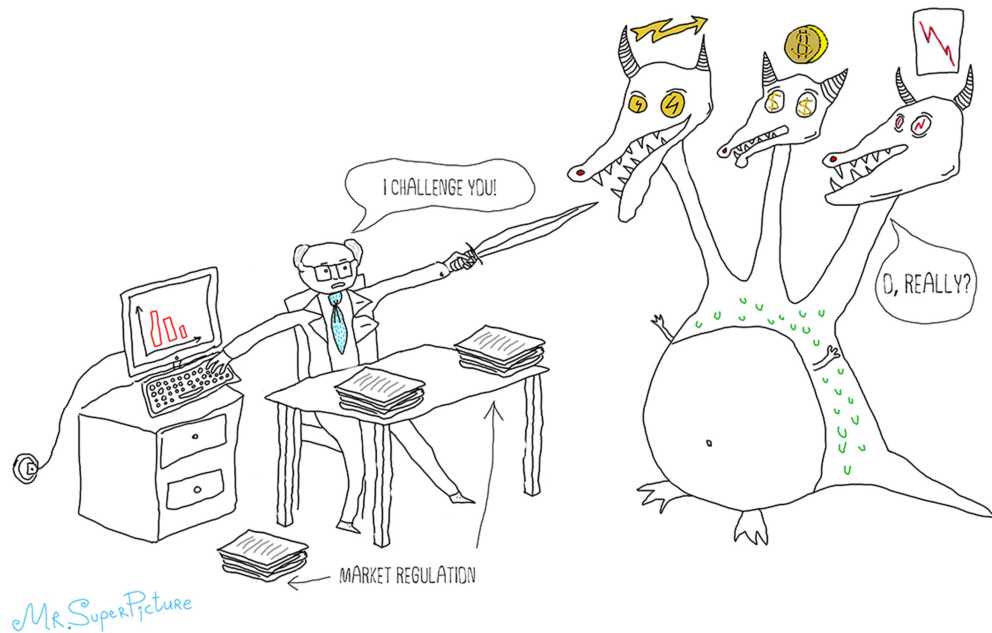


The Three-Headed Dragon: Electricity, Trading, Analysis

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Abstract

There is a noticeable lack of publications about the Russian Wholesale Electricity Market, both in English and Russian. In this paper, the author aims to outline the fundamental aspects of the Russian Wholesale Electricity Market for a wide audience. The first version of this paper was written in Russian and published in “Energo-Info” magazine and on the author's personal website www.mbureau.ru in November 2018. This second paper, the English version, has been adapted for foreign language readers.

The author wishes to express thanks to Professor A. P. Karpenko, for providing the idea

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The paper is dedicated to A.N. Eliseev.

Terminology

There are two terms in English to be applied when it comes to economy of power systems: *electricity* and *power*.

In terms of physics, *power* is the amount of energy in a tiny period – for example, a fraction of a second. Power is measured in Watts (W) and is often referred to as the rate of doing work. Meanwhile, *electricity*, to be precise *electric power* or *electrical energy*, is the amount of energy produced or consumed during a specific period – for example, one hour. In power systems, *electricity* is usually measured in Watt·Hours (Wh). Thus, *electricity* and *power* are entirely different issues.

From an economic point of view, these terms seem to be synonymous. Sometimes we come across the term *power market* and sometimes *electricity market*; the terms are interchangeable and this could confuse the reader. In this paper, the term *electricity* is used to be consistent with physics – electrical energy is to be traded. The only exception is made for the job of *power analyst*, as this is a generally accepted title. A further point of note is that, in this paper, *supply* is used to refer to *power supply* and *consumption* is used to refer to *electricity consumption*.

Finally, the term *capacity* defines the maximum power output a power plant can produce under specific conditions. This term is used consistently in papers on the subject and does not raise any issues with interchangeably.

Introduction

The first thing to note is that electricity trading is an unusual activity because electricity is a very peculiar commodity. In some ways, it can be thought of as a three-headed dragon. The power analyst who explores the electricity market and predicts its behaviour is the knight, challenging the three-headed dragon on a daily basis.

The first dragon head is named *electricity*. Why is electricity a very special commodity? Why do electricity markets function together with capacity markets? How is electricity trading

organised? Who are the electricity market participants? The first head is the simplest one for reading and understanding.

The second dragon head is named *trading*. What stages are developed for wholesale electricity trading? What do trading activities look like? How are wholesale prices formed? The second head requires both patience and attention in order to fully understand it.

The third and final dragon head is named *analysis*. What is the electricity price analysis problem? What is the solution to the problem? This head is the toughest one. To understand it requires not only patience and attention, but additionally time and a willingness to go deep into details. Two examples of price analysis for the Wholesale Electricity Market of Russia are included at the very end of this paper.

Each section of this paper is dedicated to an individual dragon head. The second and third sections of this paper are written in a more formal and, consequently, less interesting style than the first one. As a result, the last two will be interesting to readers who are already familiar with electricity trading or to those who are willing to study the subject.

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1. Power market

1.1. Basics

Electricity is one type of energy; it is obtained by converting primary resources (like coal, gas, solar radiation, etc.) to a conjunction of a current and a voltage in a network. The first technological revolution in electricity production happened in 1870–1910 [1, 2]. Currently, we are witnessing another technological revolution, related to producing electricity from solar radiation and the wind [3].

Electricity as a market commodity is a somewhat new idea if we leave aside the early electricity market experience in the USA between 1887 and 1893 with its harsh principals [1]. From the end of the 19th century until recently, the companies which produce, transmit and distribute electricity were considered to be a natural monopoly. Activities were controlled and regulated by the government. The development of electricity transmission lines led to division in this monopoly. The single entity was split into three parts regarding its activities:

- supplier, which produces electricity;
- network, which transmits electricity;
- distributor, which provides electricity to the end users.

Currently, two market types have been developed for electricity trading: wholesale and retail.

The first attempt to run an electricity market took place in Chile in 1981. During the 1990s a number of other countries, including Brazil, Peru, Columbia, and the United Kingdom, began trading electricity under market conditions. Nowadays, wholesale electricity markets operate in more than 30 countries all over the world. Improvements to trading rules are constantly being made [4].

A wholesale electricity market is only possible where there is a well-developed transmission network. A developed network allows suppliers to compete [1]. Network companies' activities are still, mainly, regulated by governments. Distribution companies buy electricity on the wholesale market and sell it on to the retail market. The public buys electricity from the distribution companies and is considered a participant in the retail market, together with other small consumers like offices, shops, gyms, etc. In 2017 approximately 93% of all the

electricity produced in Russia was sold on the wholesale market¹.

1.2. Electricity as a market commodity

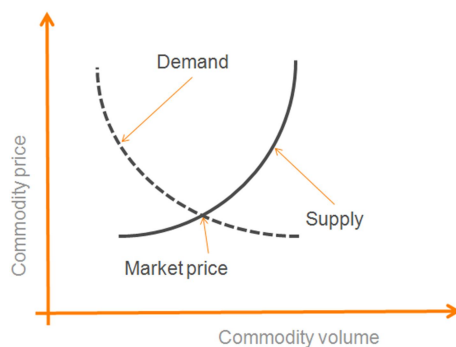
Electricity as a market commodity is distinguished from other products by two main features which have been called *demand-side flaws* [1]:

1) The lack of real-time metering and, as a result, uncertainty about the price of consumed electricity. In other words, we don't know the price while consuming electricity and can't regulate our consumption in relation to that price.

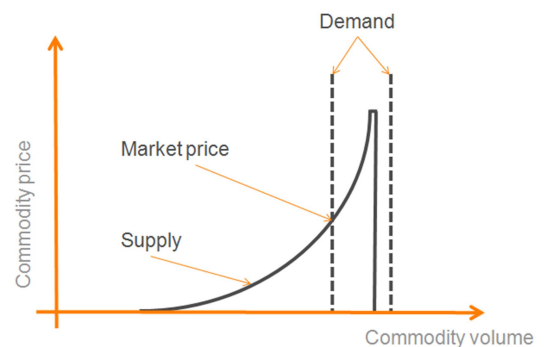
2) The lack of real-time control of power flow and, as a result, practical inability to make the electricity flow go from a particular seller to a specific buyer. In other words, electricity logistics only relate to the laws of electrical engineering, not economic laws.

The main electricity market participants are the *suppliers*, who own power plants, produce and sell electricity, and the *consumers* – companies which buy and consume electricity.

The first demand-side flaw leads to an inelastic demand for electricity on the market. Inelastic demand means that demand value doesn't depend on commodity price. There are elastic demand and supply curves for most products, as shown in figure 1a. The intersection of those two curves (demand and supply) creates the market price. In the case of elastic demand, the volume purchased by the consumer varies according to the price; if the price goes up, purchase volume will go down and vice versa. In the case of electricity, purchase volume regulation is not practically possible. In 2017 in Russia 99.5% of electricity demand was inelastic.



a) Elastic supply and demand



b) Elastic supply, inelastic demand

Figure 1. Demand and supply curves

¹ 65 out of 85 regions of Russia are included in the Wholesale Electricity Market.

Electricity supply has an upper limit, which is determined by the total capacity of operating power plants. This combination of inelastic demand and limited supply could lead to cases when demand is higher than maximum supply (figure 1b), i.e. the power system requires more electricity than can be produced by all the available power plants at that time. The constancy of the electrical grid frequency, equal to 50 or 60 Hz, is ensured by momentary balance – a precise match between produced and consumed electricity. When demand exceeds supply, an imbalance between produced and consumed electricity occurs. This imbalance leads to a drop in frequency and voltage in the power network. In such situations, special measures are taken to maintain frequency and voltage levels, including consumers being cut off from the power network.

The second demand-side flaw complicates bilateral agreements. A bilateral agreement implies that a supplier will produce and deliver a specific volume of a product to a consumer. The consumer, in turn, pays for the product and delivery. Let's imagine supplier A, who wants to sell 1 MWh of electricity to consumer B tomorrow between the hours of 12 AM and 1 AM. According to the bilateral deal, supplier A produces 1 MWh of electricity at the appointed hour and delivers it to the network. In the same hour, consumer B receives 1 MWh of electricity from the same network. As far as the power flow obeys the laws of electrical engineering, there is no guarantee that the exact 1 MWh goes from supplier A to consumer B. Nevertheless there is an organisation, which controls the power flow and knows precisely which part of the 1 MWh in question goes from supplier A to consumer B. In Russia, this organisation is called the *System Operator*.

On 1st September 2006, the Wholesale Electricity and Capacity Market was launched in Russia. The transition from tariffs (government-regulated prices) to market prices was gradual; at first, only 5% of total volume was traded by market price, the remaining 95% was still paid by tariff. Step by step, the share bought and sold by market price increased while the tariff share decreased. In 2011 the Wholesale Electricity and Capacity Market of Russia was liberalised entirely and so since that year, the maximum possible volume has been traded by market prices. Why is this not 100%? Because, according to Russian legislation, the public, i.e. people living in houses and apartments, still buys electricity according to tariffs. In 2017 approximately 16% of all consumed electricity was paid by tariffs [5].

In addition to the wholesale market, the Retail Electricity Market of Russia was launched

in 2012. The retail market price for consumers, excluding the public, consists of three main components: 1) wholesale market price, 2) price of losses in the network, where a consumer is connected (in Russia, this is paid by tariff), 3) distribution company premium. Distribution companies can only vary their premium – the first two components are out of their control. Thus, no competition is possible in the retail electricity market [1].

1.3. Capacity as a market commodity

Expenses for electricity production include two types of cost: fixed and variable. Fixed costs usually include wages, maintenance, equipment upgrades and, most importantly, investments for new power plant construction. Variable costs are mainly fuel costs [6].

If we refer back to figure 1b, we'll notice that the closer the demand is to the upper supply limit, the higher the market price. This means that suppliers are not very interested in constructing new, more efficient power plants, which might push the market price down. However, the government is terrified of cases when demand exceeds supply, because of two aspects:

- 1) It is a direct threat to supply security.

Cases where demand exceeds supply seem to be rather theoretical until a power plant accident occurs. An example of this happened in Russia on 17th August 2009 when Sayano-Shushenskaya power plant, the biggest power plant in the country, switched off accidentally. Special regulation methods were applied to maintain the supply. Thus, there must always be power plants available to replace any that are out of operation, even if they do not produce anything on a long-term basis. This available production is called the *reserve*.

- 2) It is the primary cause of very high market prices.

An example of this occurred on 15th December 2000 in California, when the wholesale electricity price went up to 1400 USD/MWh, while the average price the year before was around 45 USD/MWh. This occasion is well known as the *California Electricity Crisis* [7].

Consequently, the supplier's interests are opposed to the government's ones. Today, a compromise between these two sides is arranged through different schemes of investment return for new power plant construction and payments for the power plants in reserve.

In some countries, like the United Kingdom, USA and Russia, individual markets for electricity and capacity have been developed. For a supplier, income from the electricity market

covers the variable costs and income from the capacity market covers fixed costs. In other countries, including most of Europe, the wholesale electricity market operates with a single commodity – electricity. Here, either total cost is included in the electricity price or fixed costs are paid with special *capacity certificates* (for example, in France). Capacity contracts and reserve payments have long-term horizons of up to several years.

The government defines both technological priorities and the amount of new power capacity to be put into operation according to the long-term economic development plan of the country. The selection of new power plant projects is performed at auction within given criteria.

In 2009, in a document known as the *Renewable Energy Directive*, the European Union authority set a clear goal: by 2020 about 20% of electricity will be produced by wind and solar power plants. This assumed that new renewable power plants would replace existing gas and coal thermal power plants to reduce the amount of carbon dioxide emissions. Today the share of renewable production has reached 53% in Denmark, 26% in Germany, 23% in Spain and is continually increasing for other European countries [8]. However, when electricity production is highly dependent on weather conditions, the power system becomes vulnerable: what will happen, if the wind doesn't blow during the night? For this reason, in countries with a high share of renewable production, special measures are taken to maintain the reliability of supply. These include:

- boosting transmission interconnections between different parts of the country and even different countries (Texas, California, European Union);
- building high capacity power storage systems (Australia);
- improving wind and solar power plant production forecasting (Spain);
- incentivisation for the supplier to reduce production using negative wholesale electricity prices (Germany, Scandinavia, Austria, Switzerland); negative prices lead to additional costs for suppliers, who have to pay for produced electricity.

Before 2011 in Russia, fixed costs were paid by a capacity tariff. The first capacity auction took place in 2011 and since then fixed costs have been paid by market capacity prices. The government set the following goals for the Russian capacity market [6]:

- 1) secure a reliable power supply;
- 2) attraction of investment in building new power plants and upgrade operating ones;

3) minimise the total cost of electricity for end users.

In 2015 suppliers made 40% of total income on capacity trading. Payment is organised through a number of special contracts, government subsidies among them. Details about capacity contracts can be found in [9].

The launching of new power plants, paid for with new capacity contracts, together with lower than expected consumption increase has led to a surplus of capacity in the Russian power system. Currently, the estimated surplus is about 15 GW according to [6], and about 30 GW according to [9].

1.4. Power trade schemes

Electricity can be traded through two general schemes.

The first and most evident scheme implies the following: all suppliers make a bilateral agreement with all consumers and electricity is paid according to actual power flows in the networks. Currently, there are more than 100 suppliers and more than 240 consumers in Russia [10]. To put this scheme into operation more than 24 000 bilateral agreement would have to be made, which would be very cumbersome to negotiate, control and pay. Another disadvantage of the scheme is complete opacity: bilateral contract details can't be openly published. The opacity makes the market price unclear, market behaviour unpredictable and, as a result, the market does not attract investors. That's why this scheme is not put into practice.

The second scheme requires a particular organisation which buys all the electricity from suppliers and sells it to consumers. In Russia, the wholesale electricity market operates under such a scheme. This organisation is referred to as the power exchange (Continental Europe, Russia) or the power pool (Scandinavia) and in Russia it is known as the *Administrator of Trade System*. The two main responsibilities of the power exchange are the follows:

- 1) to perform auctions,
- 2) to publish market statistics.

This scheme makes the electricity market more or less transparent and is widely applied all over the world.

1.5. Trade participants

1.5.1. Suppliers

Power plants with an installed capacity of over 25 MW can become suppliers on the Wholesale Electricity Market of Russia [11]. The classification of suppliers can be made in several ways. One is to classify them according to the technology used to produce electricity. In Russia, there is a company, *Rosenergoatom*, which owns all ten nuclear power plants of the country. There is also *Rushyrdo*, which owns most of the hydropower plants. Thermal power plants belong to dozens of companies. So-called *Wholesale Generation Companies* own big thermal power plants, which mainly operate in condenser mode. This means that those power plants produce electricity with no heat production. Similarly, *Territorial Generation Companies* own, mostly, combined heat and power plants, which simultaneously generate electricity and heat as hot water or steam. The share of total electricity production for each supplier type in Russia in 2017 is shown in figure 2. Note that a *block station* is a small power plant which is not a wholesale electricity market participant and operates on the retail market.

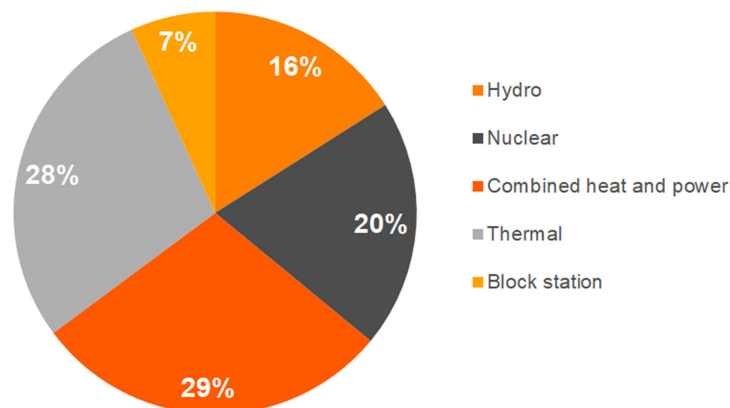


Figure 2. Supply structure by technology in 2017

Suppliers can be categorised into two big groups concerning their variable costs.

The first group includes thermal power plants, which burn fossil fuel to produce electricity. Variable costs of these power plants are within the range 300-20000 rub/MWh, which is 4-250 euro/MWh (exchange rate = 78 rub/euro, November 2018).

The second group includes nuclear, hydro, wind and solar power plants. Their variable costs are equal to zero.

1.5.2. Consumers

A consumer with an installed receiving capacity of over 20 MVA (megavolt ampere) may become the Wholesale Electricity Market of Russia participant [11].

Consumers can be divided into three groups.

The first group consists of distribution companies with the peculiar status of *guarantee supplier*. This unusual status is the legacy of the previous tariff system. Such companies, like *Mosenergosbyt*, *Volgogradenergosbyt*, *Kaluga Distribution Company*, etc., buy electricity on the wholesale market and sell it on to the retail market. Thus for end users, they are literally electricity suppliers, despite the fact they do not produce electricity. The only difference between the guarantee supplier and other distribution companies is that the guarantee supplier must accept any client who wants to buy electricity on the retail side, even if it's not a trustworthy one. Of course, untrustworthy clients increase a guarantee supplier's risks. To compensate that additional risk a special risk hedging mechanism has been developed for the guarantee supplier in the wholesale electricity market. In 2017, in the wholesale market of Russia, approximately 60% of total electricity was bought by guarantee suppliers. The public buys electricity from local guarantee suppliers by tariff. The tariff is established by local executive authorities. For example, the 2018 Q1 tariff in Moscow city (guarantee supplier *Mosenergosbyt*) was 5.03 rub/kWh (set by Moscow Government), while the average wholesale market electricity price for that region was 1228 rub/MWh, which is 1.23 rub/kWh.

The second group consists of distribution companies with no special status. Such distribution companies buy electricity on the wholesale market for their clients – big consumers. For example, *Rusenergosbyt* buys electricity for *Russian Railways*, *Lukoil-Service* buys for *Lukoil*, etc.

The third group consists of end consumers. Usually, these are big plants and factories which require from dozens to hundreds of MWh to operate. For example, *Novolipetsk Steel Factory*, *Volga Pipe Plant*, *Russian Aluminium*, etc.

1.5.3. Others

The collection of power distribution equipment and transmission lines is called the power grid or power network. Parts of the power grid belong to grid companies. The *Federal Grid Company* owns high voltage lines (voltages 150-1150 kV). *Territorial grid companies* own

medium and low voltage lines (3-110 kV). Electricity losses appear when electricity is transferred from one point of the grid to another. Losses are paid by tariff in Russia.

The import and export of electricity with Russia's neighbouring countries (Finland, Belarus, Ukraine, Georgia, China, Mongolia, etc.) is carried out by a single state-owned company, *Inter RAO*.

The *System Operator* carries out a wide range of functions:

- controls power flow in the power system;
- ensures a reliable power supply;
- maintains the balance between consumption and production of electricity;
- secures electrical grid frequency 50 Hz, etc.

Trading is carried out by the *Administrator of Trade System* and accounting is executed by the *Financial Settlement Centre*. The services of each of these are paid for by tariff.

The *Market Counsel* performs updates and improvements to the market rules.

Authorities – including parliament and government, the Federal Anti-Monopoly Service and the Federal Tariff Service – take part in the regulation and control of the Wholesale Electricity and Capacity Market of Russia.

2. Trading

2.1. Stages

To avoid situations where demand exceeds available supply, pricing on the wholesale market is organised in a way to incentivise participants to plan their consumption and production precisely.

There are two important terms: *gate closure* and *settlement period*.

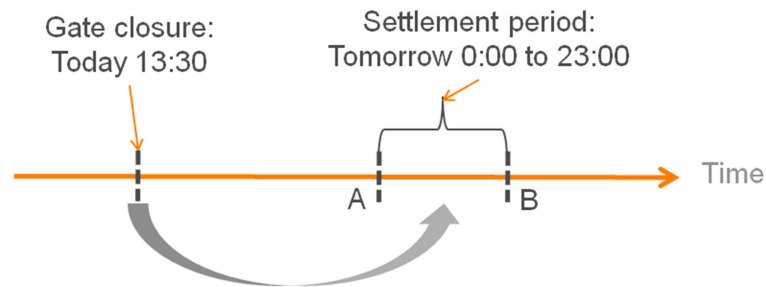


Figure 3. Gate closure and settlement period

The gate closure is the moment of time when bidding for a certain settlement period ends. For example, today at 13:30 Moscow time the gate closes for the settlement period from 0:00 (point A on figure 3) to 23:00 (point B) the following day. No more bids are accepted after 13:30.

Electricity trading agreements can be grouped according to settlement period. The contracting process can be divided into four *trading stages*.

At the first stage, long-term agreements are made. For that purpose, in many wholesale markets (European Union, USA, etc.) a specific type of contract has been developed – the *forward*. According to a forward, parties buy and sell their intention to consume and produce electricity for a month, quarter, year and even several years ahead (settlement period).

In the Wholesale Electricity Market of Russia, no forwards are available and two types of long-term agreement have been introduced instead:

- 1) Suppliers and distribution companies servicing the public make *regulated contracts*. Local executive authorities define volumes and prices of these contracts. The settlement period of each contract is one year: during the current year, the companies settle regulated contracts for the next year.

2) *Bilateral contracts*. Parties settle the volumes and prices of the contracts. The settlement period can vary from a few hours up to a few months. According to wholesale market rules, the parties must pay transmission losses together.

The goal of long-term contracts is to either decrease price risk or gain additional profit.

At the second stage, participants trade their consumption and production plans for the day ahead. The settlement period is one day. This sector of the wholesale market is called the *day ahead market*. Again, as in the case of long-term agreements, the plans are bought and sold.

In the Wholesale Electricity Market of Russia, gate closure and settlement periods for the day ahead market match the example in figure 3. This gate closure also works for the bilateral contracts with settlement periods overlapping the following day.

At the third stage, the *intraday* trading takes place. The settlement period depends on the market and varies from half an hour to a few hours within the same day. Again, during intraday trading, short-term consumption and production plans are bought and sold.

The intraday market in Russia has a settlement period equal to the rest of the day, i.e. the number of hours before 0:00 the following day. The gate closes 2 hours before physical delivery.

At the fourth stage, after the intraday gate is closed, the *balancing market* takes over. In Russia, this market is not really a market but a sophisticated mechanism used by the System Operator to match production and consumption. To ensure power supply with a given network frequency, the System Operator commands power plants to increase or reduce their supply. In Russia, no control over the System Operator actions is taken.

At the very end, after actual consumption and production values are received from measurement systems, the deviation between the intraday schedule and actual volume is estimated. These deviations are bought and sold in the balancing market. Deals in the balancing market can be considered as post factum deals.

As shown above, the basic idea of the electricity market is one of multi-stage planning.

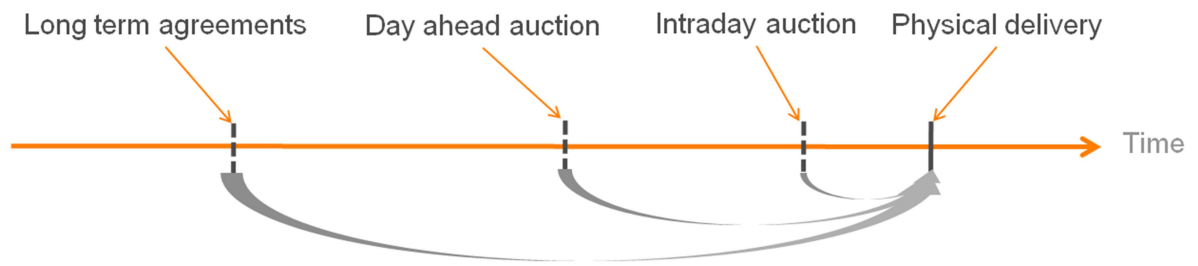


Figure 4. Multi-stage planning in the wholesale electricity market

For a single moment of physical delivery of electricity, several planned stages take place (figure 4). The very first and the least precise is the long-term plan. The closer the delivery moment is, the more precise the plan is. The pricing schemes, applied to the electricity market, for the day ahead, intraday and balancing sectors have been developed to incentivise participants, especially consumers, to plan precisely. Under conditions of inelastic demand, this works the following way: the higher the deviation between the actual and scheduled consumption is, the higher the final electricity cost is and vice versa.

2.2. Agreement examples

According to the rules of the wholesale market of Russia, all participants compulsorily take part in the day ahead and balancing market. If for some reason, the participant does not bid on the day ahead auction, the System Operator will bid for them.

Let's look at agreement examples on the day ahead and balancing markets in the wholesale market of Russia for one supplier and one consumer, which has neither regulated nor bilateral contracts in place. The supplier sells his plan to produce 100 MWh tomorrow within the hour 0:00 to 1:00 Moscow time (figure 5). The trade hour is usually denoted by the start time, i.e. 0:00. How much electricity this supplier produces in that hour will be known after 1:00. If the supplier actually produces 101 MWh, it will have two deals (figure 5a):

- 1) schedule = 100 MWh sale on the day ahead market;
- 2) a deviation = actual – schedule = 101 – 100 = 1 MWh sale on the balancing market.

If the supplier actually produces 99 MWh, it will have the following two deals:

- 1) 100 MWh sale on the day ahead market;
- 2) $99 - 100 = -1$ MWh sell, which is the same as a 1 MWh purchase on the balancing

market.

It is similar for consumers. Assuming the consumer plans to consume 100 MWh in the same trade hour 0:00, if it actually consumes 99 MWh, it will have the following deals (figure 5b):

- 1) 100 MWh purchase on the day ahead market;
- 2) $99 - 100 = -1$ MWh purchase, which is the same as a 1 MWh sale on the balancing market.

And vice versa, if it actually consumes 101 MWh:

- 1) 100 MWh purchase on the day ahead market;
- 2) $101 - 100 = 1$ MWh purchase on the balancing market.

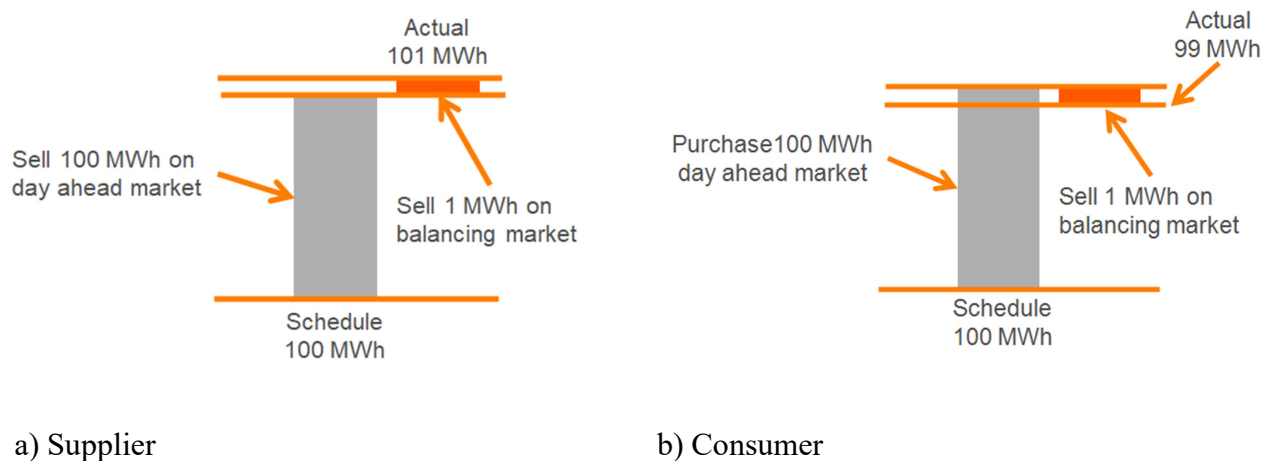


Figure 5. Illustration of the day ahead and balancing market deals

In the Russian Wholesale Electricity Market, participants bid their plans for the following day to the Administrator of Trade System. The Administrator of Trade System, in turn, collects all the bids, performs a so-called day ahead auction (p. 2.5) and estimates all volumes and prices for all the day ahead deals, considering amounts of regulated and bilateral contracts. In addition to the functions mentioned above, the System Operator collects all the bids for the intraday market and performs a so-called intraday auction. The Administrator of Trade System calculates total volumes and prices for all the deals on the balancing market at the very end.

In 2017 in Russia the day ahead market made up 76% of total wholesale electricity market turnover, the intraday and balancing markets combined made up 6%, regulated contracts

made up 15% of total turnover and approximately 3% was related to bilateral contracts [5].

As the day ahead sector is the largest in terms of turnover, let's have a closer look at how it operates in the Wholesale Electricity Market of Russia.

2.3. Consumers day ahead bid

The consumer bid for the day ahead market usually looks like a three column table (table 1): the first column contains the trading hour, the second, consumption plans and the third, price.

Table 1. Example of the day ahead consumer bid

Hour	Volume, MWh	Price, rub/MWh
0:00	100	
1:00	150	
...
23:00	90	

If a consumer leaves the price cells empty, it declares its intention to buy electricity at any market price. This type of bid is called a *price independent bid*. Such bids reflect inelastic demand, as discussed earlier. In 2017 in Russia 99.5% of bids were price independent.

2.4. Supplier day ahead bid

Suppliers squeeze their production plans into a similar table with volume and price columns. Bids for thermal power plants look different from the bids for the other types of plant because of the difference in their variable costs (p. 1.5.1).

2.4.1. Thermal power plant day ahead bid

A thermal power plant burns fossil fuel, for example, gas, coal, etc., to produce electricity. Thermal power plants are sophisticated technologies that require a lot of effort to operate and control. Thermal power plants can produce electricity within a fixed range: from *minimum operating limit* to *maximum operating limit*. These limits are defined by gas or steam turbine technical characteristics. To switch on the thermal power plant a special startup

programme is applied. For the thermal power plant, the variable cost of producing 1 MWh depends on a lot of factors: electricity load, heat load, the price of using fuel, outside temperature, etc.

A thermal power plant bid for each hour looks like a table, containing the approximation of a 1 MWh cost curve, sometimes called a *characteristic curve*. According to the market rules, this curve should be squeezed into only three points, while in reality it often has a more complex shape. To ensure offer price increment (the higher the offered volume, the higher the price) several rules have been developed for bidding:

1) As electricity volume equal to the minimum operation limit will be produced anyway, that volume is bid as price independent (figure 6, point 1).

2) The volume equal to maximum operation limit should be bid by the price equal to the cost of 1 MWh at maximum production including planned premium (figure 6, point 3).

3) The middle volume (figure 6, point 2) can be included in the bid under the following conditions:

- volume 1 < volume 2 < volume 3;
- price 1 < price 2 < price 3.

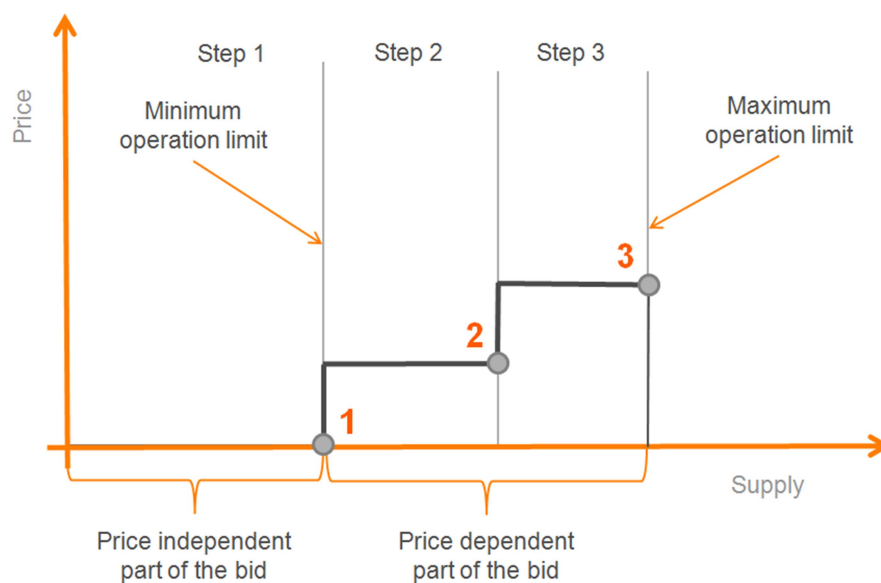


Figure 6. Thermal power plant day ahead bid for one hour

The production cost of 1 MWh between points is assumed to be constant. Since the bid

chart (figure 6) is reminiscent of stairs, the points are usually called steps. A set of steps for 24 hours ahead looks like table 2.

Table 2. Example of a thermal power plant day ahead bid

Hour	Step 1		Step 2		Step 3	
	Volume 1	Price 1	Volume 2	Price 2	Volume 3	Price 3
0:00	150		250	900	300	1500
1:00	150		250	900	300	1500
...
23:00	150		250	900	300	1500

The volume and price values in the bid are determined as a result of two mathematical problems:

1) *thermal power plant optimisation* maximising profit – defining the volumes in the bid [12];

2) calculation of so-called *fuel rates* – determining the cost for 1 MWh production which further is used to calculate the prices in the bid [13].

As a reminder – competition in any wholesale electricity market is possible only among the suppliers. In Russia, competition is possible only among thermal power plants. If a thermal power plant bids volume with a high price, that volume could be left unclaimed, i.e. non-accepted (figure 10). What is unclaimed supply? This is supply which could potentially be produced by power plants in operation. The schedule for power plants, whose offer is partly unclaimed, is below its maximum operating limit. Here two cases are possible.

1) For the power plant, it's more profitable to produce at maximum operating limit (produce as much as possible). If that power plant loses out competition to a neighbouring power plant, then part of its offer will remain unclaimed. In that case, the power plant will lose profit on the day ahead market.

2) For the power plant, it's more profitable to produce less than the maximum operating limit. The bid of such a power plant contains deliberately high prices reflecting the intention of the power plant to reduce its production.

It should be mentioned that the day ahead schedule (plan) is discussed at this stage. Furthermore, the schedule could be updated during intraday action and within the balancing activities of the System Operator.

2.4.2. Other power plants day ahead bid

Hydro, nuclear, solar and wind power plant bids look similar to consumer bids. These contain only one step (table 3). According to the rules of the Wholesale Electricity Market of Russia, the bids of these power plants should be price independent.

Table 3. Example of supplier day ahead bid

Hour	Volume, MWh	Price, rub/MWh
0:00	200	
1:00	200	
...
23:00	200	

In 2017 these power plants bid 44% of total price independent supply on the day ahead market. The remaining 56% was bid by thermal power plants. In the same year, the total price independent supply on the day ahead market was 94.3% of total supply. This means that the price dependent supply comprised less than 6% of total supply. Thus it should be stressed that the price independent parts of supply and demand prevail in the Wholesale Electricity Market of Russia. Real supply and demand curves are represented in figure 7.

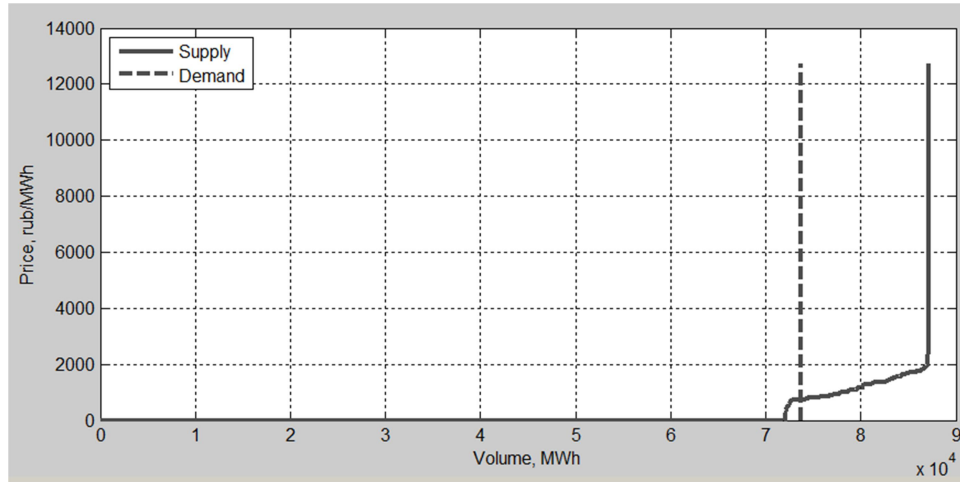


Figure 7. Real demand and supply curves: European price zone, 25th May 2018 0:00

A few other types of bids are available on the electricity market of Russia, including *integral day ahead bids* and *quick price independent intraday bids*. These types are not discussed in this paper, but details can be found in [6, 11].

In the Wholesale Electricity Market of Russia, only volumes to be physically produced and consumed are traded. No financial contracts with 'virtual' volumes have been available since 2008. This means that if you are an owner of a power plant with an installed capacity of 30 MWh, you may only trade amounts up to 30 MWh.

2.5. Day ahead auction

When all participants have made bids on the day ahead market, the Administrator of Trade System performs a day ahead auction, which is, in fact, a mathematical optimisation problem²:

$$F = \sum_{h=0}^{23} \left\{ \sum_c C_c(h) \cdot P_c(h) - \sum_g C_g(h) \cdot P_g(h) \right\} \rightarrow MAX. \quad (1)$$

Here $C_c(h)$, $P_c(h)$ = electricity consumption price (rub/MWh) and volume (MWh) within time step h and $h+1$ from consumer bid; $C_g(h)$, $P_g(h)$ = price and volume from supplier bid. The objective function (1) represents the total profit of all participants, which is called the *welfare function of the market* [6]. In equation (1), the sum goes by so-called nodes c and g . Each node

2 Consider the objective function with inelastic demand and for hourly bids (so-called integral bids are excluded from the discussion).

represents a power plant or its part, an individual block or a turbine, in the case of a generation node g ; a transformer station or other distributing equipment in the case of consumption node c . Optimising parameters are supplier volumes $P_g(h)$ in generation nodes. The optimisation problem (1) has a wide range of various constraints which come from the technical conditions of the power system [11].

As can be seen from the problem statement, in Russia the *nodal pricing system* is applied to the wholesale market: each node gets an individual price value for a certain hour. In book [1], S. Stoft claims that this is the fairest pricing system from an economic perspective. The same pricing system is used on the PJM (Pennsylvania-New Jersey-Maryland) market in the USA. There is also another system – the *zonal pricing system*. In this, the optimisation problem statement differs from the one shown above. Zonal pricing is applied in Europe, Scandinavia, etc. For markets with zonal pricing all the suppliers and consumers, located in the specific area, or *zone*, get the same electricity price for a certain hour.

Nodes are spread widely geographically throughout Russia, so it was decided to divide the territory into two price zones:

- 1) European price zone, containing more than 8000 nodes;
- 2) Siberian price zone, containing more than 800 nodes.

Both price zones make up of 65 (out of 85) regions of Russia (figure 8). The remaining areas relate to non-price and isolated zones. In such areas, electricity is still bought and sold by tariffs.

The two price zones operate independently. The Administrator of Trade System solves the optimisation problem, through use of the *Lagrange multipliers method*, individually for each price zone.

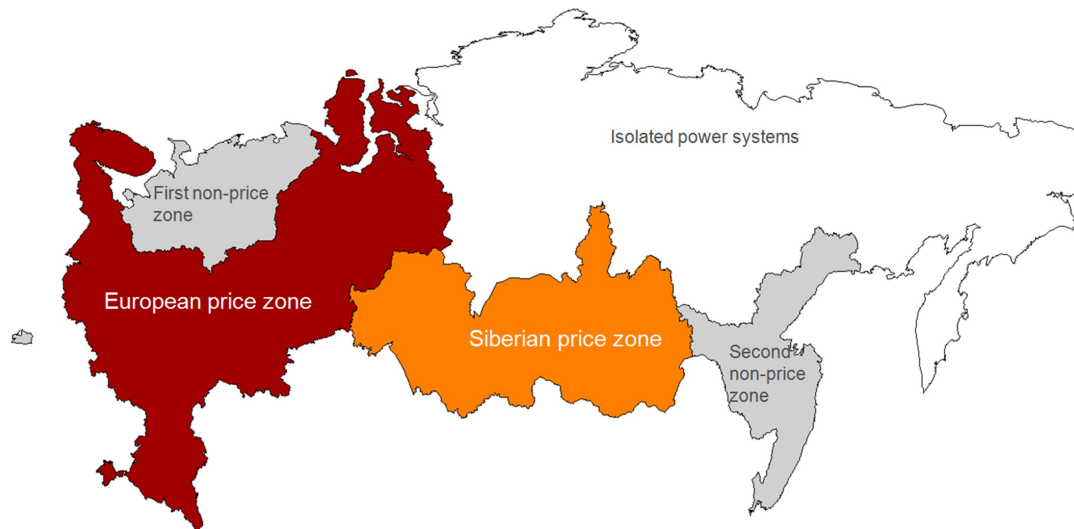


Figure 8. Price zones map of the Wholesale Electricity Market of Russia

2.6. Day ahead auction results

Consumption and production plans derived as a solution to the optimisation problem (1) for all participants are called the day ahead schedule.

The price in each node of the power system is equal to the Lagrange multiplier value in the node. The price values represent the local marginal price and usually called the *nodal day ahead prices*. Generally, there is a unique price value in each node. The price difference between two nodes in the same hour could vary from zero to a few thousand rub/MWh. Prices in nodes located close to each other geographically usually show similar behaviour. The further apart nodes are located, the less alike their behaviour is (figure 9).

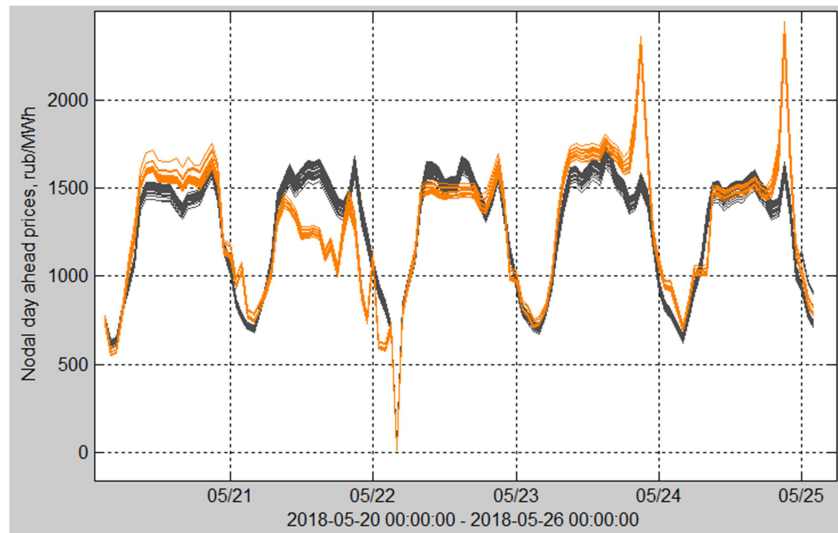


Figure 9. Nodal prices for Orel region (grey) and Chechen Republic (orange) in May 2018

While the number of nodes is very high, the general market tendencies are usually estimated using aggregated prices, i.e. averages or weighted averages prices for *zones of free flow* or entire price zone [6]. A zone of free flow is an area where the power flow usually operates with no significant network constraints, similar to the zones of European markets. When the volume numbers are available it's recommended to use weighted averages prices; when they are not available, average prices. These weighted averages and average prices usually are called *indexes* [14].

2.7. Day ahead marginal price

The key indexes of the day ahead market are the buy and sell indexes aggregated by price zone. The first, the buy index, is the weighted average of all the consumption nodal prices. The second, the sell index, is that of generation nodal prices. The values of the two indexes are published daily on the Administrator of Trade System website. The two indexes can be fused together to make a single one – the weighted average of two indexes – which can be called the *day ahead market marginal price* (often referred to as the *marginal price*). If we allow some simplifications, it can be stated that on the supply and demand curves chart (figure 1b, 7) the marginal price is an intersection point [6]. The value of the marginal price shows whether the electricity price goes up or down on average in the entire price zone, i.e. in the greatest number of nodes (see below).

The nodes in which prices do not obey general market tendencies can be grouped by

geographical location. There are several groups in the European price zone:

- 1) North-West (Karelia Republic, Leningrad Oblast, Murmansk Oblast, Novgorod Oblast, Pskov Oblast);
- 2) South (Chechen Republic, Dagestan Republic, Ingushetia Republic, Kabardino-Balkar Republic, Karachay-Cherkess Republic, North Ossetia-Alania Republic, Stavropol Krai, Krasnodar Krai);
- 3) North-East (Kurgan Oblast, Tyumen Oblast, Perm Krai).

There are two groups in the Siberian price zone:

- 1) East (Buryatia Republic, Irkutsk Oblast, Zabaykalsky Krai);
- 2) West (Altai Krai, Altai Republic, Omsk Oblast, Novosibirsk Oblast).

These local groups are the result of poor interconnection between the group nodes and the rest of the price zones. At the beginning of this paper (p. 1.1), it was mentioned that a developed power network increases competition among suppliers. Poor interconnection leads to closed local competition among a few suppliers. This local competition makes group nodal prices behave peculiarly compared to the marginal price.

Below it is shown how the marginal price reflects the nodal price behaviour for both price zones. In 2017, when the marginal price daily average increased, i.e. the marginal price was higher than the previous day, the nodal prices daily average values went up for 81% and 84% of nodes in the European and Siberian zones respectively. Similarly, when the marginal price daily average decreased, the nodal prices daily average went down for 85% and 86% nodes (table 4).

Table 4. Changes in daily average prices in 2017

European price zone		Siberian price zone	
Marginal price	Nodal prices	Marginal price	Nodal prices
Increased	Went up for 81%, went down for 19%	Increased	Went up for 84%, went down to 16%
Decreased	Went down for 84%, went up for 16%	Decreased	Went down to 86%, went up for 14%

Thus to estimate general market tendencies, a marginal price analysis is required.

3. Day ahead price analysis

3.1. Price analysis problem

The day ahead price analysis problem can be stated in two ways.

The first problem (problem 1) is to answer the question: why does the price in the node have a particular value? This answer requires splitting the nodal price value into its components. One approach is offered in [15] and called the decomposition of the nodal price. To perform the decomposition, the availability of all the supply and demand parameters, derived as an optimisation problem solution (p. 2.5), is necessary. Unfortunately, the decomposition is impossible for market participants due to the inaccessibility of most of the input parameters.

While market participants can't solve price analysis problem 1, they usually solve the second problem (problem 2) by answering the question: what is the primary cause of price change for a specific node or group of nodes for a period (hour, day, week) compared to the previous period? To solve the problem it is necessary to:

- 1) define the factors impacting the prices, the so-called *price drivers* (p. 3.2.1);
- 2) highlight the main ones (p. 3.2.2).

3.2. Solution

Thomson Reuters (the company new name is Refinitiv) analysts solved the second price analysis problem through the development of the “Eikon Power Russia” analytical product. This product allows:

- 1) price analysis for the Wholesale Electricity Market of Russia,
- 2) temperature, demand, supply, price forecast.

As input data, the product mainly uses the openly available market data, regularly published on the websites of the Administrator of Trade System and the System Operator. Additionally, the weather data from the European Centre for Medium-Range Weather Forecasts is used.

The Eikon Power Russia product consists of four major parts:

- 1) a system of grabbing data from web resources;
- 2) a system of automated calculation, which is necessary for the price analysis and forecasts problems;

- 3) a system which allows calculation results to be available to clients as files using FTP;
- 4) a system of displaying the calculated results as a set of charts and tables.

The last system allows Eikon users to access the latest market results and forecasts.

Similar analytical products have been developed by Thomson Reuters analysts for the markets of Continental Europe, Scandinavia, United Kingdom, USA, Brazil, Australia and Turkey.

Let's go through the solution of the second price analysis problem using data from Eikon Power Russia for the primary market index – the marginal price.

3.2.1. Factors impacting the marginal price

Total demand consists of participants' demand and losses. Furthermore, participants' demand is called merely demand. For price analysis purposes, five supply and demand components have been allocated (figure 10):

- 1) demand,
- 2) losses,
- 3) accepted price independent supply (hydro, nuclear, solar, wind and thermal power plants),
- 4) accepted price dependent supply (thermal power plants only),
- 5) net import (the difference between import and export of electricity).

Automatic calculation of each component of supply and demand is performed in hourly resolution by the corresponding Eikon system every day. Following this, the average for each component is calculated daily, weekly, monthly and quarterly.

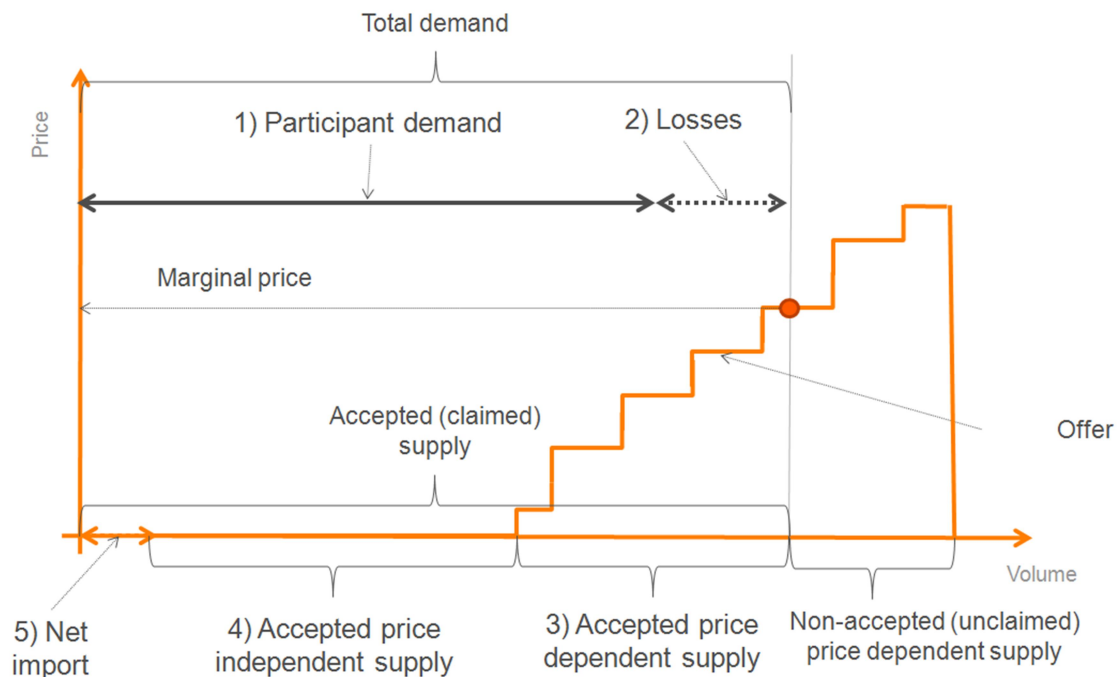


Figure 10. Demand and supply components

Demand. The demand value is available on the website of the Administrator of Trade System. It doesn't require any special treatment.

Losses. The losses depend on demand. To estimate the dependency, a report with regional daily losses is used. The report is available on the website of the Administrator of Trade System. On one hand, there are daily losses and on the other, daily demand. Once linear dependency is obtained for daily values, it's applied to hourly demand to get hourly losses.

Accepted price independent supply. Values of price independent supply for hydro and nuclear power plants are taken from the corresponding report available on the website of the Administrator of Trade System. Price independent supply of renewable power plants (solar and wind) is estimated as the sum of all regime generation units (special notation for individual blocks and turbines) with a corresponding technology type. Price independent supply of thermal power plants is calculated as the sum of two parts:

- 1) the minimum operating level of all the thermal power plants for the price zone. The values are available on the website of the Administrator of Trade System;
- 2) the volume of price independent supply above the minimum operating level, which is

estimated based on several reports³.

Accepted price dependent supply. This value is calculated as the difference between thermal power plant day ahead schedule and accepted price independent thermal power supply, obtained earlier.

Net import. The value of net import is the difference between total demand and total supply (figure 10). Note that the net import is included in day ahead auction as the price independent supply (p. 2.5).

The demand and supply components are the factors impacting the marginal price, i.e. changes in marginal price are related to combined changes of these factors⁴. Factor analysis allows Thomson Reuters power analyst and Eikon Power Russian clients to answer the question of why marginal prices have changed.

Price independent volumes for both supply and demand dominate the Wholesale Electricity Market of Russian (p. 2.3, 2.4). So, if price independent supply and net import are subtracted from total demand, the resulting value is the accepted price dependent supply. This supply, in its turn, defines the price value (figure 10). Marginal price analysis should be done in the following steps:

- 1) price independent supply and demand analysis;
- 2) estimation of changes in price dependent supply.

3.2.2. Highlighting the main factors

The main factors are the ones where change between the target and previous periods are higher than the others. The list of main factors depends on the target period. A power analyst defines this list as a result of marginal price analysis. Examples of marginal price analysis for the Wholesale Electricity Market of Russia are given below in p. 3.3.1 (European zone) and 3.3.2 (Siberian zone).

3.3. Marginal price analysis results

3.3.1. European price zone

3 The calculation is somewhat complicated due to a noticeable lack of the input data. If you need details, contact the author.

4 Price distortion by network flow constraints are not discussed in the paper; see article [15].

Figures 11 and 12 show charts available via Eikon Power Russia. The top chart contains monthly averages for the factors, or price drivers, impacting the marginal price. The bottom one includes difference (change) between the current month value and the previous one for the period from July 2017 to May 2018 for the European price zone. The values for April and May 2018 are collected in table 5.

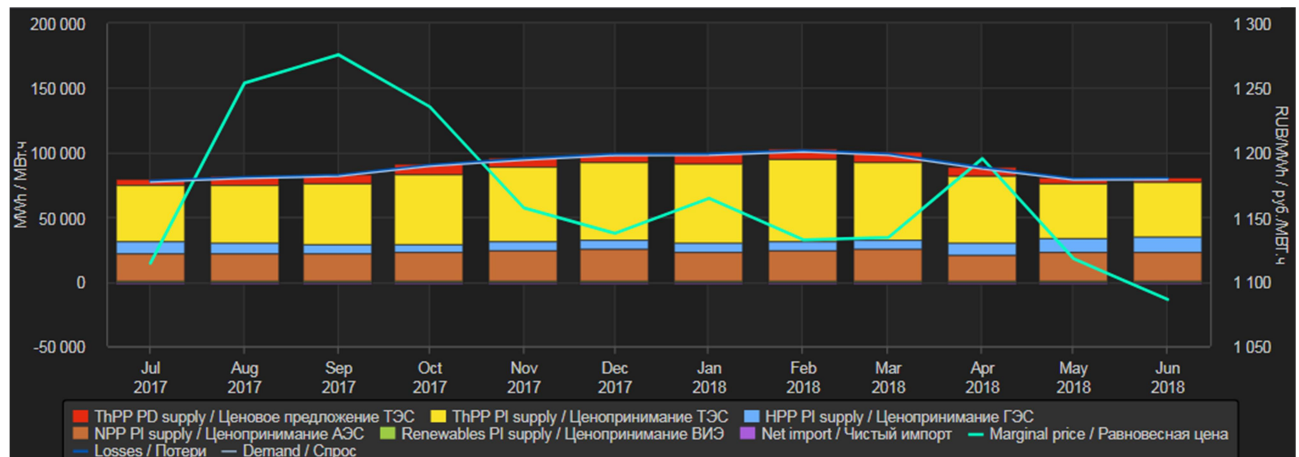


Figure 11. Monthly averages for the factors impacting the marginal price

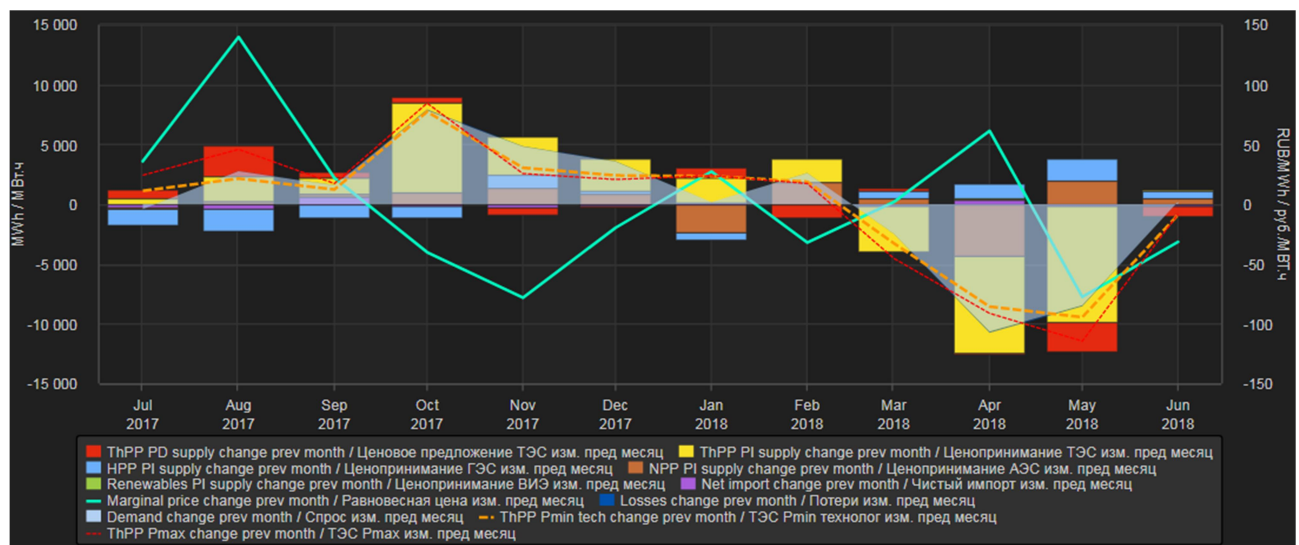


Figure 12. The difference (change) between current month value and the previous one

Table 5. Values for April and May 2018

Month	April 2018	May 2018	Month to month change
Marginal price (rub/MWh)	1 195	1 118	-77
Demand (GWh)	87.2	78.7	-8.5
Price dependent thermal power plant supply (GWh)	7.4	4.9	-2.5
Price independent thermal power plant supply (GWh)	51.8	42.1	-9.7
Price independent hydropower plant supply (GWh)	9.4	11.1	1.7
Price independent nuclear power plant supply (GWh)	20.6	22.6	2.0
Price independent renewable power plant supply (GWh)	0.2	0.2	0.0
Net import (GWh)	-1.2	-1.4	-0.2
Losses (GWh)	0.9	0.8	-0.1

From table 5 it can be seen that the marginal price in the European price zone in May 2018 was 1118 rub/MWh. The price was below April's value by 77 rub/MWh. So, we are looking to answer the question: *why was May's price lower than April's in 2018?*

Price independent supply and demand analysis. Demand in May was 78.7 GWh, which is lower than in April by 8.5 GWh. Components of price independent supply changed the following ways:

- price independent hydropower plant supply went up by 1.7 GWh;
- price independent nuclear power plant supply went up by 2.0 GWh;
- price independent thermal power plant supply went down by 9.7 GWh.

The value of net import, losses and renewable supply didn't change noticeably.

Price dependent supply estimation. Changes in all the price independent components combined led to changes in price dependent thermal power plant supply: the volume went down from 7.4 GWh in April to 4.9 GWh in May 2018. The fall was 2.5 GWh.

Outcome. We found out that the price in May was lower than in April 2018 because

demand reduction outpaced price independent supply reduction. In other words, demand went down faster than the price independent supply.

As a result, the value of price dependent thermal power plant supply went down by 2.5 GWh. This led to a price cut of 77 rub/MWh (figure 13). In this case, the main factors impacting the price were 1) price independent supply of thermal power plant and 2) demand.

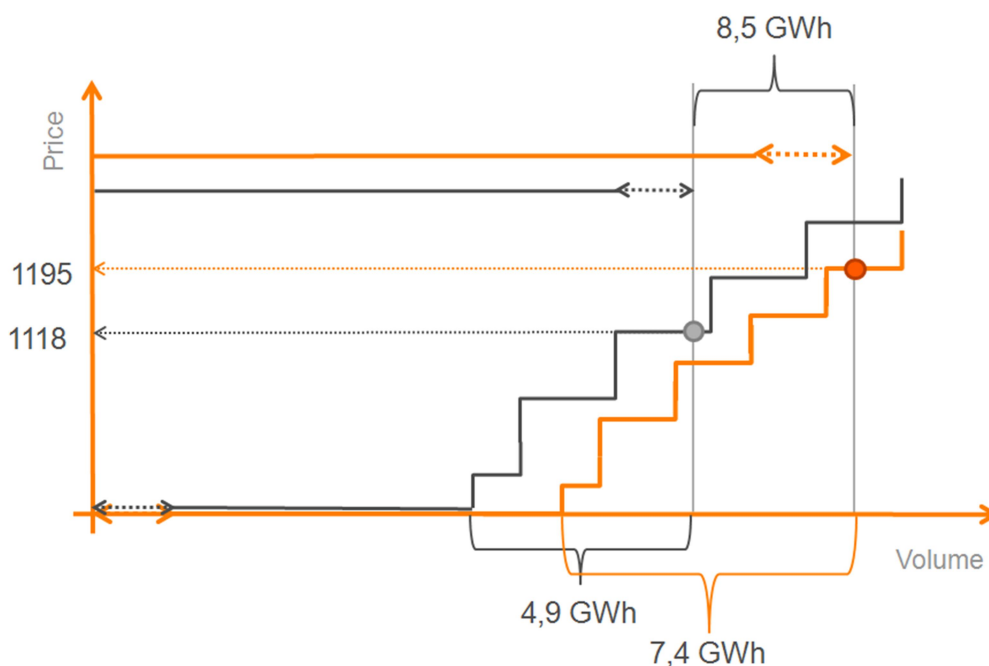


Figure 13. Changes of the marginal price for the European price zone:

Orange – April 2018, Grey – May 2018

The fall in the price independent supply of thermal power plants by 9.7 GWh month to month should also be commented on. In this case, the rapid decrease is related to the cut in combined heat and power plants production. Electricity production of combined heat and power plant depends on the heat load of the plant which, in turn, depends on outside temperature; the colder the weather is, the more heat is required and vice versa. Usually in April, the so-called heating season ends in the European price zone, which leads to significant changes in heat load and, consequently, in power supply. The average combined heat and power plant power supply in May was 20.1 GWh while in April the value was 28.2 GWh (month to month change was 8.1 GWh).

3.3.2. Siberian price zone

Figures 14 and 15 show charts available via Eikon Power Russia. Similar to the previous example, the charts contain values and change for the factors impacting the price for the period of 13th to 20th June 2018 for the Siberian price zone. The values for 18th and 19th of June 2018 are collected in table 6.



Figure 14. Daily averages for the factors impacting the marginal price

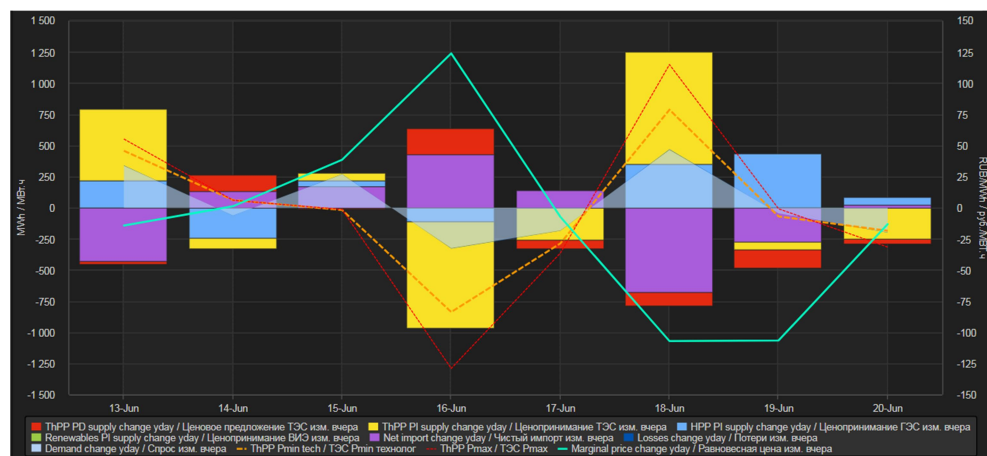


Figure 15. The difference (change) between current day value and the previous one

Table 6. Values for 18th and 19th of June 2018

Date	18 of June 2018	19 of June 2018	Day to day change
Marginal price (rub/MWh)	827	721	-106
Demand (GWh)	20.10	20.05	-0.05
Price dependent thermal power plant supply (GWh)	0.42	0.27	-0.15
Price independent thermal power plant supply (GWh)	6.59	6.52	-0.07
Price independent hydropower plant supply (GWh)	13.13	13.57	0.44
Price independent renewable power plant supply (GWh)	0.02	0.02	0.0
Net import (GWh)	0.19	-0.08	-0.27
Losses (GWh)	0.25	0.25	0.0

From table 6 it can be seen that in the Siberian price zone the marginal price was 721 rub/MWh for 19th June 2018, while a day earlier, 18th June, the price had been 827 rub/MWh. The price analysis problem is stated the following way: *why did the price fall by 106 rub/MWh on 19th June compared to 18th of June?*

Price independent supply and demand analysis. Price independent component changes 19th June compare to 18th June show that:

- demand remained at 20.05 GWh;
- price independent thermal power plant supply went down from 6.59 GWh to 6.52 GWh;
- price independent supply of hydropower plant went up from 13.13 GWh to 13.57 GWh;
- net import went down from 0.19 GWh to -0.08 GWh (on 18th June the price zone was importing electricity, while on 19th June it was exporting);
- price independent renewable power plant supply and losses didn't change noticeably.

Price dependent supply estimation. The volume went down from 0.42 GWh to 0.27 GWh as a result of changes in price independent components.

Outcome. The price on 19th June 2018 went down compared to 18th June due to the

increase of price independent hydropower plant supply, which was not compensated enough by net import changes under the condition of stable demand. In other words, too much hydro production was made that day. Not all of this surplus production was exported and this led to the fall in the price. If all the surplus had been exported, prices would have remained stable. In this case, the main factors impacting the price were: 1) price independent hydropower plant supply, 2) net import and 3) price dependent thermal power plant supply.

3.3.3. Thomson Reuters weekly commentary

Thomson Reuters analysts published weekly price change analysis results as a text commentary, similar to the cases above, every Monday of 2017-2018. Analysts were answering the question: *why have marginal prices changed compared to the week before?*

Besides the marginal price analysis results, the commentary contained discussion around the latest temperature, demand, supply and price forecast for the following week.

Conclusion

Electricity is distinguished from other commodities by two main features (flaws); firstly, the lack of real-time metering and, as a result, an uncertainty about the price of consumed electricity; and, secondly, the lack of real-time control of power flow and, as a result, practical inability to make the flow go from a particular seller to a particular buyer.

The result of these two features is a market construction where a special organisation buys all the electricity from producers and sells it on to consumers. The organisation is referred to as the power exchange or pool. In Russia, this organisation is named the Administrator of Trade System.

In Russia, both electricity and capacity markets operate. This means that suppliers split their costs into fixed and variable parts. Variable costs are considered when the supplier operates on the electricity market, fixed costs when they operate on the capacity market.

Electricity trading consists of several stages: a long-term stage with a trading horizon, called a settlement period, of up to several years; a short-term stage with a one-day horizon; an ultra-short-term stage with a horizon within the current day; and the real-time market. Market participants operate on the electricity market, mainly, by bidding their production and consumption plans. In Russia, the plans are formed in a specific table. The Administrator of Trade System collects the bids, performs a day ahead auction and defines volumes and wholesale day ahead prices for all participants. The System Operator performs an intraday market auction and balances the power system in real-time.

The wholesale electricity price analysis problem for a day ahead market can be stated in two ways. Problem one is trying to answer the question: why does the price in a specific node have a particular value? This problem cannot be solved by either market participants or analytical companies due to the unavailability of most of the input data. Problem two is trying to answer the question: why has the price changed in one period compared to the previous one?

A solution to the second problem has been provided by Thomson Reuters analysts through the analytical product Eikon Power Russia. To solve the problem, a comprehensive set of factors impacting wholesale prices is defined. The methodology for price analysis and two practical examples of marginal price analysis using Eikon Power Russia have been introduced in this paper.

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