstat, 2015).

Some other regressors were excluded from the model due to their insignificant impact on electricity prices. We also excluded from the final version of the model temperature correlated with light day duration, oil price correlated with gas price, and dollar exchange rate due to high correlation with euro – all excluded variables were less significant than the included ones.

The identification of the linear multiple regression revealed the following:

$$\begin{aligned}\hat{y} = {} & \underset{(34{,}9)}{1055{,}7} + \underset{(0{,}009)}{0{,}214}\,t^{**} + \underset{(5{,}54)}{24{,}71}\,z^{(1)**} + \underset{(5{,}53)}{19{,}11}\,z^{(2)**} + \underset{(5{,}53)}{18{,}15}\,z^{(3)**} + \\ & + \underset{(5{,}53)}{18{,}61}\,z^{(4)**} + \underset{(5{,}52)}{18{,}71}\,z^{(5)**} + \underset{(5{,}53)}{13{,}42}\,z^{(6)*} - \underset{(7{,}37)}{16{,}90}\,z^{(7)*} - \underset{(4{,}40)}{31{,}15}\,z^{(8)**} - \\ & - \underset{(0{,}008)}{0{,}069}\,x^{(2)**} + \underset{(0{,}0016)}{0{,}0069}\,x^{(4)**} - \underset{(0{,}63)}{16{,}15}\,x^{(6)**} - \underset{(0{,}0018)}{0{,}0059}\,x^{(7)*}\end{aligned} \tag{1}$$

The determination coefficient and the standard error are equal to $\hat{R}^2 = 0{,}668$, and $\hat{\sigma} = 74{,}52$ respectively. Variables marked with one and two asterisks denote regressors significant at level of 5% and 0,1% respectively.

The behavior of residuals is described by the first order autoregression AR(1):

$$\varepsilon(t) = 0{,}759\varepsilon(t-1) + \delta(t) \tag{2}$$

The determination coefficient, thus, becomes equal to $\hat{R}^2 = 0{,}859$ and the standard error decreases to $\hat{\sigma} = 48{,}42$.

At the same time in real life dependent variable isn't often changed instantly, directly after the change of regressor, but after a while which is called temporary lag. Moreover this influence is usually distributed in time. Particularly the DAM electricity price is influenced by the gas price, however fuel isn't delivered to power plants instantly, so it's better to consider the model with the distributed lag (Draper, Smith, 2014); (Galwey, 2014). We will use the Koyck lag structure combined with linear trend, dummies for the days of week, and exogenous factors. The modelling is divided into the three stages.

1. Identification and elimination of trend and cycle:

$$\begin{aligned}\hat{y}(t) = {} & \underset{(5{,}6)}{397{,}0} + \underset{(0{,}002)}{0{,}133}\,t^{**} + \underset{(6{,}42)}{24{,}88}\,z^{(1)**} + \underset{(6{,}41)}{19{,}44}\,z^{(2)**} + \underset{(6{,}41)}{18{,}48}\,z^{(3)**} + \\ & + \underset{(6{,}42)}{19{,}02}\,z^{(4)**} + \underset{(6{,}41)}{18{,}90}\,z^{(5)**} + \underset{(6{,}42)}{13{,}29}\,z^{(6)*} - \underset{(8{,}39)}{4{,}32}\,z^{(7)} - \underset{(4{,}33)}{24{,}10}\,z^{(8)**} + l(t).\end{aligned} \tag{3}$$

2. Application of Koyck transformation for the natural gas price:

$$l(t) = \underset{(0{,}011)}{0{,}821}\,l(t-1)^{**} + \underset{(0{,}00024)}{0{,}00008}\,x^{(4)} + m(t) \tag{4}$$

3. Identification of the other factors impact:

$$m(t) = \underset{(11{,}65)}{76{,}54} - \underset{(0{,}005)}{0{,}012}\,x^{(2)*} - \underset{(0{,}31)}{2{,}21}\,x^{(4)**} + \underset{(0{,}0004)}{0{,}0017}\,x^{(6)**} \tag{5}$$

The determination coefficient for the final model becomes equal to $R^2 = 0{,}857$, and the standard error decreases to $\hat{\sigma} = 48{,}66$ even though we didn't use the ARMA-models for residuals here.

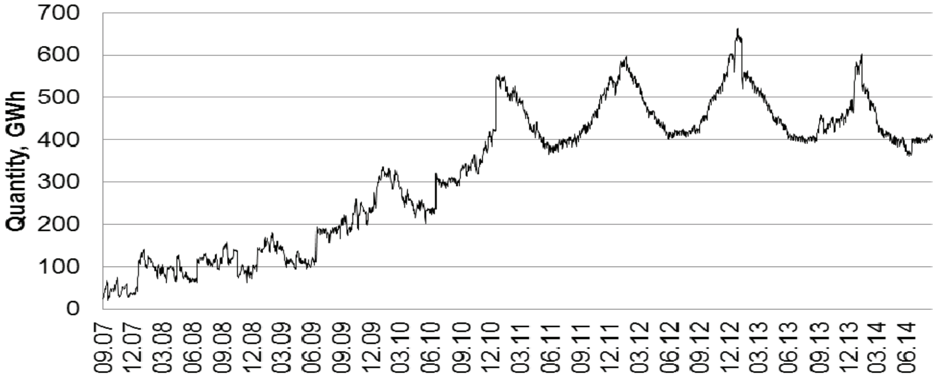
Value $\hat{\lambda} = 0{,}821$ in the Koyck model means that the gas price change is transferred to the DAM electricity price almost immediately. After a week from the initial influence there is slightly more than a quarter left, a month later – only 0,3%. At the same time it’s impossible to ignore the distributed log. The model shows very high significance of the lagged variable.

The robustness analysis was also carried out in this paper. As a result, it was stated that including into the model additional insignificant regressors or model identification on subsamples didn’t considerably change coefficients.

3. THE DAILY QUANTITY FORECASTING AT DAM

The second step in our research was the quantity forecasting at DAM. The quantity (*y*) dynamics for 2007–2014 is presented at Figure 4.

Figure 4. Quantity dynamics at DAM



Source: Own results based on Russian Trading System Administrator (2015)

Figure 4 shows that there was considerable quantity increase during 2008-2011. It was connected with agents transfer from the bilateral contracts to the day-ahead market. The process wasn’t uniform. We can see half-year shifts in quantity arises after the fixed-date contracts’ expiration on the 30-th of June and on the 31-st of December). This effect was investigated using dummies ($g^{(i)}$) for each half-year interval. We also used the same regressors together with adjusted by CPI price ($x^{(8)}$) to forecast quantities. The model (Filatov and Smirnova, 2012) constructed on the data of 2008-2011 showed the following results:

$$\begin{aligned}
\hat{y} = {} & \underset{(32,91)}{420{,}05} - \underset{(0,01)}{0{,}04}\, t^{**} + \underset{(2,17)}{4{,}19}\, z^{(1)*} + \underset{(2,14)}{4{,}34}\, z^{(2)*} + \underset{(2,13)}{4{,}25}\, z^{(3)*} + \underset{(2,13)}{4{,}21}\, z^{(4)*} + \\
& + \underset{(2,14)}{5{,}09}\, z^{(5)**} - \underset{(3,65)}{17{,}68}\, z^{(7)**} - \underset{(4,68)}{30{,}40}\, z^{(8)**} - \underset{(17,37)}{447{,}20}\, g^{(1)**} - \underset{(14,98)}{409{,}86}\, g^{(2)**} - \\
& - \underset{(11,88)}{368{,}95}\, g^{(3)**} - \underset{(10,12)}{262{,}45}\, g^{(4)**} - \underset{(7,92)}{189{,}34}\, g^{(5)**} - \underset{(5,61)}{113{,}93}\, g^{(6)**} + \underset{(3,76)}{56{,}79}\, g^{(7)**} \\
& - \underset{(0,11)}{0{,}85}\, x^{(1)**} - \underset{(0,01)}{0{,}09}\, x^{(2)**} + \underset{(0,001)}{0{,}010}\, x^{(4)**} + \underset{(0,60)}{2{,}08}\, x^{(6)**} + \underset{(0,01)}{0{,}11}\, x^{(8)**}
\end{aligned} \qquad (6)$$

One can observe that the price is positively significant. It particularly means that generation companies, but not consumers dominate at DAM. It’s opposite to the results obtained for European Union and even for the first price zone of Russia, but this situation is possible for highly concentrated markets, like energy market of Siberia.

In the long run average quantities were approximated by the logistic function. It’s interesting that the proposed forecast turned out to be quite exact. For example, on the base of calibrated on data of 2008-2011 model (Filatov and Smirnova, 2012) we estimated the peak volume for 2014. Model showed that it had to be $\hat{y} = 591{,}47$ on the 28-th of January. In reality peak volume was $\hat{y} = 603{,}16$ one day later.

4. THE HOURLY PRICE FORECASTING AT DAM

The third direction is connected with hourly forecast at DAM. It is essential to carry out preliminary processing – to eliminate outliers and to smooth the peak prices using moving average of 3 and 5 points. Then we included into the model real factors $x^{(i)}$, dummies $z^{(i)}$ for days of week and holidays, and dummies $\tilde{z}^{(i)}$ for hours:

$$\hat{y} = c + \alpha t + \sum_{i=1}^{5} \theta_i x^{(i)} + \sum_{i=1}^{7} \tilde{d}_i z^{(i)} + \sum_{i=1}^{23} d_i \tilde{z}^{(i)} \qquad (7)$$

All coefficients and the significance level for each regressor are presented in the Table 1. Let us note that all regressors presented here are significant.

Table 2. Coefficients and significance level for hourly models

	Regressors	MA (3)		MA (5)	
		Coef.	Sig.	Coef.	Sig.
c	Const	229,38	0,01	233,08	0,01
t	Trend	0,01	0,01	0,01	0,01
$x^{(1)}$	Day temperature (^{0}C)	–1,17	0,01	–1,16	0,01
$x^{(2)}$	Light day duration (min)	0,07	0,01	0,07	0,01
$x^{(3)}$	Gas price (RUB/1000m^3)	0,46	0,01	0,46	0,01
$x^{(4)}$	Dollar exchange rate (RUB)	–6,39	0,01	–6,40	0,01
$x^{(5)}$	Euro exchange rate (RUB)	4,10	0,01	4,06	0,01
$\tilde{z}^{(1)}$	Hour 1 (00:00–01:00)	–0,24	0,05	1,31	0,05
$\tilde{z}^{(2)}$	Hour 2	3,22	0,05	6,83	0,01
$\tilde{z}^{(3)}$	Hour 3	13,6	0,01	15,56	0,01
$\tilde{z}^{(4)}$	Hour 4	28,18	0,01	26,26	0,01
$\tilde{z}^{(5)}$	Hour 5	41,64	0,01	37,11	0,01
$\tilde{z}^{(6)} - \tilde{z}^{(18)}$	Hour 6 – Hour 18	54,74	0,01	52,79	0,01
$\tilde{z}^{(19)}$	Hour 19	44,54	0,01	39,43	0,01
$\tilde{z}^{(20)}$	Hour 20	29,10	0,01	29,23	0,01
$\tilde{z}^{(21)}$	Hour 21	14,72	0,01	17,49	0,01
$\tilde{z}^{(22)}$	Hour 22	6,16	0,01	8,15	0,01

$\tilde{z}^{(23)}$	Hour 23	2,10	0,05	2,49	0,05
$z^{(1)}$	Monday	18,21	0,01	17,93	0,01
$z^{(2)}-z^{(3)}$	Tuesday–Wednesday	14,61	0,01	14,39	0,01
$z^{(6)}$	Thirsday	13,52	0,01	13,36	0,01
$z^{(6)}$	Friday	15,44	0,01	15,29	0,01
$z^{(6)}$	Saturday	10,36	0,01	9,97	0,01
$z^{(7)}$	Holiday	5,69	0,01	5,72	0,01
R^2		0,31		0,30	

Source: Own results

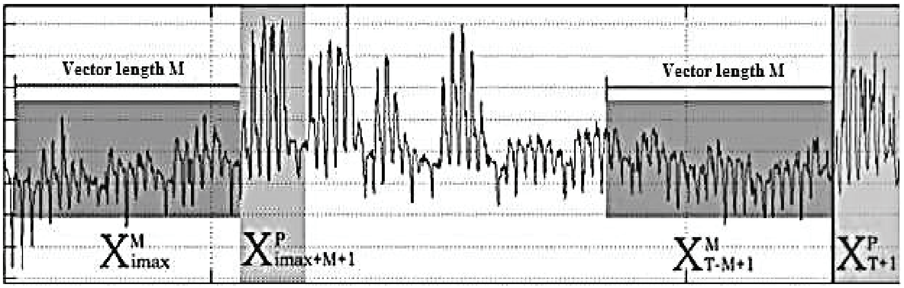
The determination coefficients of both modifications are quite the same – both models explain about 30% of hourly price variation. We can also use the first order autoregression AR(1). It will greatly increase the quality of forecast:

$$MA(3):\ \varepsilon(t)=0{,}98\varepsilon(t-1)+\delta(t),\quad \hat{R}^2=0{,}96,\ \sigma=8{,}91$$

$$MA(5):\ \varepsilon(t)=0{,}92\varepsilon(t-1)+\delta(t),\quad \hat{R}^2=0{,}98,\ \sigma=6{,}52$$

Another way how to make the hourly forecast – is to use the extrapolation model based on a method of a maximum likeness (17-19). It is based on the fact that if the general influence of all factors during any period of time had led to a certain profile of process, sooner or later process again would have a profile similar to initial (see Figure 5). The pairwise correlation was chosen as a measure of likeness.

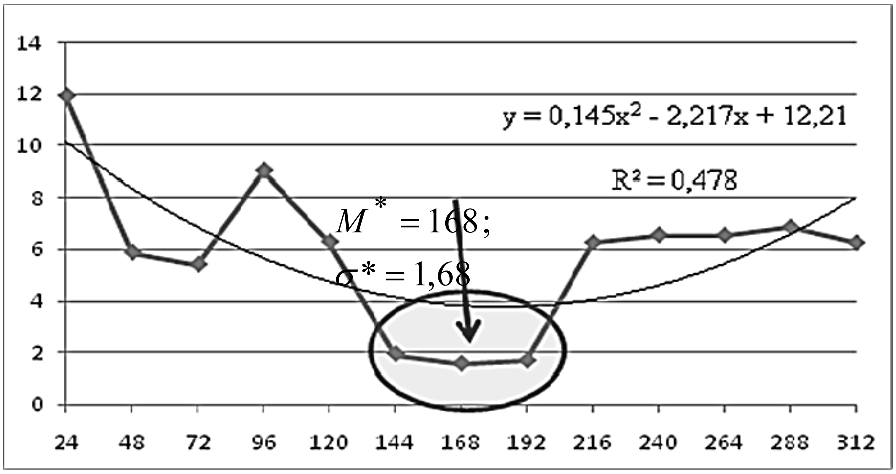
Figure 3. Graphic representation of maximum likeness method



Source: Own results

On the basis of original data it was possible to find the optimal length of a vector M (168 hours that is equal to one week), and optimal length of moving average (5 points). It allowed reducing the standard error to $\hat{\sigma}=1{,}68$ (Figure 6).

Figure 6. Optimal solution of maximum likeness method



Source: Own results

4. Conclusions and discussions

The main valued-added and the major result of the study is the development of the method that allows us to construct the medium and long term forecast of the main characteristics of the daily trade in the electricity sector, namely in the day-ahead market. The method presented in our paper is based on the construction of models that employs regression framework.

Within the framework of the statistical research, the most significant factors were revealed and the nature and extent of their influence on the resulting performance of the energy market of Siberia were quantified. The results were presented and described in a comprehensive way.

Our study was conducted based on the standard model of multiple linear regression and took into account the timing of the effect of covariates (e.g. natural gas prices), as well as diurnal variations of the price using the maximum likelihood method.

The developed method of prediction may be used by the generating companies in the preparation of optimal strategies for implementing free electric power from the perspective of profit maximization and control of the electricity market to optimize the operation and management of the current market. It becomes apparent that on the basis of the scenario approach one can analyze the dynamics of the energy market by substituting the predicted values of the interval factors in the regression equation.

Furthermore, the paper considers the worked-out techniques of the medium and long-term price and quantity forecast at the day-ahead market and the results of its calibration on the data of the Second Price Zone of Russia (Siberia). We revealed the most significant factors that impact DAM price and quantity, including geographic, economic, weekly cycles, etc.

In particular, we found positive linear trend, seasonality in prices and quantities, positive shifts in quantities on the 1st of January and the 1st of July, significant impact of prices on fuel, exchange rates, as well as the impact of the Sayano-Shushenskaya power plant accident. Moreover, it is interesting that Monday significantly differs from the other days of week, and that prices during the holidays are even lower that on Sunday. We also checked sustainability of the coefficients, analyzed the distributed in time influence of some variables, and investigated intra-day price volatility. The technique elaborate in this paper can be used by generation companies working out optimum market strategies, and also by the social planner constructing mechanisms of better market regulation.

Acknowledgements:

The reported study was partially implemented within the framework of research project No. 26.1795.2014/K supported by the Ministry of Education and Science of the Russian Federation.

The work was also supported by RFBR grant No.13-06-00152

The research leading to these results has received funding from the People Programme (Marie Curie Actions) of the European Union's Seventh Framework Programme FP7/2007-2013/ under REA grant agreement number 609642.

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