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MASTER'S THESIS

BENEFITS OF SMART METERS IN RUSSIAN ELECTRICITY MARKET

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Abstract

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Smart metering technologies have become more popular in Europe. The benefits of smart metering are obvious both for different stakeholders, and for the whole energy system. Cost-benefit analysis of smart metering system was implemented for all European countries. However, there is no similar analysis for Russian electricity market. This work aims to consider specific features of electricity market in Russia and conduct a cost-benefit analysis for residential customers from the guaranteeing supplier point of view. Main costs were defined as capital and operational expenditures and main benefits as a profit from demand response, which led to peak demand reduction and decrease in guaranteeing supplier expenses. Results suggest that smart metering system implementation is not economically justified in Russia. However, it can be implemented optionally or subsidized.

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ABBREVIATIONS

AMM	Automated Meter Management
ASMS	Automatic Smart Metering Systems
ATS	Administrator of Trading System
CDA	Capacity Delivery Agreement
CHP	Combined Heat and Power Plant
DC	Direct Current
DCC	Data and Communication Company
DR	Demand Response
DSM	Demand Side Management
ESME	Electric Smart Meter Equipment
GPRS	General Packet Radio Service
HAN	Home Area Network
HV	High Voltage
LTA	Long Term Agreement
LV	Low Voltage
NPV	Net Present Value
MV	Middle Voltage
PWR	Pressurized Water Type Reactor
SM HAN	Smart Metering Home Area Network
TGC	Territorial Generating Company
UES	United Energy System
UNFCCC	United Nations Framework Convention on Climate Change
UTC	Coordinated Universal Time
WGC	Wholesale Generating Company

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1. Introduction

One of the main challenges of humanity in the 21th century is a climate change. Consumption of natural resources is increasing and it has negative impact on the environment. Humanity is achieving its tipping point.

To prevent this trend, world leaders decided to develop a policy to decrease impact on the environment and avoid the climate change threat. Paris Agreement came into force on the 4^{th} November 2016 at the Conference of the UNFCCC in Marrakesh. 192 states and the European Union signed the Agreement, 131 of those parties have ratified or join to the Agreement, foremost, China, the United Stated and India, the countries with the largest amounts of greenhouse gas emissions. Russia has signed Paris Agreement also, but has not ratified it yet (United Nation Framework Convention on Climate Change, 2016).

Modern energy system is not sustainable socially, economically and environmentally for achieving the goals of Paris Agreement. This system has to be improved. Utilization of renewable sources of energy may help people to escape this catastrophe and its devastating consequences. They play a huge role in reduction of greenhouse gas emissions and climate change mitigation. But renewable sources of energy are intermittent, so people need smart system for their smart usage.

According to the (ABB, 2017) “a smart grid is an evolved grid system that manages electricity demand in a sustainable, reliable and economic manner, built on advanced infrastructure and tuned to facilitate the integration of all involved”. Smart grid system will work mainly on the basis of renewable energy sources implemented by consumers near their houses. Production of energy will be based on the demand of consumer. Excess energy will be sold to a common grid or will be accumulated in batteries. Power quality will increase due to reduction of losses because of close location of the power plant. Smart grid system is already implemented in many European countries and shows the improvement of the energy sector: reduction of energy losses, CO_2 emissions, price for electricity and others. However, despite a good performance in many countries, Russia is in no hurry to implement the technology in its electricity market, mainly due to many problems in the energy sector.

Smart grid is a new and wide concept, which consists of not only appliances, but it also includes behavior and work of people. There are many appliances and devices, which are related to the smart grid concept. The main features of the smart grid system are introduced in the Fig. 1.

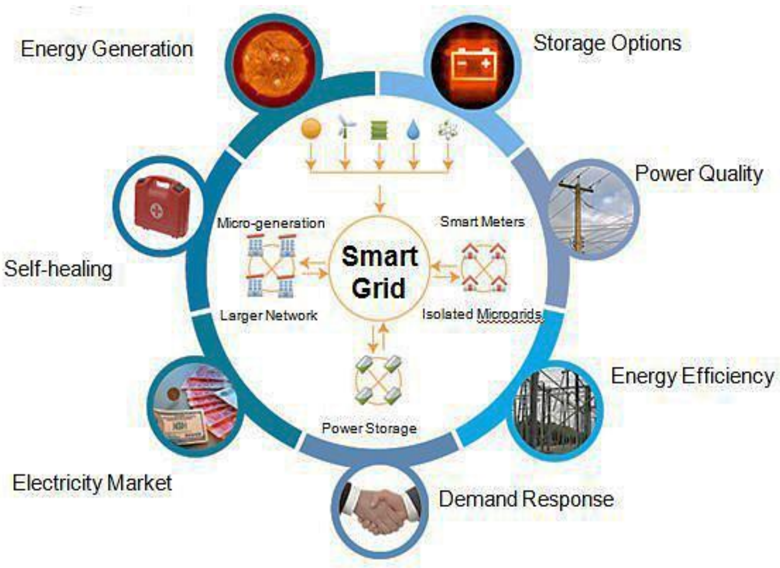

Fig. 1. Key features of the smart grid

Source: (Vette Corporation, 2016)

Firstly, this concept is aimed to increase share of renewable sources of energy and decrease share of conventional fuel utilization. Secondly, the smart grid concept solves the problem of losses in the electrical grids of different voltage by minimizing the distance from a power plant to a consumer, decreasing peak loads and wearing of the grids. It also provides an opportunity for consumers to be independent from electrical grids by use of energy storage. Furthermore, smart grids will implement self-healing from power disturbance events. Thirdly, one of the main goals of smart grids is an improvement of energy efficiency of the energy system by use of appliances with low consumption etc. And the last, smart grid concept saves huge amount of money in long-term perspective (US Department of Energy, 2009).

Smart metering system is considered in detail in this work. Smart meters represent a part of the whole system, in a line with energy storage, microgrids and demand response tool, and they may be the first step to the whole smart system. Smart meters are improved version of conventional meters, which can define data on consumption more accurately than traditional measuring instruments. They are also equipped with communication tools for transferring an obtained information to public utilities for the monitoring and accounting of bills. This term is related to electricity consumption usually, but also could be implemented for measuring other resources like water, gas and heat.

Cost-benefit analysis for smart metering has been implemented for many European countries. However, similar analysis has not been yet conducted for Russian electricity market. Furthermore, there is a lack of information about smart grids and smart meters in Russia and about possibilities of implementation of such technologies in Russian case. This work aims to:

- consider benefits of smart metering;
- describe specific features of Russian electricity market;
- define, which benefits have more impact in relation to smart metering, according to specific features;
- identify costs and beneficiaries;
- monetize costs and benefits and compare them;
- analyze prospects for smart meters in Russian electricity market.

Furthermore, answers to following research questions are found after the cost-benefit analysis conduction:

- Which benefits can bring smart meters to electricity market and to different stakeholders, such as generating companies, grid companies, guaranteeing suppliers and end-users?
- Which benefits can be monetized and which cannot? What are the reasons for that?
- Is it profitable to implement smart metering system in Russian case? What can be done to make it profitable?

In this thesis, smart meter technologies and their specific features are discussed. This work defines their benefits comparing with conventional meters. Russian power sector is also considered to determine its specific features and possibilities of implementation smart meter technology. Following chapter is about tariff formation which affects the profit of guaranteeing supplier. Cross-subsidization, as one of the main problems of Russian power sector, is considered in chapter five. Benefit and costs for European countries are also discussed and are taken as initial data for costs per metering point.

2. Literature review on smart meters technology

After deregulation of power industry and opening of electricity market, government inspections started to search for tools that can match generation with consumption. Conventional meters register only consumption of electricity and do not provide any information about time of consumption. Smart meters are cost-effective instruments for getting such information. This fact might allow companies to establish differentiated tariff on consumption, which would be dependent on time of the day or season. It also can realize a monitoring of consumption and, hence, control it, decreasing unnecessary expenditure of resources. Actually, benefits depend on how actively people manage their energy consumption. Smart meters represent also major labor savings for the utilities and dismissing of conventional meter readings due to their ability to connect or disconnect service and obtain data remotely.

The time, when electricity prices usually reach their peak, can be easily predicted. If generating capacities are limited, prices might grow dramatically, when electricity is purchased at more expensive sources of energy. It can be assumed that if consumers are provided with differentiated bills, where would be data about time of consumption and price in accordance with the day time, it would incentivize them to change their character of consumption in accordance with market signals. Inspecting and price-setting organizations expect that such signals would help to delay building new capacities or, at least, purchasing electricity from expensive sources, that may lead to electricity cost decrease for consumer in general.

2.1. Technical specification of electricity smart meters

According to Smart Metering Technical Equipment Specifications (Department of Energy and Climate Change, 2013), devices have to satisfy next minimum technical requirements to be installed by supplier. First of all, smart meters should provide readings and data should be easily understood even if a consumer does not have special skills. Equipment could be distinguished to a single element, twin and polyphase element electricity metering equipment.

Remote reading is one of the main functionalities especially for grids and networks support. It makes possible two-way communication between the meter and external networks, for example, suppliers or grids, to provide maintenance and control of the meter and also monitoring of power quality (European Commission , 2011).

The bills are sent automatically, that means consumers do not have to fill papers or take readings, including taking meter readings by company representatives. However, technical service is needed every few years to support appropriate state of meters.

Meters may display amount of consumed electricity in kWh, currency and even in greenhouse gas emissions. Directly they don't decrease amount of consumed energy, but they provide data in detail about consumption, the choice is made by end-users.

Meters use GPRS technology like mobile phones. They help to track amount of electricity which is consumed by devices. End-users are able to plan their budget, in the case of exceeding it, the device gives a signal to switch off some of them. This is very good opportunity to plan the budget and follow expenses.

New methods of payment are also possible, for example, with the help of apps in a phone through online banking. There is an opportunity to set a signal and follow the balance online, hence the bills will not be a surprise. The tariff could be chosen or changed with the help of this device, if it would be beneficial for customer.

Smart meters support possibilities to change suppliers. This procedure could be easier and faster, however, in case of switching to a new supplier should support the same technological standard as previous one, otherwise problems may occur with that process. The same software of smart meters should be implemented.

Physical requirements for smart meters are clock, data store, measuring element, Home Area Network (HAN) interface, load switch, random number generator, user interface and Communications Hub, which shall include interface that meets the requirements determined by the Data and Communications Company. HAN connectivity gives an opportunity for offering, besides billing, other services, for example, dynamic pricing, home load control and energy monitoring (Networked Energy Services Corporation, 2016).

Communications Hub allows connection of smart meters and displays to each other within the home area Smart Meters Home Area Network (SM HAN). It also provides connections with DCC (Data Communication Company, 2016) and energy company via Smart Meters

Wide Area Network (SM WAN); this function allows getting data remotely and automatically.

Electrical Smart Metering Equipment (ESME) should be designed to prevent unauthorized access and communications, because it can compromise personal data, such as consumption data used for billing, security credentials, electricity meters etc. A clock should be accurate to within 10 seconds of the UTC date and time, in case of more difference ESME should give signal. This is very important function; because data should be updated frequently enough to provide consumption in real time. Only in this case, necessary measures for energy savings can be implemented by end-users. All information should be saved at Data Store of device, even in case of power losses.

Consumption should be registered and recorded for the whole day according to the local time, week, month and year. Costs are calculated based on gathered data. It is made to compare consumption for some months or weeks.

2.2. Challenges

Critical technological problem of all smart meters is an organization of connection with them. Every device should be able to transfer obtained data reliably and securely to the central node. It could be very challenging taking into account difference in environments and locations.

Smart meters, like innovation, could not help attracting more attention from the media side. Secure issues concerning smart meters also cause anxieties in Europe. This article (Guardian, 2016) in Guardian claims that smart meters system may be very attractive for hackers' attack, so energy utilities have to pay more attention to secure issues. The lack of security may cause cutting power or even catastrophic overload, which may lead to exploding meters or starting house fires. In case of successful attack hackers will know, exactly when and how much energy is consumed or even what kinds of electronic devices people uses.

Also authors of the article give an example to prove the facts. The situation has happened in 2009 in Puerto Rican, where smart meters were hacked altogether. That had lead to cheating with bills. Weak security decisions according the article:

- Encryption keys derived from short (often just six-character) device names.
- Pairing standards with no authentication required, allowing an attacker to simply ask the smart meter to join the network and receive keys in return.
- Hardcoded credentials, allowing administrator access with passwords as simple and guessable as the vendor’s name.
- Code simplified to work on low-power devices skipping important checks, allowing nothing more than a long communication to crash the device.

Another article in this edition (Guardian, 2016) tells that in case of switching suppliers it could become just conventional meter reading, that mean they lose their functionality. European Union has the goal to replace about 80% of conventional meters to smart meters to 2020, but facts like above mentioned makes governments review the plans and postpone the achieving of this aim (European Commission, 2017).

2.3. Examples of implementation

More than 3.5 million devices were established in Britain (Department for Business, Energy & Industrial Strategy, 2017). The government realizes one of the greatest changes in infrastructure in power industry. Smart energy Outlook provides information about this program, for example, such fact that 8 from 10 people, who have smart meter devices, would recommend them to others (Smart energy GB, 2017). According to this report, people become more active in saving energy and controlling their energy usage, they become more aware of their consumption and expenses on it.

Enel has already presented the next generation of meters that will become the key element of new company strategy (Enel, 2016). It is expected that new meters will replace the old ones, which were installed in 2001. The innovative features of the new smart meter include faster changes of supply, the elimination of fixed time bands and the availability of data on electricity use for greater savings. The measurement of customer data every 15 minutes, for example, provides a much timelier picture of daily power use and the consumption behavior of customers, who are increasingly aware of how they use electricity and alert to opportunities for achieving greater energy efficiency.

2.4. The first smart metering system in Russia

The realization of the pilot project in Permian region started in 2011-2012 years (Smart Metering Journal, 2011). This project was experimental and the results were supposed to influence application of this system to other subjects of Russian Federation. This project was first in this sphere. It was realized in the framework of federal program “Count, save, pay”. Firma “Echelon” was chosen as a supplier of equipment for this project. Expectations from this project are shown in the Table 1.

Development of measures and determination of optimal technical solutions for registration systems of retail market, which satisfy modern requirements for accuracy class, opportunities for regulation of consumption, systems of transmission and analysis of data will create possibilities for:

1) Conditions for payment for actual consumed energy resources;
2) Designing the system that will provide full payment for consumed resources in accordance with meters data;
3) Introduction of economically viable, legislatively formalized and tested in practice system of accounting.

For creating such large-scale system of accounting, following tasks have to be solved:

1) Remote reading of energy resources consumption data;
2) Working with a large number of metering points, providing a high level of performance;
3) Remote control metering devices;
4) Accounting of loses and power balance;
5) Opportunities for data exchange;
6) Possibilities for adaption to other tasks.

Table 1. Expected effects from realization of this project (Smart Metering Journal, 2011)

Government	• Decrease in energy consumption • Transparency of energy consumption structure
Generation	• Potential decrease in new capacities volume • Smoothing of energy consumption peaks
Grids	• Decrease in energy losses • Decrease in operating expenses in consequence of staff reducing
Sale	• Improvement of accounts receivable turnover • Decrease in consumers appealing in general
Consumer	• Possibility to control volume and cost of energy consumption

2.5. Demand response and Demand side management

According to the Federal Energy Regulatory Commission, demand response (DR) is defined as (Balijepalli & Pradhan, 2011): "Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized."

Demand response is going to become a significant part of future smart system operations. More active participation in demand response is observed on the retail level rather than wholesale level (Federal Energy Regulatory Commision, 2007). Demand response may be very helpful tool in case of time of peak demands and lack of reserves; it will maintain reliability of energy supply.

Demand response is alternative or comprehensive tool for energy storage. Both of them can be used to shift consumption, if it is unnecessary, to another time. Combination of grid energy storage and demand response has some benefits (U.S. Department of Energy, 2016):

1) Conventional power plant can operate more efficiently at constant production level and carry base load;
2) Electricity generated by solar, wind or other intermittent resources can be stored and used later;
3) More stable prices, if the cost of storages and demand response is included in prices initially;
4) Readiness for emergency situations. DR can be dispatched during the short time, comparing the peaking power plants.

The term of Demand Side Management (DSM) appeared in 1980s. It includes many concepts, for example, load management, energy efficiency, energy saving etc. The problem which is solved by DSM can be divided on short term (above mentioned issues) and long terms, like problems of fossil fuel utilization and impact of power industry on climate change. Long-term benefits of demand response include:

1) Delay in building of new capacities as result of decreasing peak system load in long term, hence, decreasing negative environmental impact;
2) Possibilities for improving the reliability of transmission networks;
3) On the distribution level DR can be used for handling the constraints of network.

DSM and DR implementation has potential to make grids more flexible, reliable and socially beneficial, but public utilities need government support to fund new technology program. Ageing equipment should be changed to a new one, for example, smart meters should be implemented instead of conventional ones. To realize DR in many countries, policy regulations and also introduction of standards are essential. Management of smart grids may be challenging as result of lack of experience with new infrastructure.

3. Russian electricity sector

Electrical energy has specific features, which are determined by its physical properties. They have to be considered for market organization:

- Match of the processes of generation and consumption of electricity in time;
- Equality of volumes generated energy and consumed at every moment of the time;
- Impossibility to store energy in sufficient amounts for energy system;
- Impossibility to arrange accurately in advance volumes of generation and consumption;
- Impossibility from the physical point of view to define, who generated electricity, which was consumed by customer.

Electricity market can function in a proper way only by observing condition of balance between generation and consumption. However, in practice, generators and consumers allow deviations from their obligations concerning their production or consumption. The presence of load oscillations, in combination with circumstances, leads to the fact, that during the year some volume of generated capacity is under-loaded, because available capacity of power stations has to exceed the value of annual maximum load with required reserve

The impossibility to make storages of generated power leads to a necessity to build reserves of generating capacities, new capacities of electric networks and reserves of fuel on power stations. The amount of reserves is standardized and expenses for supporting reserves are included in tariffs for electricity.

3.1. The United Energy System of Russia

The United Energy System (UES) of Russia consists of 69 regional energy systems, which, in their turn, form 7 united energy systems: East, Siberia, Ural, Middle Volga, South, Center and North-West. All systems are connected with intersystem high voltage transmission lines with voltage 220-500 kV and higher. All systems work in a synchronous mode (in parallel).

Electric power complex of the UES includes about 700 power stations with capacity higher than 5 MW (Minenergo, 2017). In the beginning of 2016, total installed capacity of power plants in Russia was 235.30 GW. Table 2 represents the structure of installed capacity in Russia.

Table 2. The structure of installed capacity of the UES Russia on 01.01.2016 (Minenergo, 2017)

	Total, MW	Thermal power plants		Hydroelectric power plants		Nuclear power plants		Solar power plants		Wind power plants,	
		MW	%	MW	%	MW	%	MW	%	MW	%
UES	235 305, 6	160 233	68,1	47 855,2	20,34	27 146	11,5	60,2	0,03	10,9	-
Center	53 306, 92	38 684,1	72,6	1 788,85	3,4	12 834	24,2	-	-	-	-
Middle Volga	27 040, 22	16 078,2	59,6	6 890	25,4	4072	15,0	-	-	-	-
Ural	50 707,82	47 327, 1	93,3	1853,54	3,66	1480	2,92	45,0	0,09	2,2	-
North-West	23 142, 97	14 427,3	62,3	2 950,34	12,8	5760	24,9	-	-	5,3	-
South	20 116, 80	11 357,4	56,3	5 756,05	28,6	3000	14,9	-	-	3,4	-
Siberia	51 808, 33	26 516,7	51,2	25 276,4	48,79	-	-	15,2	0,03	-	-
East	9 182, 50	5 842,5	63,6	3 340	36,4	-	-	-	-	-	-

3.2. The main principles of the Russian wholesale market organization

Capacity and electricity, despite of their connection, are considered as different products. The realization of capacity represents the obligation and readiness to produce power by generating equipment, while electricity represents a physical delivery of electrical energy to consumers. The model of electricity market usually has three sectors of electricity trade:

- Long - term bilateral agreements;
- Day – ahead market;
- Balancing market.

In the market of long - term bilateral agreements, the trade is implemented according to regulated agreements and free bilateral agreements between producers and consumers.

Federal Antimonopoly Service establishes tariffs for electricity in the sector of regulated agreements. The volumes of energy, which are not contracted by regulated agreements, are sold at free prices in the frameworks of free bilateral agreements or in a day-ahead market. In the framework of free bilateral agreements, market participants determine contractors, prices and delivery volumes. Electricity market is organized a day ahead the physical delivery of electricity. The basis of the day-ahead market is competitive selection of price bids, which is conducted by Administrator of the Trading System (ATS). In case of deviation from planed volumes of supply, the participants buy or sell power in the balancing market.

Fig.2. Price and non-price zones of the wholesale market in Russia. Number one on the figure means the first price zone, number two is the second price zone, number three is the first non-price zone, number four is the second non-price zone and number five is the isolated zone.

The wholesale electricity and capacity market in Russia is divided into two price zones:

- European part of Russia and Ural;
- Siberia.

The territories of the Russian Federation, where the functioning of the wholesale market is impossible due to different reasons, are related to non-price zones (Archangelsk region, Kaliningrad region, Komi republic are included in the first non-price zone and energy system of the East on the territory of the Far East are included in the second non-price zone). The electricity trade on the territory of non-price zones are implemented based on the regulated prices and has some specific features, for example, the model of single buyer. There are some territories in Russian Federation, where the wholesale market is absent, they are called isolated territories. Such territories as Kamchatka, Sakhalin, Sakha Republic (excluding South-Yakutsk energy region), Chukchi Autonomous Area, Norilsk-Taimyr, Magadan region are related to isolated territories. Energy companies are not separated according to business spheres in those territories and organized to joint stock companies.

3.2.1. Day-ahead market

On the day-ahead market, volumes of planned hourly production and consumption are bought or sold with regards to volumes of the regulated agreements. On the day-ahead market the trade is implemented at price, which is established under influence of demand and supply. Equilibrium price of electrical energy is determined on the basis of price bids, which was made by suppliers and buyers in the price zone with considering power flows to the other zone.

The conduction of the competitive bids and determining of planned production and consumption by market participants includes three stages. On the first stage, Administrator of the Trading System gets from the System Operator actual calculated data on the energy system, including the scheme, state of working equipment, limitations and other parameters. On the second stage, suppliers submit their price bids for every hour of the operating day. It is allowed to submit bids without price, in that case suppliers agree to sell energy at the established price as result of competitive bids price.

Buyers also submit bids for every hour of operating day. The bids reflect their readiness to buy electrical energy at the price and volume specified in the bids. Administrator of the Trading System, based on obtained from System Operator data and bids of market participants, defines for every price zone hourly equilibrium prices and volumes of generated and consumed energy, forming the new trade schedule. The equilibrium price is defined by maximum price offer of power plant to meet the forecasted demand.

On the third stage, the Administrator of the Trading System sends formed trade schedule to the System Operator for maintenance of energy system regime. In case if after the competitive selection part or the whole volume of planned production (consumption) was not included in the trade schedule, the participants can limit the production (consumption) on the level of the trade schedule or generate (consume) deficient volume on the balancing market.

3.2.2. Balancing market

Balancing market represents market of deviations from actual hourly production and consumption of energy from planned trade schedule and intended to provide balance of generation and consumption in real time. Generators, who decreased production at their own initiative and consumers, who increased load, have to give extra payment. On the balancing market suppliers submit bids to the System Operator for the load (deviation "up") and unload (deviation "down") of their capacities comparing with planned volumes, which were formed on the day-ahead market. In case of imbalance in energy system, System Operator increases production of electrical energy or limit load for consumers-regulators, starting with those, who established the lowest price in the bids.

3.2.3. Capacity market

Capacity is a special product, i.e. investors get paid for support of generating equipment in the state of readiness for electricity production. Capacity market is needed to guarantee adequate long-term revenues for generators. Functioning of market mechanisms increases investment attractiveness of building and exploitation of power production plants.

The purpose of capacity market introduction is a creation of advantageous conditions for attracting investments in the power sector to ensure sufficient capacity to meet forecasted peak demand plus reserve. The selection is conducted by the System Operator based on competitive bids selection. Suppliers, which were chosen as result of competitive selection, obtain the capacity payment.

Four years before the actual delivery, System operator organizes the Competitive Capacity Auctions. System Operator estimates, how much capacity will be needed to ensure the reliability and security of the system. Consumers of electricity do not participate in the competitive selection bids. Generating companies, which were chosen by System operator, have to fulfill their obligations guaranteeing that their generating equipment is constructed to produce the amount of capacity they obliged to supply. Furthermore, they have to prove that their equipment corresponds to the technical requirements, which were represented in price bids (Boute, 2013).

For new generation (commissioned after 2007), the capacity compensations depend on the type of generation and agreements with the government. For instance, new thermal power plants that have been commissioned after 2007 may operate under Capacity Delivery Agreements (CDAs) that guarantee a specific return on investment for 15 years. New nuclear and hydro power plants, on the other hand, have Long-Term Agreements (LTAs) where the return on investments is guaranteed for 20 years. New generation that is not included in a CDA or LTA participates in the Competitive Capacity Auctions (Gore, et al., 2011)

3.2.4. The wholesale market participants

The main participants on the wholesale market are

- Suppliers of electrical energy and capacity (generating companies or organizations, which have a right to sell electrical energy (capacity), which was generated on the equipment; and companies, which implement operations of export and import);
- Buyers of electrical energy and capacity, which have got the status of the wholesale market subjects and the right to participate in the trade of electrical energy (capacity) on the wholesale market:
    - Retailer companies;
    - Large consumers of electrical energy (capacity);
    - Guaranteeing suppliers;
    - Organizations, which implement operations of export/import.
- Commercial operator and other organizations, which provide the functioning of the commercial infrastructure of the wholesale market according to the wholesale market rules;

- Organizations, which provide functioning the technological infrastructure of the wholesale market (organizations for controlling united national electrical grid and System Operator);

3.3. Infrastructure companies and organizations

3.3.1. System operator

Open Joint Stock Company "System operator of the United Energy system: implements centralized dispatching and control of Russian energy system. In the process of the activity System Operator solves three main problems (Minenergo, 2017):

- Management of technological modes of operation in real time;
- Provision of the perspective development of the UES;
- Provision of unity and effective work of technological mechanisms in wholesale and retail market of electricity and capacity.

3.3.2. ATS

Joint Stock Company ATS is subsidiary body of non-commercial partnership Market Council. ATS conducts trades and provides settlements between producers and buyers of electricity. For the present time, it is leading organizer of trade on the wholesale market of electricity and capacity in Russia. The main goal of the company is a provision of reliable and transparent functioning of Russian wholesale market of electricity and capacity. Main activities of company are (ATS, 2016):

- Registration of bilateral contracts for the purchase and sale of electricity and capacity;
- Organization of a system for measuring and collecting information on the actual production of electricity and power and their consumption in the wholesale market;
- Interaction with organizations of technological infrastructure for forecasting the volume of production and consumption of electric energy, maintaining the parameters of the quality of electric energy established by technical regulations, stability and reliability of energy supply;
- Development, implementation and maintenance of software and information systems that support the implementation by the company;

- Provision of information and consulting services.

3.3.3. Association NP Market Council

Association Non-commercial partnership Market Council for effective organization of wholesale and retail trade of electricity and capacity organize functioning and control of the wholesale and retail markets. Priority areas of NP Market Council activities are (NP Market Council, 2016):

- Functioning organization of the wholesale and retail capacity markets;
- Control over the participants of the electricity and capacity markets, commercial and technological infrastructure, as well as regulation of disputes between the wholesale market participants;
- Analytical support for more effective decision making by the market participants and bodies of government administration.

The Federal law on the 4th of November 2007 № 250 "About alteration in separate legislative acts of Russian Federation connected with reforming of the Untied Energy System" established the specific features of legal status for commercial infrastructure of the wholesale market, including the fact, that on the 1st of April 2008 the functions of the market council were laid upon non-commercial partnership ATS (NP Market Council, 2016).

NP Market council is summoned to unite buyers and sellers of electric energy (capacity) on the basis of membership. They can be subjects of the wholesale market; participants of power exchange in the wholesale market; organizations, which provides functioning of commercial and technological infrastructure in the wholesale market and other organizations, which realize activity in the sphere of electric power industry.

3.4. Electric grids companies

3.4.1. Rosseti

Public Joint-Stock Company, Russian grids, (PAO Rosseti) is an operator of grids in Russia and one of the largest grid companies all over the world. The company control 2.29 millions km of power lines, 480 thousands substations with transformer capacity more than 751 GVA. In 2014, supply of electricity to customers was 715 billion kWh (Rosseti, 2016).

Property complex of Rosseti includes 37 affiliated companies and dependent society, including 14 interregional and trunk grid companies. The controlling shareholder is the state, represented by the Federal agency for control of the state property of the Russian Federation. This organization owns 85.3 % share in the authorized capital.

PAO Rosseti is a leading company in the Russian market concerning introduction of innovation technologies in trunk and distribution grid complex. The company pays great attention to the issues of energy savings, energy efficiency, international cooperation, environment protection and occupational safety and health.

Fig. 3. Subsidiary companies of Rosseti (Rosseti, 2016)

3.4.2. OAO FSK UES

Open Joint Stock Company Federal Grid Company of the United Energy System ("FSK EES" in Russian abbreviation) was created in accordance with the program of energy sector reforming as organization for control of the united national grid (ENES in Russian abbreviation) with the purpose of its maintenance and development.

According to the government of Russian Federation from the 11th of July 2001 "About reforming of power sector in the Russian Federation", the united power system of Russia was admitted "nationwide property and guarantee of energy safe" of the state (Government of Russian Federation, 2001).

The main part is united grid, including the system of trunk power lines, which connects majority of Russian regions and represents one of the main elements of guaranteeing the integrity of the state. FSK UES was created for its maintenance and reinforcement, provision of the unity for technological control and government policy realization in power industry. The property of PAO Rosseti include 80.13% shares of PAO FSK UES, 19.28% shares are in the property of minority shareholders, 0.59% of shares are the property of Russian Federation (FSK UES, 2017).

3.4.3. PAO MRSK

Public Joint Stock Company MRSK is subsidiary company of Rosseti (50.2% shares). Company implement transmission of electricity through 0.4 – 110 kV electrical grids and provide technological connection of customers to electrical grids. The company is divided on to eight parts: MRSK Volga, MRSK South, MRSK Siberia, MRSK Center, MRSK North-West, MRSK Center and the Volga region, MRSK Ural and MRSK North Caucasus (Rosseti, 2016). The companies implement their activities on the territory of different regions.

3.5. The largest generating companies

3.5.1. PAO Inter RAO UES

Inter RAO group is an energy holding, which controls energy production assets in Russia as well as in Europe, and in the Commonwealth of Independent States (CIS). Inter RAO is the only Russian operator of power export and import.

Activity of Inter RAO group includes:

- Generation of power and heat;
- Supply of energy;

- International energy trading;
- Engineering and export of equipment;
- Management of distribution grids outside of the Russian Federation.

Installed capacity of Inter RAO on the 01.01.2016 was 35 GW. The volume of output, according to the results of 2015, was 141 billion kWh (Inter RAO, 2017). Generating assets of Inter RAO are

- 40 thermal power plants and 6 generating plants of small capacity;
- 12 hydroelectric power stations (including 7 small hydro stations);
- 2 wind farms.

3.5.2. AO Concern Rosenergoatom

Rosenergoatom is the only company in Russia, which fulfill the function of nuclear power plants operator. Rosenergoatom includes all 10 of Russian nuclear power plants, which endowed the status of concern branches, and also enterprises, which ensure the activities of generating company. 10 nuclear power plants consist of 35 power units (18 power units with pressurized water type reactor (PWR), among them 12 power units PWR – 1000 and 6 power units are PWR – 440 of different modifications). 15 power units with channel type reactor (11 power units with high power channel type reactor (RBMK in Russian abbreviation) – 1000, four units with energy heterogeneous loop reactor (EGP in Russian abbreviation) – 6 reactor); 2 power units with sodium cooled fast reactor (SFR – 600 and SFR - 800). Total installed capacity of nuclear plants is 26.2 GW (AO Concern Rosenrgoatom, 2017).

3.5.3. PAO RusHydro

RusHydro is a leader in electricity generation based on renewable sources of energy; power production is based on water flow energy, sea tides, wind and geothermal energy. Total installed capacity of RusHydro is 38.6 GW, including capacities of PAO Energy Systems of the East and also the newest and modern hydro power plant in Russia – the Boguchany Dam. It has an installed capacity of 2 997 MW (PAO RusHydro, 2017).

Considering the largest plant in Russia – the Sayano-Shushenskaya Dam, the company unites more than 70 objects of renewable power industry, including 9 power station of the

Volga-Kama Dam cascade with installed capacity more than 10 273 MW, the first Dam on the Far East - the Zeiskaya Dam (1 330 MW), the Bureyskaya Dam (2 010 MW), the Novosibirsk Dam (460 MW) and several dams on the North Caucasus. Furthermore, RusHydro includes geothermal power plants on the Kamchatka and highly-maneuverable capacity of the Zagorsk Pumped Storage Station in Moscow region, which is used for the alignment of daily unevenness of the electricity load curve in the Central region.

3.5.4. Gaspromenergoholding

GazpromEnergoholding is a vertically integrated company (100% daughter company of PAO Gasprom). It controls the generating companies of Gasprom Group according to the united corporative standards. Gasprom Energoholding is one of the largest shareholders in such assets as PAO Mosenergo, PAO MOEK. Territorial Generating company number 1 (TGC – 1) and Wholesale Generating Company number 2 (WGC – 2) belong to Gasprom. Total installed capacity of the company is 38 GW (17% of total capacity of Russian power industry) (Gaspromenergoholding, 2017).

3.5.5. Eon Russia

E.ON Company is the largest international investor to Russian power industry. Total investment of the concern to Russian power industry before 2005 was 6.1 billion euro (E.ON Russia, 2016). EON Russia has an intention to become the active player on the market of distributed generation, and also it develops projects on the basis of renewable sources of energy. Main shareholder of the company – concern E.ON – takes leading places in the renewable energy sector in the whole world. E.ON is engaged in the building and maintenance of the wind farm and solar station, and also power station, which utilizes biofuel. As a result of program for constructing new capacities and modernization, the total installed capacity of the E.ON group in Russia is 11.145 GW.

3.5.6. Enel Russia

An Italian company, Enel, is one of the largest energy companies in the whole world, has been operating in Russia since 2004. The most important step in the strategy of activity extension in Russia became an acquisition of WGC – 5 (Enel Russia in present time). The company owns 4 power stations with total capacity of 9.5 GW (Enel Russia, 2017).

3.5.7. OAO Fortum

Fortum realizes activity for generation and supply of electricity and heat in Russia. Eight power stations of the company are located in Ural and in Western Siberia. The total installed capacity of power plants is 4 512 MW and heat production assets is 9 920 MW. Investment program for construction of 2 400 MW capacities was finished in 2016. Input of new power units provided increase in amount of installed capacity almost twice since 2008. The share of Fortum in OAO TGC - 1 is 29.5% (Fortum, 2017).

3.5.8. PAO Quadra

Quadra is one of the largest TGC, which was created after the reforming of RAO UES and registered on the 20th April 2005 (before the 18th of May 2010 company was called OAO TGC - 4). The main activities of PAO Quadra are generation and realization of electricity in the wholesale market of electricity and capacity, and also generation, transportation and realization of the heat energy in the retail market. The company supplies heat energy for 25% of consumer in the territory of the Center federal region. The company includes 20 power stations, 248 boiler stations and also heating network with total extension 4 970.4 km. Total installed capacity of electricity generation is 2 862.2 MW and heat generation – 15 653.9 MW (PAO Quadra, 2017).

The number of the wholesale market participants changes every year. For example, in the 01.01.2017, the register of the wholesale market subjects included following organizations (NP Market Council, 2017):

- 92 generating organizations;
- 100 guaranteeing suppliers;
- 115 retailer organizations;
- 26 large consumers;
- 1 organization with import/export functions (PAO InterRAO UES);
- 4 infrastructure organizations (AO System Operator UES, PAO FSK UES, NP Market Council, AO ATS)

For comparison, in the 01.01.2012, 134 guaranteeing suppliers, 113 large consumers and 113 generating organizations were included in the register.

3.6. Retail market

Electricity, which was bought on the wholesale market, can be sold in the frameworks of retail market. Following subjects are allowed to implement their activities (participants of the electricity in the retail market) (Government of Russian Federation, 2012):

- Consumers of electrical energy;
- Executors of public services (they buy electrical energy for further sell it to population, i.e. providing public services);
- Guaranteeing supplier;
- Independent supplier organizations;
- Generating companies, which have not status of wholesale market subject or lost this status for some reasons;
- Net services and also infrastructure owners;
- System Operator.

Producers of electrical energy, independently from amount of capacity, are allowed to sell electricity in the retail market, if they should not sell all energy in the wholesale market. Such producers are called producers of electrical energy for the retail market. These producers are allowed to sell generated energy to consumers, which are located in the same subject of Russian Federation as the producer of energy.

3.6.1. Price formation on the retail electricity market

Consumers, which are related to population category, buy energy at regulated tariffs. The rest categories buy electricity day-ahead:

- In price zones (majority subjects of the Russian Federation) – sale is implemented at non-regulated prices;
- Non-price zone – sale is implemented at regulated prices.

In the retail market's price zones, guaranteeing suppliers implement sale of electricity at non-regulated prices (excluding population), but not higher than limited level of non-regulated prices (Government of Russian Federation, 2012).

Regulated prices are established on the basis of forecast for social-economic development of the Russian Federation for a year. This forecast is developed by the Ministry of

Economic Development and should be also approved by the Government of Russian Federation.

Federal tariff service for every subject of Russian Federation establishes range of the regulated tariffs for consumers, which are related to population category. In the framework of range, local authority in the sphere of government tariff regulation established tariffs for specific region. Also regional tariff services establish tariff for power transmission services, in this case calculations are accomplished with grid companies. The prices, which are calculated by supplier companies, are also regulated.

3.6.2. Price formation in non-price zones

The regulated prices for non-price zones are established according to planned values of consumption in the region, which were affirmed for the whole next year in the document "Consolidated forecast balance of production and supply of electricity within united energy system" (Government of Russian Federation, 2012). The System Operator is guided by principles of cost minimization for energy generation. It is the reason, why the System Operator sets the schedule of production which does not match with consolidated forecast and actual consumption does not match planned.

The purchase of deficient volumes is occurred at non-regulated prices for electricity. Due to that guaranteeing supplier has an additive obligation for generating companies concerning payment for purchased energy. They are not covered by consumers at regulated prices. These components are distributed to all consumers of electricity in non-price zones additionally to costs of electricity, which were presented to consumers at regulated prices.

Furthermore, planning for hourly consumption is mandatory for customers with maximum capacity more than 670 kW. Due to that in case of deviations in planned consumption from actual one, such consumers have to pay the deviation costs, which are defined by guaranteeing supplier in the wholesale market. If consumer plans is accurate, the costs of such deviations are not high. Consumers with capacity less than 750 kVa do not plan their hourly consumption.

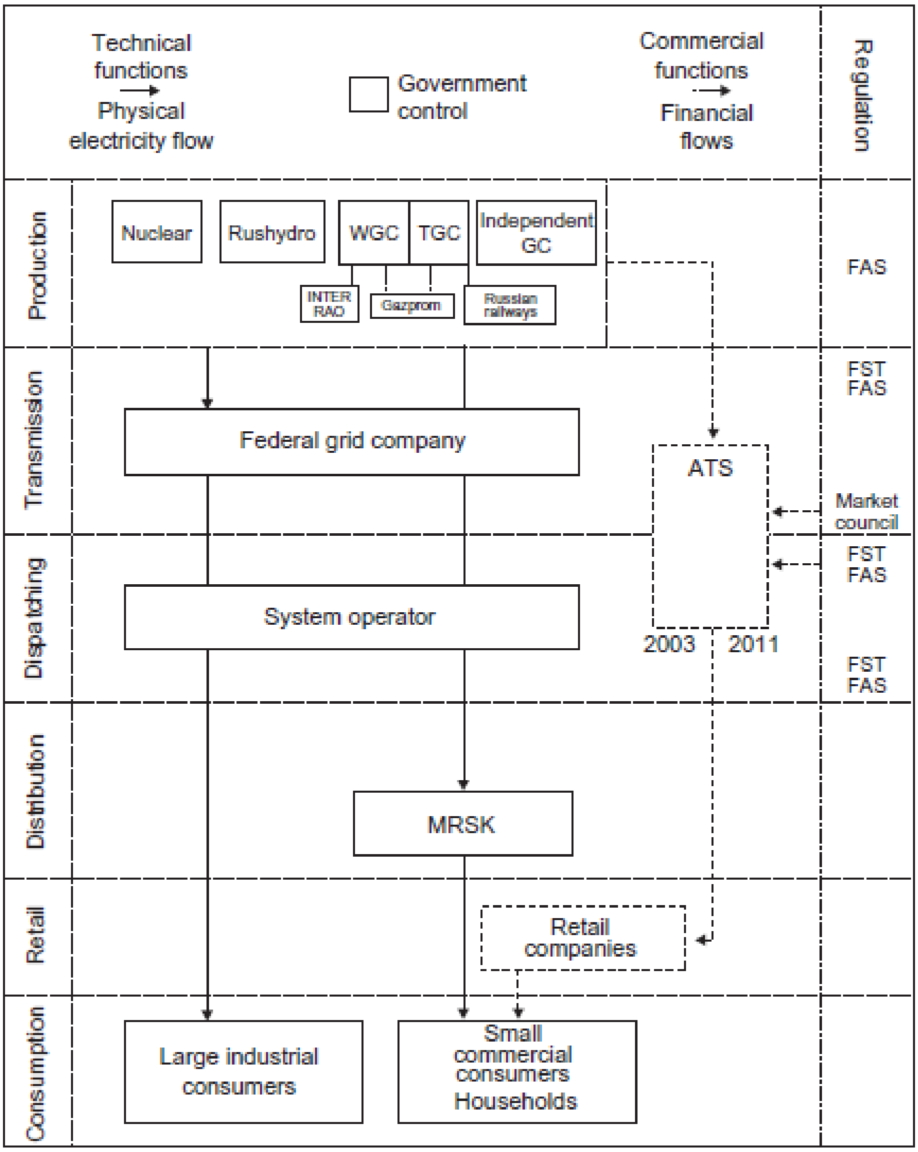

Fig. 4. The new corporate structure of the Russian electricity sector (Boute, 2013)

4. Electricity tariff formation

Federal Antimonopoly Service in Russia establishes limits for electricity tariffs: maximum and minimum values. Power engineers count expenses and submit the values to the Committee of prices and tariffs (every region has its own Committee) (Federal Antimonopoly Service, 2015). The commission consists of representatives of the government. Reasonability of these values is estimated there and price for electricity (id est tariff) is established.

The tariff includes three main parts: generation costs, transmission and distribution, suppliers' surcharge. Suppliers buy electricity from the generators, pay for the transportation and sell it to the customers. Suppliers' surcharge is essential for suppliers companies work. The amount of surcharge is also established by the local Committee. The Committee of tariffs in the end of the year publishes tariffs. They publish balance indicators of electricity supply planned volume, which were implemented in calculations of tariff, in the same document.

Tariff increases every half of the year. Tariffs are different for residential consumers, living in rural areas, and for people living in cities and they also consider the type of stove in the home: gas or electric. The growth of tariffs is important for decreasing the amount of cross-subsidization. Different factors may also influence on the growth, for example, increase of gas prices, salary, input of investment part into tariffs or change in tax law. The fact of ineffective management in the companies, which are engaged in generation and transportation of energy, also plays role in the tariff growth (AO Korolev electricity grids, 2016).

4.1. The categories of tariffs

From the first January of 2012 such notion as price category was implemented (Government of Russian Federation, 2012). There are six price categories for consumers of energy in Russia. The consumer is allowed to choose one price category, then the accounting will be implemented according to its specific features.

First category offers calculations, which is defined according to consumption values for the whole month. If consumer have not notified about willingness to change the tariff, the calculations will be done in first category automatically.

Second category includes differentiation according to a daytime, after that all data are summarized. There are two type of this tariff, one considers two time zones: night and day; other considers three zones: peak, half-peak and night time. The companies with prevailing night time work are characterized to this category, as the energy is much cheaper during night time according to the tariff. The metering devices are also supposed to be established for taking accurate data of consumption and especially time of electricity consuming.

Other price categories include calculations not only for energy, but also for a capacity, that fact makes them different form the first and the second price categories. For the third category the electricity costs are defined separately for every hour of a day (they include the part of transportation costs) and after that they are summarized together with capacity price.

The forth category contains the calculations of electricity costs for every hour, partial payment for transportation, capacity payment in the wholesale market and transmission capacity, and transmission cost according to power consumed.

The fifth category is similar to the third but with the great difference in obligatory condition to plan electricity consumption one month ahead for every hour and to inform about it the supplier. Factual consumption is calculated first, and after that the deviation is calculated. The sixth category is similar to the forth one, the difference is in planning and reporting data to supplier like in previous case.

To change the price category, consumers have to compose and send notification to supplier, who is able to change price category. This operation should be done in 10 days before the beginning of next counting period. The system of price formation in the wholesale market is connected to costs of electricity purchase. For the consumers of the first category, the level of free prices depends on maximum capacity of electrical devices and also on level of their voltage (Energylogia, 2016).

If consumer would like to change the price category, he should pay attention to following criteria. First, seasonality of consumption, i.e. graphs of consumption are identical in the summer and winter period or not. If such phenomenon as seasonality is present and the graph is not uniform, it might be necessary to account for all seasons according to different price categories and compare them to find out, which could benefit more.

Second, a daily profile of consumption also influences the price category choice. For example, in case of prevailing night time job, the second price category would be the best option. Third, it is necessary to consider tariff for transmission service. In case of changing this tariff the proper analysis should be conducted to find more beneficial option.

The enterprises with maximum capacity more than 670 kW are allowed to choose only between the third – sixth prices categories. Hence, in case of choosing fifth-sixth prices categories it is necessary to estimate possibility of accurate hourly planning. Savings could be done due to deviation minimization of realized volume from planned volume of consumption. The households are related to the first and the second price categories.

The last criterion is an establishment of metering devices to take hourly data of consumption, especially in tariff considering different day time. The consumer should pay attention to installation costs and operation costs.

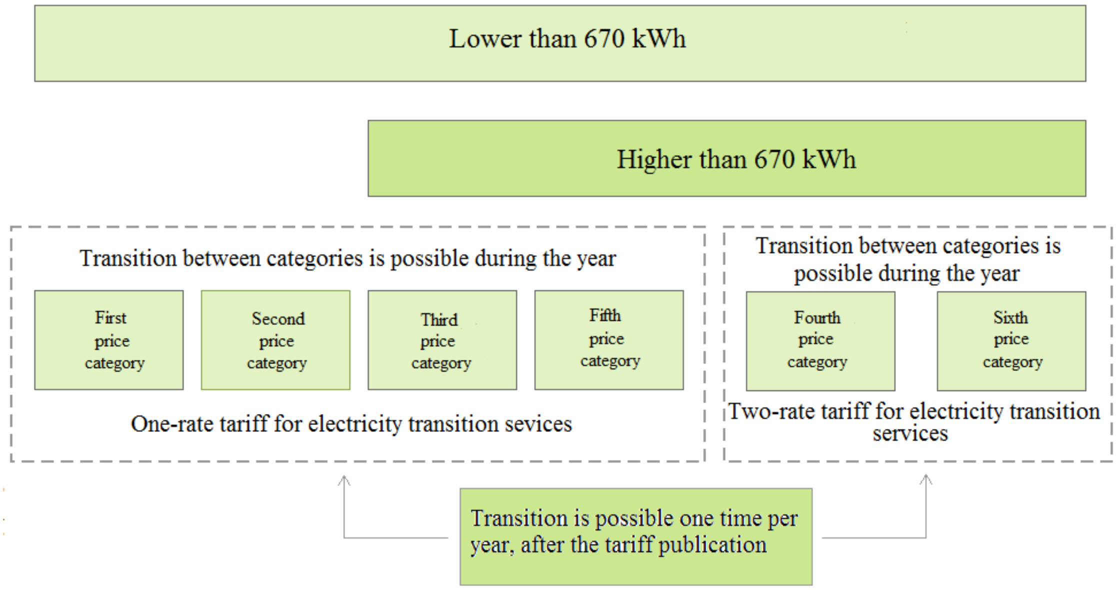

Fig. 5. Price categories of electricity market (EnergoMart, 2016)

4.2. Guaranteeing supplier

Guaranteeing supplier of electricity is a commercial organization which is obliged to enter into contract purchase and sale of electric energy with every consumer or with the representative, which acts in the interest of consumer and wish to buy electric energy

(Government of Russian Federation, 2003). The status of guaranteeing supplier is spread over defined territory according to the registry (Federal Tariff Service, 2015).

The status of guaranteeing supplier means, that consumer can not be in situation, when all independent supplier companies will refuse to conclude a contract with this customer. Contracts, which are concluded between consumers and guaranteeing supplier, are public, that means the conditions of these contracts (for example, price formation) are regulated by the government of the Russian Federation.

Every guaranteeing supplier works in established zone of activity. Out of this zone, guaranteeing supplier is allowed to work as independent supplier company. The boundary of activity area of different guaranteeing suppliers does not intersect. These boundaries are established by local executive bodies in the sphere of tariff regulation. Independent suppliers are not obliged to conclude contract with every consumer and, as a rule, conclude contracts only with large consumers, which are advantageous to service.

Guaranteeing suppliers and independent suppliers are allowed to conclude with consumers following types of contracts (Government of Russian Federation, 2012):

- The contract for buying and selling electricity. According to conditions of this contract, consumer should himself regulate infrastructure issues with grid services organizations concerning electricity transmission services. In this case, consumer should conclude contract with grid organization separately.
- The supply contract. In this contract, supplier regulates issues concerning energy transmission or distribution himself. In this case, supplier concludes contract for power transmission with grid companies.

The activity of guaranteeing supplier is regulated by authorized regional authority and the Federal Antimonopoly Service. The competence of regulators includes tariffs approval and guaranteeing supplier surcharge, control over observance of financial coefficients and conditions of activity implementation.

Guaranteeing supplier buys electrical energy and capacity in the wholesale and retail markets, signs contract with grid companies within their area of activity and also the signs contract for payment of grid companies losses. Suppliers sell electricity and capacity to end-users according to electricity supply contract. They implement accounting of consumption and billing, fund-raising and collection of indebtedness. Also many guaranteeing suppliers are engaged in other forms of activities, for example, sell, installment and service of metering devices, realization of electro technical goods, receiving of payments from another organizations (communal payments), conduction of energy audit etc.

According to standards of information disclosure by subject of the wholesale and retail market of electricity, which were approved by the Government of Russian Federation on the 21 of January 2004, every subject of electricity market have to disclose the information about its activity, for example, the volumes of purchased capacity in the wholesale and retail markets (Government of Russian Federation, 2004). Hence, on the website of guaranteeing supplier it is possible to find all necessary information concerning tariff and price formation for every region of the country. The tariff for customers consists of different part, including regulated part (payment for infrastructure organization services), free part (payment for energy, which was bought in the wholesale market), supplier surcharge etc. These components are considered in detail in the following parts.

4.2.1. Regulated part of tariff

This part considers different type of electrical energy (capacity) consumers. The rate is differentiated according to diapasons of voltage: High Voltage (HV), Medium Voltage - 1 (MV-1), Medium Voltage -2 (MV - 2) and Low Voltage (LV). This part includes rate for electric energy transmission, electric grids maintenance, rate for technological losses (in electric grids) payment and also rate for cross-subsidization.

Regulated part of tariff includes payment for other services, besides costs of purchased electricity or capacity and expenses for electricity transmission, but the provision of these services is essential for electricity supply for consumers. Table 3 is given as example of such services and their prices.

Table 3. The tariff for provision of other services (Petersburg Electricity Supplier, 2016)

Regulated organization	Nomination of service	Time period	Rate, rub/MWh	Decision of authorized body
OAO "ATS"	Services of commercial operator provided by OAO "ATS" to subjects of the wholesale electricity (capacity)market	01.01.2016 - 30.06.2016 01.07.2016 - 31.12.2016	1,103 1,110	Order of Federal Antimonopoly Service on 28.12.2015 №1349/15
OAO "System operator of United Energy System "	Services of operational dispatch control in electric power industry in the part of providing operational reliability by the way of selection performers organization and payment of services for ensuring system reliability, services for provision of solving emergency situations and services for formation of technological capacity reserves	01.01.2016 - 30.06.2016 01.07.2016 - 31.12.2016	1,639 1,639	Order of Federal Antimonopoly Service on 25.12.2015 №1348/15
AO "Center of Financial Accounting"	Comprehensive service for accounting of requirements and obligations of wholesale and retail market participants	01.01.2016 - 30.06.2016 01.07.2016 - 31.12.2016	0,310 0,318	Decision of Association NP "Market Council" On 19 of March 2015

4.2.2. Free prices

Free prices are prices which were formed directly in the wholesale market. Free prices consist of electricity (capacity) purchase costs. Every month supplier publishes data concerning purchasing in the wholesale market:

1) Differentiated by time zone and weighted average non-regulated prices ;
2) Weighted average prices for capacity;
3) The volume of electrical energy, purchased by participant of electrical market at regulated prices;
4) The volume of electrical energy, purchased according to results of competitive selection of bids at the day-ahead market;
5) Differentiated by hours non-regulated price for electrical energy, determined by results of competitive selection of price bids at the day-ahead market and for balancing system;
6) Differentiated by hour non-regulated price for electrical energy, determined by results of competitive selection of price bids for exceeded volume of fact consumption over planned one and for exceeded volume planned consumption over realized one.

4.2.3. Limited level of non-regulated prices

The level is defined for every price category. For the first category, limited level is defined by maximum capacity of energy receiving devices (lower than 150kW or from 150 kW to 670 kW) and by the level of voltage (HV, MV-1, MV-2, LV). For the second price category, level is defined according to a day time, type of tariff (for two- or three-zones), capacity of energy receiving devices and the level of voltage. The level of the third price zone is differentiated according to capacity of devices, voltage and hour of the day, but also the rate for capacity, purchased by consumer, is added to calculations. The only difference in limited level price calculations between the third and fourth categories is addition rate for grid services. In the fifth there is no rate for grid services, but there is rate for sum of planned hourly purchases and the rate for absolute amount of difference between realized and planned amount of purchase (this rate also included into the sixth price category calculations) (Government of Russian Federation, 2012).

Calculation of the price limited level contains many data, among them:

1) Weighted average non-regulated price for electrical energy in the wholesale market;
2) Weighted average non-regulated price for capacity in the wholesale market;
3) The coefficient of payment for capacity by consumers, included in first price category calculations;
4) The volume of fact peak consumption of guaranteeing supplier in the wholesale market;
5) The amount of capacity corresponding to purchase of electrical energy by guaranteeing supplier in the retail market;
6) The sum of capacity amounts, paid in the retail market by consumers, included in second-sixth price category calculations;
7) The volume of capacity consumption by residential consumers and equal category of population;
8) The volume of consumption by second price category consumers;
9) Actual amount of consumption by guaranteeing supplier in the wholesale market;
10) The volume of purchased electrical energy by guaranteeing supplier in the retail market;
11) The sum of consumption volumes for second-sixth price categories;
12) The volume of electrical energy consumption by residential customers and equal category of population.

4.2.4. Supplier surcharge

The surcharge is essential for work of supplier. The amount of surcharge is established by Federal Antimonopoly Service for every guaranteeing supplier in the local area. Surcharge differs for every supplier. For example, in Table 4 are given data for guaranteeing suppliers in Saint-Petersburg for 2016. However, the company "Oboronenergosbyt" lost the status of guaranteeing supplier in the 23th of December 2016 by the order of Ministry of Energy in Russia due to elimination of this company from the register of the wholesale market subjects (Oboronenergosbyt, 2016).

Table 4. Examples of supplier surcharge for all guaranteeing supplier in Leningrad region (Petersburg Supplier Company, 2016)

Name of guaranteeing supplier	Supplier surcharge for residential customers and equal type of population, rub/kWh		Supplier surcharge for tariff type “grid organizations buying electrical energy to compensate energy losses”, rub/kWh	
	1 half-year	2 half-year	1 half-year	2 half-year
“Petersburg Supplier Company ”	0.39	0.36	0.28	0.08
“Rusenergosbyt”	0.05	0.07	0.05	0.05
“Oboronenergosbyt”	0.25	0.15	0.07	0.08

Table 4 shows that supplier surcharge is not necessarily increasing in the second half-year, in contradistinction to electricity tariff. Supplier surcharges for consumers of all price categories, excluding categories residential customers and grid organizations, are established in the formula. It includes prices for electricity and capacity in the area of guaranteeing supplier, profitability of services and coefficient. The coefficient expresses the influence of regional parameters of supplier activity to amount of supplier surcharge (Petersburg Supplier Company, 2016). All data are calculated according to the methodical instructions affirmed by the Federal Antimonopoly Service order.

4.2.5. Reasons for supply limitation

The government decree from 04.05.2012 №442 (Government of Russian Federation, 2012) gives information about functioning of the retail market, including possibilities to limit energy supply in different cases. People in Russia often do not know their rights and responsibilities, thus limitation of energy supply become unexpected event for them. The smart metering system could give information about bills and indebtedness. In the case of non-fulfillment or inappropriate fulfillment of payment obligations, including preliminary payment according to the contract guaranteeing supplier can limit the provision of services. However, this measure can be implemented if amount of indebtedness increased more than for one period between the established term of payment and for residential customers – more than 2 calculated periods or more than amount, which was specified in the contract.

If guaranteeing supplier revealed fact of indebtedness, the electricity could be limited only observing next conditions:

1) Initiator of limitation should send the notification about necessity of energy consumption limitation not later, than 10 days before disconnection;
2) Initiator should specify the name of consumer and description of the supply point, for which limitation is going to be implemented;
3) The basis for limitation regime should be also specified;
4) The type of the limitation: full or partial (reduction of the consumption level), electricity supply termination during the defined hours or in full volume.
5) The terms of the limitation regime (in case of partial limitation - level).

5. Cross subsidization

One of the main problems in Russian power sector is a lack of marketing research and events concerning promotion of energy products and services. It is connected with the problem of cross subsidization in power sector. Cross subsidization occurs when prices are established higher than marginal costs for some part of consumers with the purpose of establishment lower than marginal costs prices for other part of consumers. Cross subsidization cannot be continuous in competitive markets because consumers can easily change the supplier to prevent overpaying for services. Cross subsidization distorts price proportions and works poorly as countervailing mechanism.

The first type is subsidization of electricity production at the expense of heat production at Combined Heat and Power Plant (CHPs). This is one of the most widely spread types of cross subsidization, which is implemented at CHP. This type of subsidization also includes transfer of expenses between base, half-base and peak load energy of generator.

The second type is a subsidization of electricity consumers at the expense of heat consumers. Qualified heat engineering calculations of primary fuel expenses shows that every consumer, who utilizes heat of exhaust steam of CHP, saves significant amount of fuel. Russia is a country with cold climate thus consumption of heat energy is intensive (10-12 times more comparing with electricity) (Bogdanov, 2009). This circumstance explains the fact, that habitants of town and villages, who consume heat from CHP, "provide" with cheap energy not only themselves, but also other habitants of the region. Technical calculations concerning fuel consumption show that transition from combined energy consumption toward separated leads to significant overspending of fuel in country (Bogdanov, 2009).

The third type is a subsidization of capacity reserves at the expense of electrical energy. This type of cross subsidization is implemented in transmission of electrical energy. Its amounts are included in costs of services of electrical grid companies, System Operator and ATS. It is difficult to measure the payments for such categories as reserve, guaranteeing of proper level of security and continuity of electricity supply. They are not distinguished as separate type of services due to lack of methodology approach concerning their determination and with the purpose of simplification of calculations. However, they are included as surcharge in the payment for transmission of electricity and capacity by the way of cross subsidization.

The fourth type is a subsidization of heat capacity at the expense of heat production. This type is determined by the lack of methodological approach for definition of expenses at provision of security and continuity of heat supply. The real cost of heat energy and capacity is distorted due to excluding of expenses for providing security in the form of transferring costs to other items of expenditure.

The fifth type is a subsidization of socially significant consumers. The social difference is in the basis of this type of subsidization. Population is subsidized at the expense of industrial and commercial customers. It can be implemented in the explicit form (tariff establishment) or implicit form. One of the examples of implicit form is an introduction of different tariffs for natural gas. Exemption tariff is established for population; for industrial customers the tariffs are higher.

The sixth type is a subsidization of distant consumers at the expense of consumers, who are located near to sources of energy. Considering electricity, it is subsidization of villages, summer cottages and rest zones, which are located relatively far from power supply sources (15-30 km). The most common form of cross subsidization in this case is an artificial unification of diverse sources in some kind of energy supply center, in other words, unification of ineffective sources with effective sources.

The seventh type is a subsidization of new consumers at the expense of “old” consumers. This type is implemented in the case of connection of new customers to electrical or heat energy systems. The eighth type is a subsidization of new and energy-saving technologies. Traditional suppliers of heat and electrical energy are subsidized the building of recycling plants, development of new technologies, including eco-friendly and green technologies (Bogdanov, 2009).

6. Cost-benefit analysis of smart meters

6.1. Possible benefits from using smart meters

6.1.1. Reduction in meter reading and operation costs

Operational costs play a major role in the estimation of benefits. However, due to lack of information about meter reading costs and operation costs, this benefit hardly can be calculated, despite of evident advantageous. In smart metering scenarios many operations can be implemented remotely, for example, change of tariff, connection and disconnection, programming and reading. However, there is such a problem, as a communication failure rate for smart metering devices; in this case local operations are required. Technical service is needed once per half-year to check the accuracy of measurement even if smart metering device work without problems.

Reduced billing costs are possible benefit due to more accurate consumption measurements. This benefit is referred to billing operations and not led to direct decreasing of billing. Actually, billing costs is difficult to estimated, perhaps, they are included in a tariff or in the supplier surcharge, but it would be wrong to equate supplier surcharge and billing costs, because they are not the same.

Reduced call centre or customer costs are related to reducing customers' claims, due to possibility remote billing. Actually, remote billing is not available for all customers. There are some categories of population, which have difficulties while using new technologies, for example, old people. In case of implementing new scenario, it would be easier for them to continue billing as usual. It should be added, that they constitute significant group of population. However, remote billing may become very useful option for people with disabilities.

6.1.2. Reduced operational and maintenance costs

These benefits are related to distribution operations and maintenance. They may include different components, for example, reduced rate of breakdowns or maintenance costs. Smart meters may benefit to Distribution System Operator (DSO) due to monitoring, real-time network information, possibility of breakdown reparation during less amount of time. Like in previous case, the net operations could be implemented remotely, thus, bringing benefits to Distribution System Operator. Costs may be reduced due to more accurate consumption planning that may result to better knowledge of power flow and distributions of charge in the grid.

6.1.3. Deferred distribution capacity investments

This benefit can be monetized only allowing assumption, that smart grids will decrease consumption, peak load to be precise, and, hence, investments into peak capacity will decrease at the same time. However, it is not considered that consumption may increase due to other factors, such as population growth or other social and economic factors.

The effect of consumption and peak load reduction would lead to a reduction in maximum installed capacity and, consequently, to deferment of investments. The procedure of monetizing depends on the accuracy of Smart Grid projected data of savings. The simplest formula may include investments due to assets remuneration and investments due to assets amortization. Annual DSO investments to support growing capacity may be found in annual financial reports. Deferred time and remuneration rate directly depends on the project.

Estimation of this benefit shall also include possible consumption growth, social factor and category of population, which can shift peak consumption to non-peak hours. Most likely, it would be residential customer and small commercial loadings. The calculation should include grids, where peak corresponds with general peak, for example, 9 p.m. The same idea might be used for calculation benefits for transmission capacity investment. Deferred generation capacity investments follow the same idea: possible consumption reduction, hence, peak load reduction, that provides demand side management to cope with supply variability. For the simple calculation, such values, as annual investments to support generation capacity and deferred time can be used.

6.1.4. Electricity technical losses

Technical losses, occurred due to electricity transmission, represent a significant problem of a modern power sector, especially in Russia, because of old equipment and weak capacity. Smart meters cannot benefit directly, however, they can provide cumulative effect of indirect benefits. The influence of effects and possibility to monetize them depends on different cases, type and state of power system, country, access to information etc.

In overall, such effects are related to this category as energy efficiency (again due to consumption reduction and demand side management), decreasing imbalance power due to more accurate planning, possibilities to consider micro-generation (distributed generation), voltage control etc. Development of micro-generation is a challenging task in Russia, due to lack of the government support and abundance of conventional resources. However, modern history gives example of micro-generation in Russia, but it is rather an exception.

Couple of years ago, one Russian businessman published his history about installation of solar panels on his house and connection of it to the common grid. (Ryzhikov, 2015) This person met several problems on his way such as lack of information about installation of solar panels in Russia, problem of energy storages and time. Simple process of considering the request about accession to the grids took around 6 months. Possibly, in the future this process will be done faster due to accumulation of experience. However, for accomplishing of it there should be a demand.

From the beginning of this year the government of Russia decided to support the development of microgeneration on the basis of renewable sources of energy (Government of Russian Federation, 2017). It might be the first step on the direction to distributed generation and transition to renewable sources of energy. Generating objects with established capacity of 15 kW are related to microgeneration. From the beginning, such projects will be implemented only for individual homes, because in individual home it is easier to maintain and to accumulate experience of renewables usage. The block flats are excluded from consideration, because it is challenging to transport energy just for one person but not for common usage.

Installation of bilateral meters is essential for supporting accounting of consumption for every hour of a day. However, the installation is accomplished at the expense of applier. The purchase of microgeneration product is obligatory for guaranteeing supplier. The price of purchase or selling is equal average non-regulated price on the wholesale market. Revenue of producer, which was obtained due to realization of extra energy, is not a subject for taxation.

6.1.5. CO2 emissions and fossil fuel usage

The smart metering could help to reduce greenhouse gas emissions due to more accurate planning, increasing of efficiency, reduction of technical losses etc. However, this benefit cannot be monetized in Russia, because there is no direct tax for greenhouse gas emissions. As country, which signed Paris Agreements, Russia considered implementation of the tax for CO_2 emissions, however, if it happens, it would mean immediate increase of tariffs for energy and possibility of bankruptcy for many companies, prevailing in metallurgy, oil and gas industry and even generation of electricity. For countries, which are specialized on the extraction and utilizing of fossil fuel, implementation of such tax threatens with negative economic consequences.

6.1.6. Calculation of payment for environment pollution

The policy regulation in the sphere of environment has specific features in Russia. The payment is regulated by the federal law "About environmental protection" from 10.01.2002, however, it was renewed repeatedly. The payment for environment harm should be transferred to the budget. According to the law on environment harm (Government of Russian Federation, 2002), Russian companies have to charge payments on their own, using

- Data, which reflect the amount of payment base related to contaminant substance (or waste);
- Rate, defined for environmental pollution payment;
- Coefficients, established legislatively.

After calculation of harm to ecology, made by every contaminant substance or waste, the company should sum all figures and get the final amount of payment, which have to be transferred to budget of the Russian Federation. The wastes are divided into hazard classes. The payment is based on substances and waste corresponds to their volume or mass, which got in environment. The amount of payment is determined by payer in the order of environment control. In estimation considering base, following parameters are counted (Government of Russian Federation, 2002):

- Standards for allowed contaminations;

- Standards for temporarily allowed contaminations, including emissions and droppings, which exceeds them (including emergency situations);
- Limits for contamination placing and their exceeding.

Standards of emissions should be estimated separately for every industrial object, which execute emissions. Industrial companies have to calculate amount of emissions by their own (or with expert involvement) and correlate them with standards. If generating company spends money for actions that may decrease harmful effect to ecology, this sum will be deducted from environmental pollution payments. The corresponding expenses should be confirmed by documents (Government of Russian Federation, 2015).

6.2. Costs

List of benefits and costs should be determined for every country-case. The data for European countries are represented in the Table 6. If benefit-cost ratio is less than one, it means smart metering have no financial benefits in this country case, for example, in Romania costs are 99€ per metering point and benefits are 77€. The main benefits are reduced meter reading costs and reduced commercial losses, the main costs are implementation and investment costs and costs for system maintenance and operation.

Table 6. Costs and benefits normalized by a number of metering point (European Commission, 2014).

Member States already completed roll-out	Costs per metering point	Benefit per metering point	Benefit-Cost ratio
Finland	€ 210	NA	NA
Italy	€ 94	€ 176	1.87
Sweden	€ 288	€ 323	1.12
Member states rolling out smart metering			
Austria	€ 590	€ 654	1.10
Denmark	€ 225	€ 233	1.03
Estonia	€ 155	€ 269	1.73
France	€ 135	NA	NA
Greece	€ 309	€ 436	1.41
Luxembourg	€ 142	€ 162	1.14
Malta	€ 77	NA	NA
Poland	€ 167	€ 177	1.06
Romania	€ 99	€ 77	0.77
Spain	NA	NA	NA
Member states rolling out smart metering in ELE and GAS jointly			
Ireland	€ 473	€ 551	1.16
Netherlands	€ 220	€ 270	1.23
United Kingdom – GB	€ 161	€ 377	2.34
Member States not-rolling out smart metering yet			
Belgium	NA	NA	NA
Czech Republic	€ 766	€ 499	0.65
Germany	€ 546	€ 493	0.90
Latvia	€ 302	€ 18	0.06
Lithuania	€ 123	€ 82	0.67
Portugal	€ 99	€ 202	2.04
Slovak Republic	€ 114	€ 118	1.04

Despite of many possible benefits of smart metering, the contribution should be determined for every country separately. Examples for some European countries are given in Table 7. The list of costs is similar for majority of countries; however, list of benefits differs a lot. The difficulties are a possibility to monetize these benefits due to lack of data in Russian case.

Table 7. Most significant cost and benefits, considered in Member States analyses (European Commission, 2014)

Country	Main benefits	Main costs
Austria	Energy savings – 55% Operational savings due to more efficient supplier switch procedure – 19% (indirect benefits to the consumers) Reduction of DSO associated meter reading cost – 9%	Operational costs (30%) Capital costs – smart meter, installation, communication infrastructure, IT system (26%) Supplier associated network balancing costs due to consumer behavior change (24%)
Czech Republic	Reduced electricity theft (53%) Peak load transmission (42%) Deferred generation capacity investments (5%)	Meter procurement (24%) Investment in ICT (10%) Operation costs of ICT – meter reading (9%)
DE	Energy savings (33%) Load shifting (15%) Avoided distribution grid investments (13%)	Investments in smart metering systems (meter, gateway, communication infrastructure) 30 % Communication costs (20%) IT costs (8%)
DK	Saved metering investment (29%) Increasing competition (21%) Energy savings (16%)	Capital costs (smart meter, installation, communication infrastructure, IT system) – 67% Tax distortions (8%) Operational costs (data collection and validation)

7. The model of monetizing benefits from smart meters implementation

7.1. Review and description of goals of the thesis

The idea of the thesis is to replace conventional meters with electronic devices using AMM standards. Leningrad region is considered as a study case in this work. The purpose of this work is to implement regional specific cost-benefit analysis to compare costs and benefits of smart metering project. There are some kinds of automatic meters in Russia, but they do not offer the same functionalities as smart meters. They only collect data of consumption and send to the central office for invoicing.

The purpose of the work is to change all metering system to a new one with the same technology and characteristics. All customers will have smart meters. It would be easier for operation and maintenance, and may be beneficial to different stakeholders of power system. Smart meters are the first step to a development of smart system.

Currently, bills are formed on the basis of metering data, reported by customers themselves. There are some ways to do it, for example, by phone, via SMS or online. If customer does not provide information in a proper time, the bill will be calculated according to average consumption or standards for consumption. There are also automatic meters, which are plugged to the accounting system. Customers, who own such meters, do not have to provide any information for billing.

The bills can be paid in the payment centers. In this case customer can find nearest center and go there. There is a possibility to pay for energy bills online. In this case customer has to define the meter readings. The negative size of such operation is a time for accomplishment of transaction. The payment takes 5 hours at the least. If the payment was not confirmed during 5 working days, only then customer are recommended to give notification.

It is possible to count for benefits of guaranteeing supplier. However, due to the lack of accurate data, it is necessary to assume some values. The earnings of guaranteeing supplier are represented in the equation (1):

$$GS = T_eQ_e-(P_eQ_e+P_mQ_{mpeak}+I) \qquad (1)$$

Where GS – guaranteeing supplier earnings;

T_e – tariff for residential customers;

Q_e – electricity, consumed by residential customers (load curve);

P_e – electricity price on the wholesale market;

P_m - price for peak capacity;

Q_{mpeak} – maximum amount of electricity consumption;

I – infrastructure payment.

The load curve is defined in all calculations, however, there is no accurate data concerning consumption of residential customers during the day. On the website of guaranteeing supplier, it is possible to find total consumption for the whole month with separate data for residential customers' consumption. Furthermore, on the website of ATS there are data concerning hourly consumption both industrial and residential customers in every region of Russian Federation (ATS, 2016). At the moment of calculation load curves of six months were available: October, November, December, January, February and March. According data from the guaranteeing supplier, represented in Table 8, the consumption of residential customers constitutes 22.4% from overall consumption. However, it should be also noticed that shape of peaks might be different.

Table 8. Aggregated consumption of three guaranteeing suppliers in Leningrad region during 2016 year (Oboronenergosbyt, 2016) (Rusenergosbyt, 2016) (Petroelectrosbyt, 2016).

2016 year	The actual consumption of electricity on the territory of Leningrad region		The ratio of residential customers consumption to total consumption
	Total, kWh	Residential customers, kWh	
January	1 005 462 368	217 661 600	0,217
February	845 368 219	201 772 385	0,240
March	894 197 035	194 895 436	0,218
April	763 484 004	167 319 305	0,219
May	677 771 278	159 023 214	0,235
June	692 765 408	176 638 274	0,255
July	701 359 508	148 843 914	0,212
August	723 485 114	154 141 453	0,213
September	745 860 383	158 729 331	0,213
October	857 992 533	178 612 312	0,208
November	906 485 718	190 799 508	0,211
December	901 848 532	226 720 894	0,251
Average			0,224

Analysis of load curve has shown that consumption increases rapidly during the evening hours and peak consumption is related to exactly the same hours. If it is possible to implement demand response tool, the peak capacity can be decreased. Even slight decrease of peak capacity means great savings for the guaranteeing supplier, because the price for 1 MW capacity is about 7 460 € per month (ATS, 2016).

Peak consumption in majority days is observed during the night hours (from 22 p.m. to 0 a.m.). It might be due the fact that people mainly work in Saint-Petersburg and live in suburbs of the city. They have to spend time every day for getting home in the evening after working hours.

For example, considering consumption in October, the maximum amount of consumed energy for one hour is related to 11 p.m. (1477.8 MWh). Demand response tool was implemented in next way: the consumption in peak hour 23 p.m. was decreased to 3% (the actual amount of decreasing was equal to 44 MWh) and increased in next two hours (on 31 MWh at 0 a.m. and on 13 MWh at 1 a.m., it was equal to 70% and 30%, relatively, of decreased consumption). As result the maximum amount of consumed energy was decreased to 1466.6 MWh.

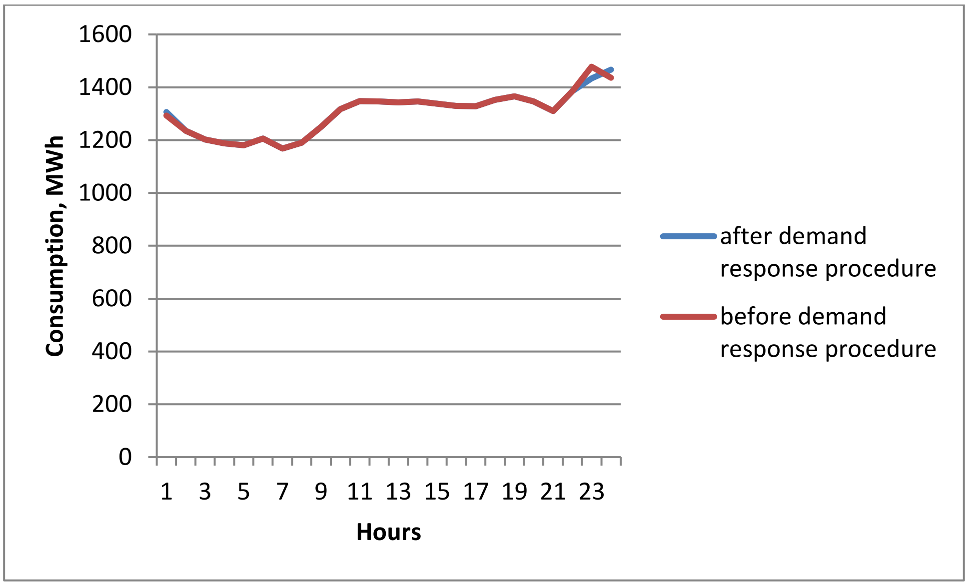

Fig.6. Consumption of residential customers during the 28th of October 2016

Statistics show that consumption does not increase rapidly at 5 – 6 p.m. It would be easier to change and control consumption during the day instead of the night. Despite of assumption, the high peak during night hours can be explained only by activity of residential customers. However exactly on this day, the consumption during the day stays almost on the same level.

Demand response procedure may bring benefit from the market price point of view. The price was chosen as equilibrium price of calculated period in the wholesale market, which was determined as result of competitive selection among bids for day-ahead market and for balancing system. Considering example of 28th of October, the price for 23 p.m. is higher than for 0 a.m. and 1 a.m. Thus shifting the peak might bring benefits. However, if we consider other example, the 10th of November, the peak is on the same place, but the price for 0 a.m. is higher than for 23 p.m. If we shift consumption, the peak amount will decrease, however, the expenses of guaranteeing supplier in the wholesale market will be higher. Nevertheless, in some cases implementation of demand response procedure cannot be implemented for decreasing consumption, because shifting peak leads to rapid increase in next hour, hence peak consumption shift to next hour.

The consumption is changing significantly during the different season that is why the load curve should be considered and analyzed in different months separately. In some cases consumption during the day time may have some peaks and demand response also have some sense. For example, on the 7th of February, we can observe peak from 13 p.m. to 17 p.m. In this case, we can observe situation, when it has sense to decrease consumption not only for one hour, but for two hours. On the Figure 7 it is shown the actual shape of curve and after the demand response procedure. It should be also mentioned, February is month when due to peak shifting the major decrease in peak consumption was obtained (50 MWh).

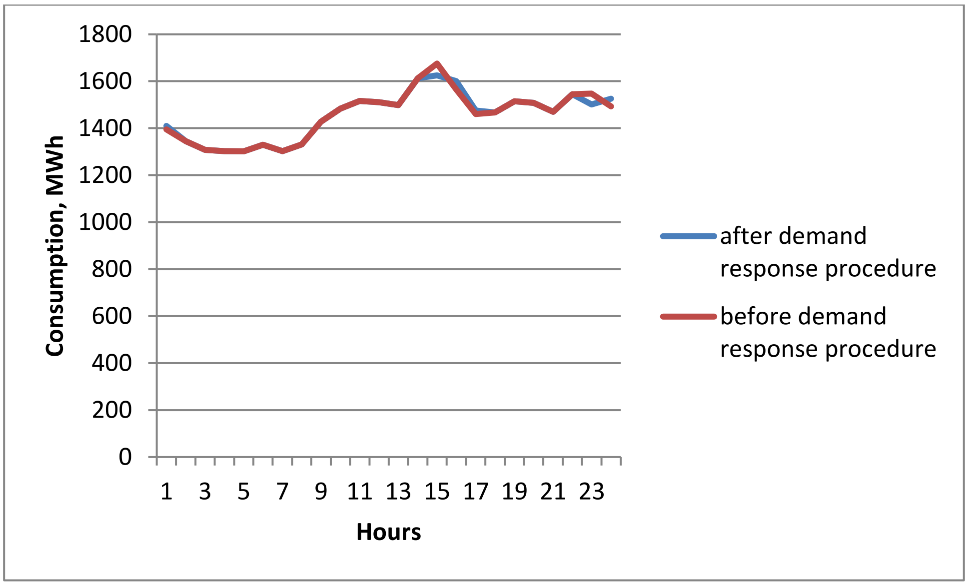

Fig.7. Consumption of residential customers during the 7th of February 2017.

If consumption could be shifted not from one hour, but from two hours with peak consumption, than power curve will have next form as on figure. In this case consumption in the evening hours and daytime is almost equivalent, that characterize demand procedure as successful.

Considering the fact, that guaranteeing suppliers pay for maximum amount of capacity, it seems, and that we should take this maximum considering also industrial customers.

However, in this case such position leads to calculating extra expenses, because earnings from industrial customers are not considered. The formula (1) also includes payment for infrastructure. This payment can be calculated by multiplying planned consumption and tariff for infrastructure use for residential customers.

The fixed-price tariff for residential customers was considered for the start. However, exactly differentiated types of tariffs can incentivize people to change their consumption to get benefits from demand response procedure by decreasing their electricity bills. As it can be seen from the Table 9 companies adhere to the policy of installment meters, all clients of these companies have metering points.

One of the most important directions in the sphere of power production or public utilities is an efficient consumption of resources and improving efficiency of operations. Accurate registration of resource consumption is the basic factor, which influence on the efficiency index. The order of the Government of Russia №603 from 29 June of 2016 is guided to installing devices for accurate metering of consumption, in case of device absent or impossibility of installment metering device multiplying factor will be applied for billing (in 2016 factor was equal to 1.4, in 2017 increased to 1.5) (Government of Russian Federation, 2016).

Table 9. Guaranteeing suppliers in Leningrad region and their statistics concerning metering points and number of customers (Rusenergosbyt, 2016), (Oboronenergosbyt, 2016), (Petroelectrosbyt, 2016).

Name of organization	Number of metering points	Number of clients
Petroelectrosbyt	451800	444200
Rusenergosbyt	5656	5 577
Oboronenergosbyt	4306	4 238

7.2. NPV calculation

Considering this model, main benefits are changes in load curve, decreasing peak capacity and decreasing consumption in peak hours.

$$GS_1 = T_eQ_{e1}-(P_eQ_{e1}+P_mQ_{mpeak1}+I) \qquad (2)$$

$$GS_2 = T_eQ_{e2}-(P_eQ_{e2}+P_mQ_{mpeak2}+I) \quad (3)$$

GS_1 – guaranteeing supplier profit before the implementation demand response procedure;

GS_2 – guaranteeing supplier profit after implementation of demand response procedure;

$$NPV = \sum_{t=0}^{n} \frac{(Benefit - Costs)_t}{(1+i)^t} \quad (4)$$

t – time of cash flow;

n – number of years;

i – discount rate;

Benefit = $GS_2 - GS_1$; (5)

Costs = capex +opex. (6)

Capex can be found as a number of metering points multiplied by costs normalized by a number of metering points (Table 6). Data concerning tariffs for the region, electricity price in the wholesale market and infrastructure payment can be found on the guaranteeing supplier website (Petroelectrosbyt, 2016).

The lowest costs per metering point is equal 77€on the Malta. Exchange rate on 22.04.2017 1€ = 60.32 rub, discount rate – 3.5%. However, considering this price, net present value stays negative during the indicated period (15 years). Net present value calculated for full roll-out is represented on the graph below. The prices are specified for one metering point. Opex was not included in this calculation, considering Opex NPV stays negative even with these low prices. The full data of calculations for October is shown in Appendix 1. The reasons of that might be exchange rate, relatively expensive equipment, but also with the fact, that not all benefits can be monetized and not all benefits are taken into account in this analysis.

Table 10. Capex for different costs per metering point

Costs per metering point	Capex, €
55€	25 396 910
60€	27 705 720
65€	30 014 530
68€	31 399 816

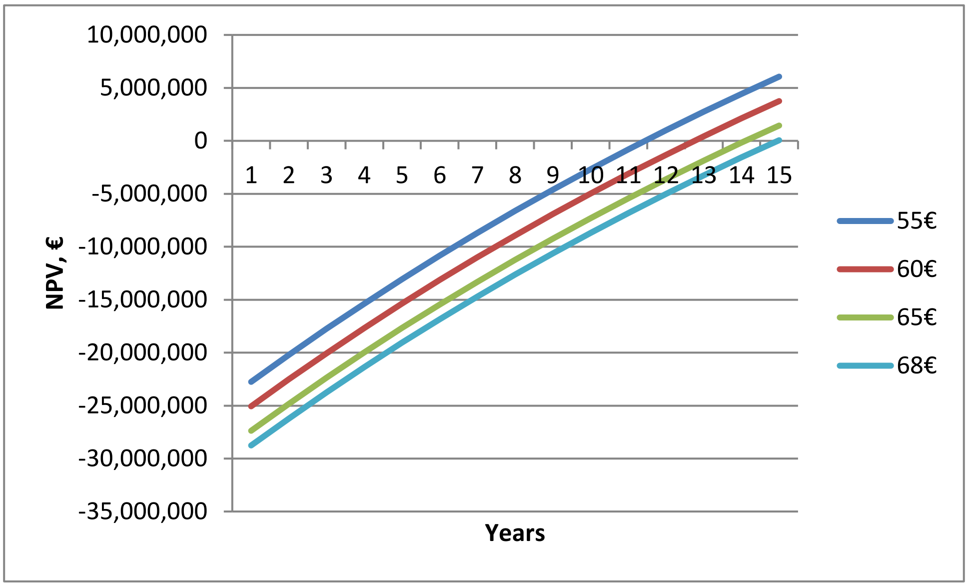

Fig. 8. NPV with different costs per metering point.

It can be seen that 68€ is a tipping point. This is the highest value which determines implementation of smart meters as beneficial.

Table 11. Data obtained at initial calculation for all months.

Month	T_eQ_e,€	P_e Q_{e1},€	P_eQ_{e2},€
October	1 343 145	551 223,6	551 074,2
November	1 537 292	608 768,4	608 850,8
December	1 576 205	663 084,6	662 884,5
January	1 421 333	613 301,3	613 184,7
February	1 498 968	629 563,4	629 391,1
March	1 383 753	578 543,1	578 434,3

7.3. Sensitivity analysis

7.3.1. Different percentage of smart metering devices

It has sense to consider profitability of different percentages of smart meters. If replacement of metering devices in large scale has no sense from benefits point of view, replacement in small scale might have sense. However, in this case the same shift should be implemented by lower number of customers. The costs per metering point should be determined. Considering the previous case, the lowest cost in Europe can be taken as basis (Malta - 77€ per metering point). For next calculation the value of 80€ per metering point has been taken for Capex, Opex assumed as 10% from Capex and decreasing in consumption for demand response procedure was 3%.

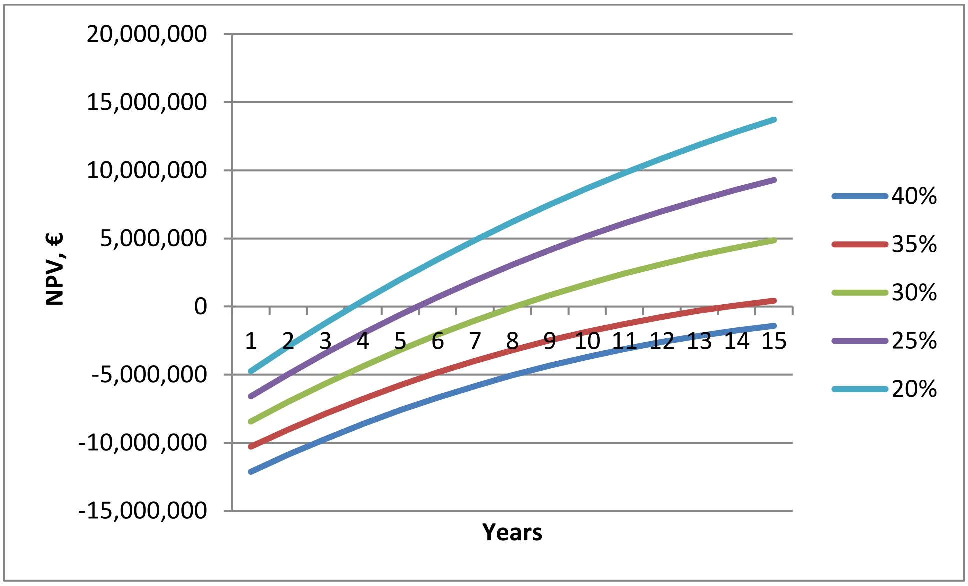

Fig. 9. NPV with different percentages of metering devices

Considering Figure 9, 30% replacement of conventional meters seems the best option for further analysis, the payback period is about 7.5 years, increasing percentage to 35%, the payback period becomes 13 years, in case 40% - payback period is more than 15 years. Capital and operational expenditures are represented in the Table 12 and the dynamics of NPV calculation for all percentages is shown in Appendix 2.

Table 12. Capital and operational expenditure for different percentage of roll-out.

Costs per metering point	Capex, €	Opex, €
80€, 40% roll out	14 776 384	1 477 638,4
80€, 35% roll out	12 929 336	1 292 933,6
80€, 30% roll out	11 082 288	1 108 228,8
80€, 25% roll out	9 235 240	923 524
80€, 20% roll out	7 388 192	738 819,2

7.3.2. Different tariff type

There are three different tariff types for customers in Russia. Considering different tariff types in the frameworks of implemented model, the amount of purchase on the wholesale market for guaranteeing supplier will be the same, however, the income obtained from customers will be different. The implementation of differentiated tariff significantly decreases the income of guaranteeing supplier, however this tariff more beneficial for residential customers.

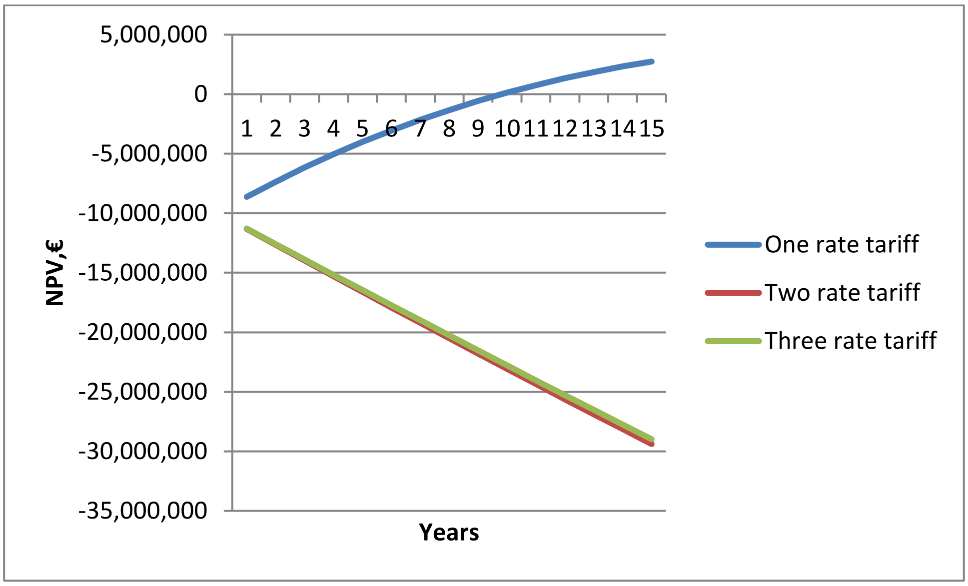

Fig.10. NPV with different tariff type.

The different between two rate type and three rate type is small, however the net present value is negative in both types, and the difference between baseline scenario and smart metering scenario has been shown in Table 13.

Table 13. Guaranteeing supplier earnings depending on tariff type

	Baseline, €	Smart meters, €
Demand response 3%, One rate tariff	165 594 682,7	168 233 639,1
Demand response 3%, Two-rate tariff	116 261 166,4	116 027 263
Demand response 3%, Three rate tariff	151 683 880,3	151 483 588,8

7.3.3. Demand response

For initial calculations decreasing in consumption was taken as 3%. In the frameworks of sensitivity analysis it has sense to consider different percentage of demand response procedure to define the optimal solution. The difference between 2% and 3% is small; payback period is 7.5 and 9 years relatively. In case of shifting only one per cent, payback period is more than 15 years. While in case of shifting 5%, the NPV is decreasing during the whole considered period of time. This can happen because of rapid increase of load in next hour and, as a consequence, guaranteeing supplier has to spend more money in capacity market. Thus, profit in the baseline scenario exceeds profit in smart metering scenario in case of such shift, see Figure 11.

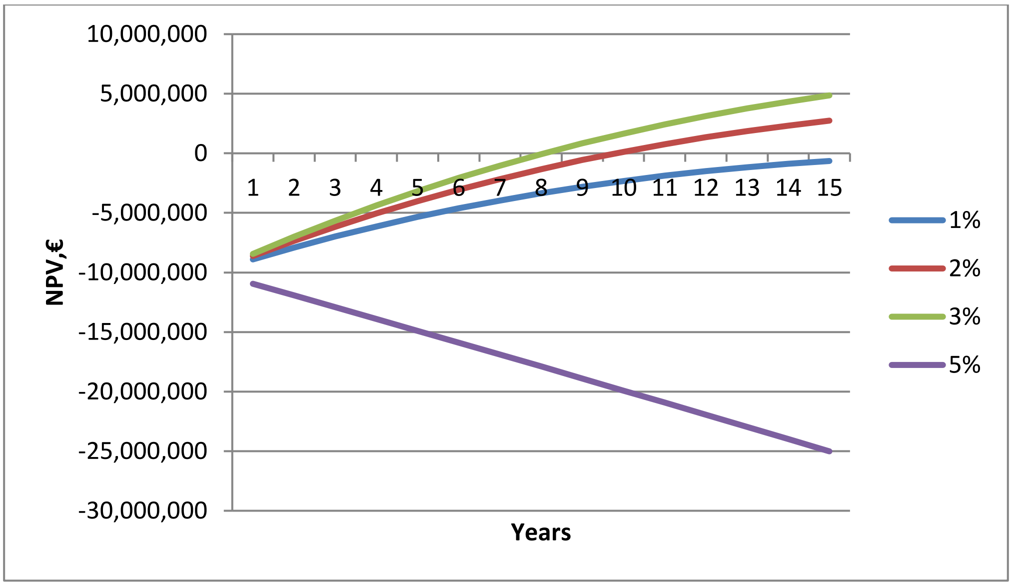

Fig. 11. NPV with different decrease in consumption

7.3.4. Energy saving

Energy saving as result of smart meters implementation means significant benefits for some country cases, for example, in Austria – 55% of benefits, in Germany – 33% and in Denmark – 16%. Energy saving potential in Russia is huge, especially considering residential customers, because people are not used to tracking the consumption. The case with different percentage of energy saving should be considered.

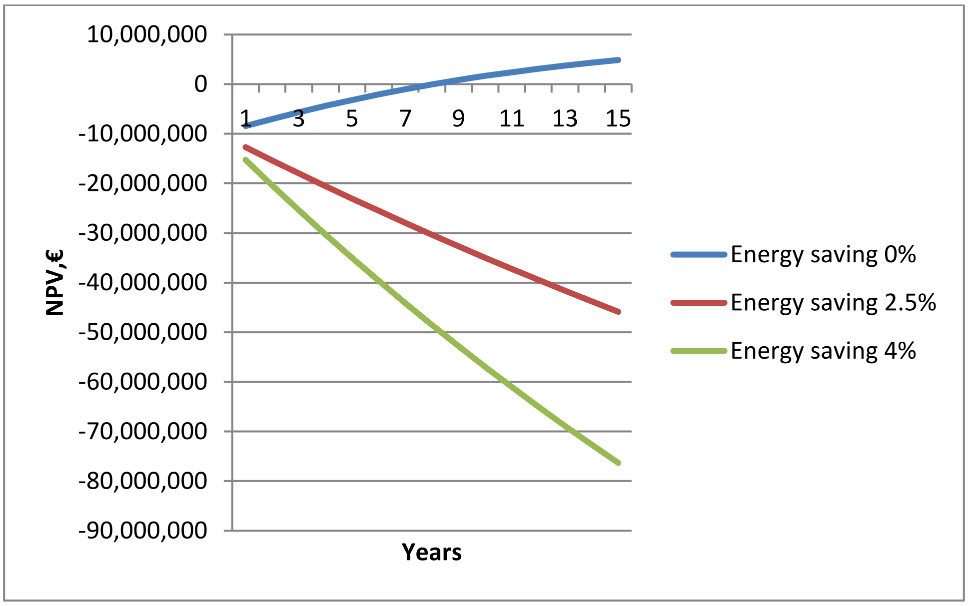

Fig.12. NPV with different percentage of energy saving

The calculation was implemented for savings from 2.5 to 10%, however, after the first calculations; it became obvious that due to less payment from customers earnings of guaranteeing supplier in baseline scenario are higher than in smart metering scenario. Nevertheless, despite of negative NPV for supplier, energy savings are beneficial for customers and environment. Guaranteeing supplier profit for all cases is shown in Appendix 3.

8. Discussion

Cost-benefit analysis has shown that prices per metering point, which are fit for European countries, are high for Russian case. The lowest price per metering point (77€) was taken as initial data, however, even with this price profit did not exceed expenses for the whole considered period. The tipping point was defined as 68€ per metering point. At this value, NPV of installing smart metering system becomes positive after 15 years; however, this value does not include operational expenses.

Many parameters influence NPV, such as percentage of consumption shifting, amount of peak capacity, price on the wholesale market, a type of tariff etc., thus, sensitivity analysis is very important to understand, what can be done to change situation. To start with different percentage of smart metering points, it has a sense to change conventional meters gradually. The best option seems to be 30%, because payback period is in such case 7.5 years. However, it is very low number, comparing with Europe. Expected diffusion rate for 2020 in European countries, which have decided implement replacement in large scale, varies from 80% (Greece, Poland and Romania) to 100% (for example, in Denmark, Estonia and Finland), at the same time diffusion rate for countries, which have not decided yet, is mostly 23% (Germany, Latvia and Slovak Republic) (European Commission, 2014).

Furthermore, residential customers are allowed to choose different tariff type and from this point of view, two rate tariff type is more beneficial for them, and at the same time the most expensive for a guaranteeing supplier. The tariff, which is not differentiated according to the day time is only one that provides positive NPV, id est profit for guarantying supplier. There is no motivation for consumers to shift their consumption in such tariffs, because they cannot decrease their electricity bills in such way.

The influence of capacity prices can be shown in the analysis, which represents different shift in consumption. The best option should correlate price on the wholesale market and amount of the peak consumption. Comparing 3% and 5% shift, the difference between these results are significant: demand response with 3% shift seems to be the best option and at the same time demand response with 5% shift seems to be the worst option. Decrease in consumption in one hour means an increase in the next hour, id est peak capacity shifts to that hour also and it exceeds peak capacity in baseline scenario. All values of peak capacity are represented in Appendix 4.

Energy saving seems to be an important option for the system as the whole, for end-users and electrical equipment. However, from the guaranteeing supplier point of view, it means less profit, because of less payments from the customers.

The reason for these results might be because of a relatively flat load curve, where difference between peak and off-peak hours is not high, id est overall benefits are not high too. Power generation in Russia has a low diversity. It is mainly based on gas, especially in European part of Russia, which is considered in this work. The price on the wholesale market depends on the type of generation, id est variation of the prices is not so high and volatility is low.

One of the reasons might be the fact that not all benefits can be monetized especially for Russian case, for example, reduction in meter reading and operation costs cannot be calculated without data about baseline expenses for these operations, but guaranteeing suppler does not provide these data. There is an evident benefit due to possibilities of remote operations such as billing, connection or disconnection, programming etcetera. Smart meters give a real-time information about consumption that helps to plan load more accurately, and, as result, decrease power equipment breakdown. The forecast about reduced number of breakdown is quite obscure that is why this benefit cannot be monetized.

Decrease in peak capacity is a quite useful option not only for guaranteeing supplier, but also from the point of view deferred capacity investments. Peak can be reduced due to energy savings or demand response tool, as result, it would lead to deferment of investments. The problem is that similar calculations also include many variables, such as population growth or other socio-economic factors. Decreasing of electricity technical losses relates to energy efficiency category and combines all above mentioned benefits, for example, more accurate planning, deferred capacity investments etc. It depends on them and can be calculated only together.

Generating and grid companies will benefit because of deferred capacity investments and decrease of power equipment breakdown. Due to more accurate planning and shift in consumption, the equipment will not be loaded heavily and it can help to prolong the life of power installations in a proper state. Grid companies are also able to get data about grids state in real time that will reduce outage time and help to reveal and eliminate equipment breakdown. In case of establishment carbon tax or emission trading system in Russia, smart meters can bring benefits for generating companies, because of more accurate planning that will reduce utilization of fossil fuel, and, as consequence, reduce greenhouse gas emissions. Power industry is very carbon intensive and this benefit can serve also for the whole system.

Guaranteeing suppliers will benefit from reduction in operational and meter reading costs, from more accurate planning, because they have to buy electricity on the wholesale market and in case of imbalance they have to pay penalties. Guaranteeing supplier will benefit also from demand response procedure, because it decreases peak capacity and shift peak consumption.

End-users will be provided with more accurate data on consumption, thus their benefits depends on them. Implementation of demand response or energy saving will decrease their electricity bills. The bills can be also reduced because of decrease in expenses for power generation or transmission because of different factors such as benefits, which cannot be monetized in this analysis.

Power system as the whole will benefit from all above mentioned factors: amount of imbalance power will decrease, as consequence equipment breakdown, amount of peak capacities and even greenhouse gas emissions will be decreased also.

Nevertheless, smart metering is not profitable in Russian case, based on analysis of this thesis with all assumptions and limitations. However, for some cases smart meters can be beneficial, for example, smart metering implementation in small scales (change only 30% of metering devices). Another option is to consider possibility to change imported meters to domestic devices, but it requires the development of Russian analogue of such systems or improvement of existing systems. In this case capital and operational costs will be lower and as consequence, payback period will be also shorter.

According to Table 6 in Chapter 6, relation between benefits and costs defines expedience of smart metering. To compare these data with analysis for Russia, the value of benefit/cost ratio can be defined for Russian case: if costs per metering point are equal to 68€, than benefits per metering point are 5.71€ and benefit/cost ratio is 0.084. Comparing to European case, the lowest values are in Latvia (0.06), Czech Republic (0.65) and Lithuania

(0.67). All these countries have not decided to implement smart metering in large scale, only optionally.

9. Conclusion

Smart technologies become more popular with transition from a conventional power generation to renewable sources of energy. Smart metering implementation might be the first step towards the whole smart system. Cost-benefits analysis is essential before replacement of conventional meters with smart meters. Similar analysis was conducted for all European countries. Some of them have already started implementation, some of them have decided to establish a new generation of smart metering system and some of them have decided to implement roll-out only optionally.

Smart metering roll-out includes many benefits, for example, reduced operational and maintenance costs, shift of peak consumption, deferred new generation investments etc. The main problem is not all of them can be monetized due to the lack of information. That is why obtained results cannot show the full picture.

Considering Russian electricity market, cost-benefit analysis has not been conducted before at all, not mentioning lack of literature about smart grids in Russian. This dissertation includes description of Russian power sector and specific features of electricity tariff formation. This work contains detailed cost-benefit and sensitivity analysis of smart metering system application from the guaranteeing supplier point of view for Leningrad region.

The results shows, that NPV of smart meter system introduction is negative in Russian case. Comparing with similar situation in European countries, for example, Germany and Czech Republic, replacement can be implemented, but only in small scale or optionally. There is another option for smart metering roll-out: it can be subsidized, for example, at the expense of end-users. However, this solution is not likely to be socially acceptable in Russian case.

The cost benefit analysis was implemented from the guaranteeing supplier point of view. At the same time for the most European countries, which decided to implement smart metering on large scales, responsible party was DSO, excluding the Great Britain, where responsible party was a supplier. Financing of roll-out is done mainly by Network Tariffs and suppliers (in Britain's case only). As a suggestion for future research, it would be possible to implement similar analysis from DSO point of view in Russian case and compare the results.

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Appendices

Appendix 1. Initial data for calculation

Data for 28.10.2016 (other data are used for November, December, January, February and March).

Hour	Q_{tot}, MW	Q_{e1}, MW	Q_{e2}, MW	P, €/MWh	P_e Q_{e1}, €	P_eQ_{e2}, €	T, €/MWh	T_eQ_{e1}, €	T_eQ_{e2}, €
1	5772,8	1293,1	1306,4	13,55	17526,8	17707,1	42,9	55522,9	56094,0
2	5510,9	1234,4	1234,4	13,14	16223,3	16223,3	42,9	53003,9	53003,9
3	5368,2	1202,5	1202,5	13,07	15715,2	15715,2	42,9	51631,9	51631,9
4	5303,6	1188,0	1188,0	12,74	15139,0	15139,0	42,9	51010,1	51010,1
5	5270,9	1180,7	1180,7	12,92	15249,3	15249,3	42,9	50695,8	50695,8
6	5380,9	1205,3	1205,3	13,95	16811,3	16811,3	42,9	51753,4	51753,4
7	5214,3	1168,0	1168,0	14,17	16551,2	16551,2	42,9	50151,0	50151,0
8	5313,9	1190,3	1190,3	17,04	20285,5	20285,5	42,9	51108,9	51108,9
9	5577,8	1249,4	1249,4	18,22	22765,0	22765,0	42,9	53647,1	53647,1
10	5880,9	1317,3	1317,3	19,18	25264,3	25264,3	42,9	56563,1	56563,1
11	6014,2	1347,2	1347,2	19,40	26130,1	26130,1	42,9	57845,1	57845,1
12	6009,1	1346,0	1346,0	19,68	26487,1	26487,1	42,9	57795,4	57795,4
13	5994,4	1342,7	1342,7	19,23	25824,4	25824,4	42,9	57654,1	57654,1
14	6009,2	1346,1	1346,1	19,22	25870,0	25870,1	42,9	57796,5	57796,5
15	5974,1	1338,2	1338,2	19,56	26173,8	26173,8	42,9	57459,4	57459,4
16	5937,0	1329,9	1329,9	19,04	25321,4	25321,4	42,9	57102,2	57102,2
17	5929,5	1328,2	1328,2	18,91	25117,4	25117,4	42,9	57030,5	57030,5
18	6038,9	1352,7	1352,7	18,86	25518,7	25518,7	42,9	58082,6	58082,6
19	6097,9	1365,9	1365,9	19,80	27051,1	27051,1	42,9	58649,6	58649,6
20	6011,0	1346,5	1346,5	21,17	28500,8	28500,8	42,9	57814,1	57814,1
21	5850,6	1310,5	1310,5	20,04	26268,1	26268,1	42,9	56271,3	56271,3
22	6182,4	1384,9	1384,9	20,17	27932,8	27932,8	42,9	59462,3	59462,3
23	6597,3	1477,8	1433,5	19,48	28791,9	27928,2	42,9	63453,4	61549,8
24	6408,8	1435,6	1466,6	17,21	24705,3	25239,41	42,9	61640,17	62972,69
Total					551223,6	551074,2		1343145	1343145

Q_{tot} – overall consumption (load curve);

T_e – tariff for residential customers;

Q_{e1} – electricity, consumed by residential customers (load curve before demand response procedure);

Q_{e2} – electricity, consumed by residential customers (load curve after demand response procedure);

P_e – electricity price on the wholesale market;

P_m - price for peak capacity;

Q_{mpeak} – maximum amount of electricity consumption;

I – infrastructure payment.

Appendix 2. Dynamics of NPV calculation different percentage of smart metering devices

Year	40%, 80	35%, 80	30%,80	25%, 80	20%, 80
1	-12137427,6	-10290379,6	-8443331,6	-6596283,6	-4749235,6
2	-10880644,9	-9033596,9	-7001844,1	-4970091,3	-2938338,5
3	-9710084,4	-7863036,4	-5646578,8	-3430121,2	-1213663,6
4	-8622830,5	-6775782,5	-4374620,1	-1973457,7	427704,7
5	-7616066,1	-5769018,1	-3183150,9	-597283,7	1988583,5
6	-6687069,2	-4840021,2	-2069449,2	701122,8	3471694,8
7	-5833210,1	-3986162,1	-1030885,3	1924391,5	4879668,3
8	-5051947,8	-3204899,8	-64918,2	3075063,4	6215045,0
9	-4340827,4	-2493779,4	830907,0	4155593,4	7480279,8
10	-3697477,0	-1850429,0	1658962,2	5168353,4	8677744,6
11	-3119604,7	-1272556,7	2421539,3	6115635,3	9809731,3
12	-2604996,4	-757948,4	3120852,4	6999653,2	10878454
13	-2151512,8	-304464,8	3759040,8	7822546,4	11886052,0
14	-1757086,7	89961,3	4338171,7	8586382,1	12834592,5
15	-1419721,1	427326,9	4860242,1	9293157,3	13726072,5

Appendix 3. Profit of guaranteeing supplier

Case	Guaranteeing supplier earnings, €
Baseline	165 594 682,7
Demand response 5%, One rate tariff	165 727 470,0
Demand response 3%, One rate tariff	168 233 639,1
Demand response 2%, One rate tariff	168 055 884,1
Demand response 1%, One rate tariff	167 771 695,8
Demand response 3%, Energy savings 2.5%	163 976 811,0
Demand response 3%, Energy savings 4%	161 422 714,4

Appendix 4. Amount of peak capacities for different cases

Month	Baseline, MW	Demand response (decrease in consumption), MW				Energy savings, MW	
		1%	2%	3%	5%	2.5%	4%
October	1477,8	1463	1456	1467	1487	1430	1408
November	1649,3	1615	1616	1612	1665	1572	1548
December	1767,2	1720	1720	1720	1776	1677	1651
January	1566,4	1551	1545	1556	1578	1517	1494
February	1675,4	1659	1665	1625	1624	1585	1560
March	1535,4	1520	1505	1515	1537	1477	1454