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Evaluation of Smart Grids effects in Russia

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- Introduction to Smart Grids and Ripple Control technology
- Current state of Smart Grids in specific countries
- Usage of Ripple Control in Czech Republic and other relevant countries
- Methodology for economic calculation of Ripple Control establishment in Russia
- Use proposed methodology in the example and evaluation of benefits

Seznam odborné literatury:

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Declaration

I hereby declare, that the present diploma thesis is the result of my own work and I used only information sources mentioned in the References section. The work is done with respect of ethical principles of information usage. I agree with a public availability of my work.

May, 2014 Bc. S. Chervonnyy ________________

Signature

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Abstract

The present work aims to investigate the possibility of Ripple Control implementation in one of the regions of Russian Federation and its economic expediency. The selected region is Siberian District, which is located in the middle of Russia and has the second largest territory. The real data of the electrical energy generation and consumption was analyzed and used for economic evaluation of Ripple Control technology in proposed region by using special software solution, such as Excel and Mathcad.

Key words

Smart Grid, Ripple Control, storage heaters, economic evaluation, Energy Cost Savings, Investment Cost Savings, Siberian region

Content

List of abbreviations

AC	Alternative Current
AFCS	Audio-Frequency Controlled System
CAPM	Capital Asset Pricing Model
DER	Distributed Energy Resources
DSO	Distribution System Operator
DC	Direct Current
ECS	Energy Cost Savings
FACTS	Flexible Alternative Current Transmission System
HPP	Hydro Power Plant
ICS	Investment Cost Savings
IDO	Interregional Dispatching Office
IIDS	Improved Interfaces and Decision Support
IPS	Interconnected Power System
LLC	Limited Liability Company
LV	Low Voltage
LW	Long Wave
MV	Middle Voltage
R&D	Research and Development
RC	Ripple Control
RCR	Ripple Control Receiver
RFCS	Radio-Frequency Controlled System
SH	Storage Heater
TCS	Total Cost Savings
TPP	Thermal Power Plant
UES	Unified Energy System
JCS	Joint Stock company
IDO	Interregional Dispatching Office

Introduction

Nowadays Smart Grid has been one of popular and developing trends in the power engineering sector. There are a lot of definitions of what a Smart Grid is. According to European Technology Platform a Smart Grid can be defined as «*A Smart Grid is an electricity network that can cost efficiently integrate the behavior and actions of all users connected to it – generators, consumers and those that do both – in order to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety for supply and the consumer*» [1]. According to the Department of Energy in USA a Smart Grid is a grid that must include particular characteristics such as self-healing from power failure in grid, provision of certain power quality for today's needs, operational stability against physical attacks and active participation of consumers in demand response [2]. Smart Grids play an important role in the transforming process of the present transmission and distribution networks.

Smart Grids include a combination of software and hardware, which provide high levels of quality and security of supply, operation sustainability, reliability and economic efficiency for all users connected to this grid. Integration of Smart Grid will lead to appearance of new perspectives. The consumers will have possibilities to interact with power system and generation by using special automated control of their electrical appliances and in such way acting as significant part of the power system **[**3**].**

In recent years, the implementations of Smart Grid projects are started in many industrialized and developing countries. The large-scale projects and programs are developed and implemented in USA, Canada and EU countries. Furthermore, it is decided to develop similar projects in such countries as Russian Federation, China, India, Australia and other.

One the main parts of the Smart Grid is Ripple Control technology. Ripple Control can be defined as load control method, which is used in many countries, such as Australia, Germany, New Zealand, United Kingdom, etc. The purpose of this technology is to disconnect the load (especially heating load) at peak times and switch on this load at off-peak time.

The main objective of the present work is to evaluate the economic effects of the Ripple Control project in the Siberian Region by developed methodology and to determine all necessary technical and economic possibilities of the project realization. Moreover, the specific objectives of the work are to give an overview of Smart Grid concept and Ripple Control, to describe current state of Smart Grid and Ripple Control in specific countries.

1. Overview of Smart Grid

1.1. Smart Grid concept

In general, Smart Grid is a combination of transmission and distribution systems that uses a bidirectional communication between power plant, customer and control center to optimize the power supply and demand. Moreover, development of Smart Grid leads to increasing of energy efficiency.

The main features of Smart Grid concept:

- allows customers to automatically manage their electricity consumption and also gives ability to decrease their expenses;
- self-repair possibility in the case of failure in the network;
- interconnection with a large amount of energy resources (including renewable energy producers);
- improvement of the power quality and transmission of electricity.

The Smart grid implementation will give customers the ability to understand how they use electricity, how they can use energy more efficiently and how reduce the carbon dioxide emissions due to use of renewable energy [5].

Smart Grid consists of not only technological innovations, but also an accurate economic planning and realization of the grid. Smart Grid concept can be described by a pyramid, where the asset management is the foundation of the Smart Grid realization (Figure 1.1.) [70].

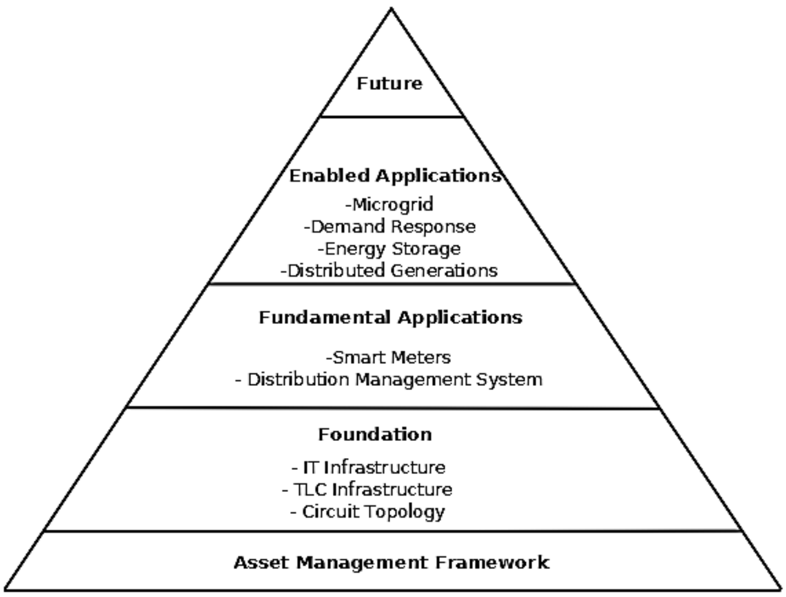

Figure 1.1 – The pyramid of Smart Grid concept [70]

The implementation of Smart Grid does not mean to replace the existing power grids, because there is inappropriately from technical and economic points of view. Smart Grid is focused on improvement of existing power grids due to integration of new technologies and services. The several advantages of Smart grid over traditional grids can be highlighted:

- *Improved Reliability*

Generally, grid with high reliability is one that delivers electrical energy to customers when it is necessary and quality of this energy must supports the requirement of customers. In such way, Smart Grids provides reliable power supply reduction in duration of outages, reduction of disturbances and also elimination of power cutoff. It is achieved by using digital information, automated operation and stand-alone systems.

- *Improvement in Safety and Security*

A Smart Grid has a possibility to detect and protect itself from cyber or physical attacks that can affect on reliability and safety. Information protection, cyber security and privacy protection are guaranteed for all users of a Smart Grid.

- *Energy Efficiency*

Smart Grids are more efficient traditional grids and provide a decrease in power consumption, decreases peak demand and reduces energy losses. Moreover, improvement of efficiency leads to reduction of the production, delivery and consumption costs. The power system based on Smart Grid has possibility of reducing consumption instead of activating new generating capacities.

- *Environmental improvements*

It is known that Smart Grids are “green”. Environmental result of these grids is a reduction of emission and discharges. These improvements lead to reduction in CO_2 from generating units and in case of smart grid electric vehicles it reduces tail pipe emission.

- *Cost Efficiency*

Also use of Smart Grids has economic benefits. The customers can know about energy resources that are being used and according to this information they can decide how to reduce the amount they pay for energy consumption [6].

1.2. Technological part of Smart Grid

The concept of Smart Grid is not only focused on modernization of individual technologies and equipment, but also on development and creation principles of innovative technological basis for electrical power industry. It should provide much more satisfaction of customers and other stakeholders through a significant change in the physical and technical characteristics and also functional properties of all components of the energy system. In order to create a new technological basis of electrical power industry it is possible to form five main groups of basis technological areas:

- *Measuring instruments and devices*

These devices include smart-meters and smart-sensors. Measuring instruments and devices are a key component of modern power system based on the concept of Smart Grid. These technologies have the potential to perform various functions, such as ensuring the continuity of monitoring data, facilitate network optimization and emission reduction due to the ability to regulate demand, evaluate the condition of equipment and the level of integration of the network and facilitate direct interaction between the energy supplier and the consumer.

- *Innovative technologies of Power System*

There are innovative components and devices based on the latest achievements of science and technology in areas such as superconductivity, power electronics, energy storage and system diagnostics. Examples of these technologies are renewable energy, FACTS devices, DC electricity transmission system, superconductors, smart devices, power electronics based on modern semiconductor devices.

Another approach is the development of distributed power generation. Integration of distributed generation are capable to increase the energy efficiency in energy transportation area, to reduce energy losses through transportation and the length of transmission lines, and also to provide more reliable way of energy supply.

- *Advanced control methods*

Improved control methods are one of the important parts of Smart Grid, which provide an opportunity to build a safe, reliable and "friendly" to the environment the modern energy system. Advanced Control technologies are represented by different devices and algorithms that can analyze, diagnose and predict the conditions of modern power system operation, as well as to identify and make decision to eliminate, reduce the negative impact and prevent system failures and disruptions in quality of delivered power. These methods provide control at the level of transmission, distribution and consumption of electricity. As a result of such opportunities the power system significantly increases the level of its reliability.

- *Improved interfaces and decision making methods*

Improved interfaces and decision support (IIDS) are the technologies, which are necessary for network operators and managers to operate a power grid. IIDS technology will transform the complex power system data into information that is understandable to a human. In many situations, the time allotted to the operator to make a decision, reduced from hours to minutes or even seconds. Thus, the current energy system requires extensive use of applications, operating in real time and special tools in order to make rapid decisions. Animation, virtual reality and other data display technology can be used in these cases and its usage can prevent overload of data and helps operators to identify, analyze and respond the problems of power system.

- *Integrated communications*

The implementation of integrated communications is the basis for the development of all considered technologies and it is the basis for the development of modern power system. Its operation will be significantly depend on the data collection, protection and control. Therefore, the methods and technologies of communication have the highest priority for a modern grid.

Integrated Communications will create a dynamic, interactive infrastructure for information access in real time and electric power changing. It allows users to interact with electronic devices of power system. Moreover, integrated communications can optimize the reliability of power system and allow avoiding any negative effects (failures) in the network. The power system with advanced communication technology can regenerate itself through constant monitoring, self-diagnosis and self-correction of errors in order to maintain high quality and reliability of power supply [46].

2. Ripple Control technology

2.1. Operational principle of Ripple Control

Nowadays energy management considers the two most important questions: optimal use of electrical energy and efficiency of consumption. Suppliers buy electrical energy from electrical plant and after this sell it to customers. Suppliers have limited possibilities to control electrical energy consumption, but they have interest to maintain the daily consumption on smooth level. One of the possible solutions of this problem is integration of special compensation tools such as Ripple Control System for heating units [4].

Ripple control operates on the principle of sending particular control signals, which is superimposed on the frequency of the grid supply. The signal is received by customer equipment and electric relay switch on or off the load depending on the requirements of the electricity company. In case of heating devices, Ripple Control is used for load management by switching off the electrical heaters at time of maximum load (load peak) [8].

The principle of RC operation is to either increase or decrease power consumption in particular time. When total power consumption exceeds the limit, some groups of loads, especially HVAC equipment (electric heating, hot water boilers and heat pumps) or swimming pool pumps are switched off [9].

2.2. Types of Ripple Control

Centralized Ripple Control System can be divided into two types: audio-frequency controlled system (AFCS) and radio-frequency controlled system (RFCS). AFCS includes 6 key elements (Figure 1). Audio-frequency message (the impulses with 60 s duration) is generated by the Central Computer at each transformer station in different geographical regions. This message should be coupled and filtered before modulation of the signal to the high voltage network [4]. The frequencies of these signals must not to coincide with harmonics of AC power (50 Hz or 60 Hz) and usually lie in the range of 150 Hz to 1350 Hz. The amplitude of injected AF signal is approximately 1-2% of main voltage [11]. The signal is received by customer equipment and electric relay switch on or off depending on the command of this signal.

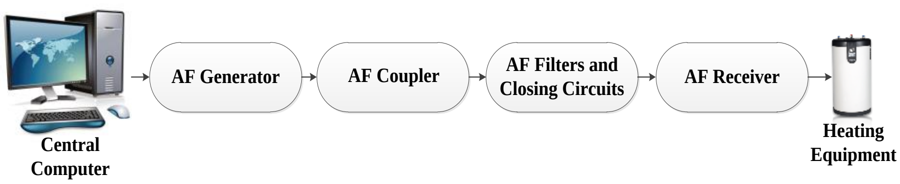

Figure 2.1 – Structure of the AFCS

The message should include minimum elements: start pulse, address and switching command. The difference in these messages can be expressed in their number of pulse, pulse duration of number of controlled consumption groups.

The structure of RFCS does not include couplers, filters and closing circuit modules. From there, the central computer and long wave (LW) transmitting equipment can control the number of consumer at the same time from one place (Figure 2.2). The transmitting equipment generates LW telegrams, which broadcast through objects such as mountains and ensure the safe data-transmission. LW telegrams consist of start, user address and control command to the receivers [9].

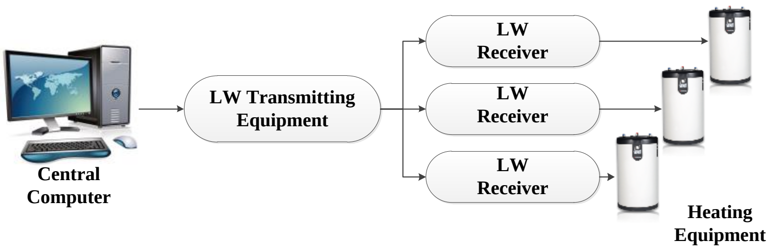

Figure 2.2 – Structure of the RFCS

2.3. Possibilities of Ripple Control

RC has found applications in many fields of electrical energy sector, which are connected with the load switching. Thus, the RC can solve several tasks:

- *Load Management.* Ripple control enable to control a customer demand with the switching program stored in the receiver and also include the possibility to change this program in real-time mode.
- *Lighting control*. The costs of street lighting can be reduced by using a special switching schedule and RC technology.
- *Reduction of power losses in the network*. It is known that losses are higher at time of maximum load, than at another time. It is possible to move on the part of load to time of minimum load by using RC.
- *Tariff control*. It is possible to reach certain customer in network and offer flexible tariffs [12].

3. Storage heaters

Storage heaters are special electric heating devices, which are designed to store thermal energy during low electricity demand time. This is usually night time period (off-peak), when electricity demand and electricity price are lowest. After that this stored heat is released when it is required during the whole day.

One of the main elements of storage heaters is a core where heat is stored. This core includes ceramic refractory bricks, which are made of materials with a high density and heating capacity. The electric heating elements are built in these bricks due to special grooves. Thus, the bricks can be heated up by using these elements. The core is thoroughly insulated to prevent energy losses and in such way it leads to efficient use of heat output. Moreover, this core insulation avoids high temperatures in the external surfaces of the heater. Heat is produced from the heater by radiation and convection processes and/or air circulation through the core.

3.1. Types of Storage heaters

In the market there are two available configurations of storage heaters depending on core structure: with horizontal heating elements (dynamic heaters) and with vertical heating elements (static heaters).

Operational principle of static heaters is that approximately 80% of the stored heat is released by convective and radiative processes in the surface of the heater. The air in the core is circulated by natural convection processes [10].

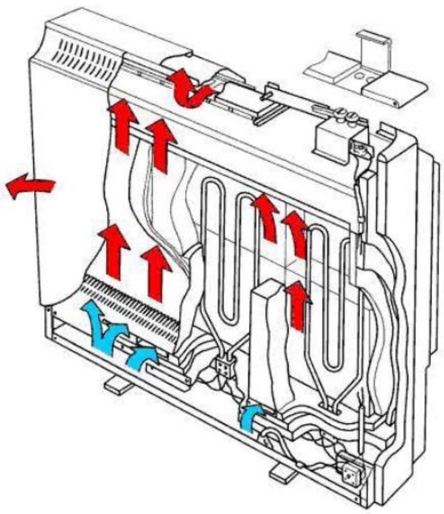

Figure 3.1 – Construction of the static storage heater [10]

Static storage heaters usually consist of two controls: input and output. The purpose of the input (thermostatic) control is to determine the amount of heat that was stored in the heater during the charging period (night time). This is important control, because it is known that night rate electricity is cheapest and this is no point pay for more than consumer needs. For example, when consumer is out of house for several days, it is not necessary to set the input on maximum level. Thus, thermostatic control changes the maximum allowable temperature of the core. The more this temperature the more heat can be stored.

The function of the output control is to regulate the air that enters (and leaves) the core of the heater by changing the position of dampers. The dampers are attached to bimetal systems and in this way they are only opened when the core begins to cool down and increasing of the heat output is required. This system only covers around the 20% of the heat released by the heater.

These types of storage heaters provide a gradual heat output during the day and it is not perfectly controllable. Application of these storage heaters is convenient for spaces occupied during around the whole day or, in other words, where a constant heat supply is required.

In case of dynamic storage heaters the heat output is more controllable due to a good insulation. Thus, around 20% of the stored heat is released by convective and radiative processes in the surface of the heater. A well-regulated heat output is provided by a small fan that blows air into the core.

Figure 3.2 – Structure of the dynamic storage heaters [10]

Dynamic storage heaters as well as static storage heaters have an input and an output controls, but they are more automatic. The operation of the input control is similar to the static heater. The output control manages the air flow coming into and going out of the core. Moreover, a lot of dynamic heaters are produced with a timer in addition to the output control. The use of the timer allows the heat consumer to set a heating schedule on a daily basis. Some dynamic heaters are designed with a room temperature control instead of the output control. In this case, users can just only set a desired temperature and the heater will spread hot air into the room until the temperature reaches an installed limit.

Nowadays, the main issue in dynamic storage production is to replace the input control by an automatic system. Modern heaters usually contain a built-in computer that can evaluate the heating requirement of the following day based on weather condition and usage setting using a self-learning algorithm. Furthermore, dynamic heaters can also include a communication system allowing remote control from the grid utility suppliers. In this way, the storage heater can be applied for load regulation in the grid. Also, this type of heaters includes a converter to provide on-peak extra heating, when the stored heat is not enough to meet necessary requirements.

3.2. Comparison of static and dynamic storage heaters

The Figure 3.3 illustrates the comparison between static and dynamic storage heaters. As it can be seen, the dynamic heater due to high controllability is more efficient and allows providing optimal space heating. The difference between dynamic heater's curve and static heater's curve is possible energy saving that the dynamic storage heaters can lead as opposed to static heaters. Nevertheless, as was said before, static storage heaters may find application in specific situations [33].

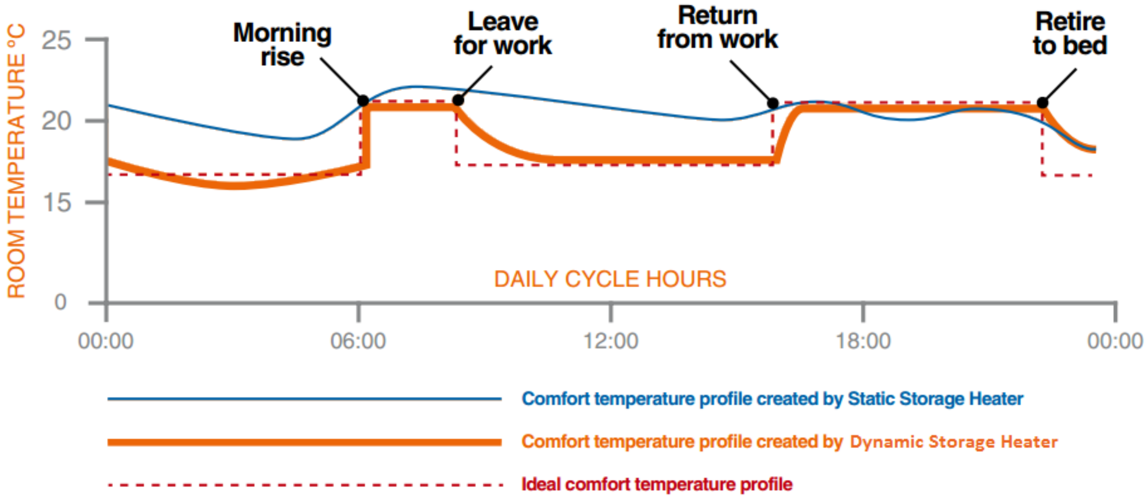

Figure 3.3 – Comparison of static and dynamic storage heaters [71]

Application of storage heaters could only provide benefits to consumer if electricity price during off-peak time cheaper than in on-peak time. Especially for this purpose the Economy 7 tariff was established in 70s in the United Kingdom. Proposed tariff is a kind of electricity tariff that indicates on different price for electricity at different times of the day. This tariff offer cheapest energy price during the night period. Thus, consumers could reduce their electricity bill by using electricity overnight. According to this tariff the hours of cheap electricity are usually from 12 midnight until 07.00 in winter, and from 01.00 to 08.00 in summer, although this time can change depending on seasons and regions. Described tariff and other off-peak tariff require the installation of special electricity meter. This tariff is attractive for hot water heaters and storage heaters. Also, it is possible to maximize the effectiveness of storage heaters by proper preparation of the building where they will be used. The windows, walls and attic space can be perfectly insulated. Moreover, special draft-blocking doorstops may reduce heat losses.

Table 3.1 – Advantages and disadvantages of storage heaters [71]

Advantages	**Disadvantages**
1. Low capital cost 2. Simple installation 3. Require no maintenance 4. More economic in combination with an off-peak tariff 5. Good option for users without gas grid distribution 6. The whole energy consumed by heater goes into heating space 7. No emissions 8. Can be CO_2-free if it consume energy produced by renewable or nuclear sources; 9. The whole energy consumed by the heater goes into the heating space	1. A lot of heat is released by convective and radiative processes during charging 2. Some heat is realized during the day when it is not needed 3. Require planning of heating for the following day 4. Can lead to over- or under heating, because of outside temperature change 5. Difficulty in sizing of the device 6. Expensive and less efficient operation without an off-peak tariff available

In the present work the storage heaters will be used in combination with Ripple Control. Storage heaters allow maintaining the temperature at home on the certain level during the whole day. Moreover, the application of storage heaters can reduce energy costs. All possible benefits of Ripple Control and storage heaters are represented in the Chapter 7.

4. Current state of Smart Grid in specific countries

4.1. Smart Grid projects in Europe

Nowadays there are approximately 280 Smart Grid projects in Europe with total investment of 1.8 billion euro. These projects include around 150 research and development (R&D) projects with total budget of 500 million euro and around 130 demonstration projects with budget of 1,3 billion euro. As it can be seen from the Figure 4.1 the Smart Grid projects and investments on them are differently distributed across Europe depending on the country. Some countries, such as the United Kingdom (~15% of the total), Germany, France (~12% each), Spain, Italy and Denmark (~10% each) stands out in terms of spending on the R&D projects and demonstration of Smart Grid projects. Investment of Germany and the UK together compose around 0,5 billion euro. In the UK a lot of investment is supported by Low Carbon Networks Fund and this is equal to around 200 million euro. The leader in R&D projects development is Denmark and there are usually small-scale projects supported by the Forskel financing program [13].

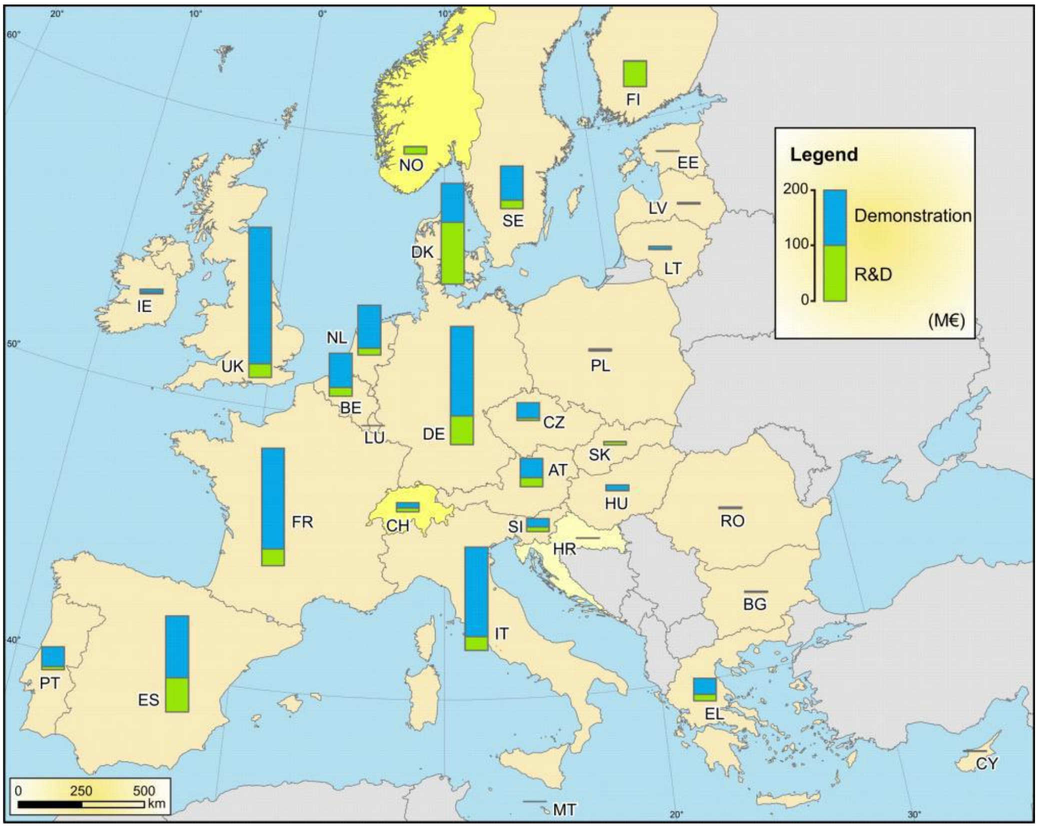

Figure 4.1 – Investment in R&D and demonstration SG projects [13]

The figure 4.2 shows distribution of European Smart Grid projects and their quantity in 2011-2012. As it can be seen around 70 % of all projects are located in seven countries: Denmark, Germany, Austria, Italy, United Kingdom, Spain and France.

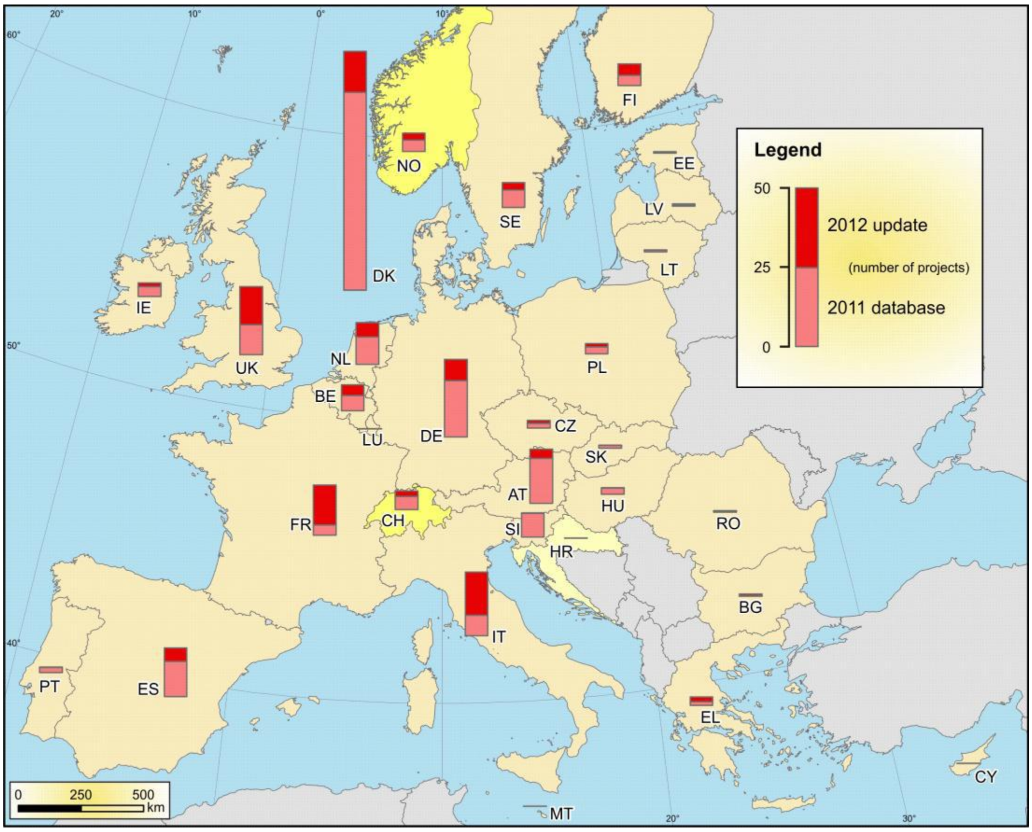

Figure 4.2 – Distribution of Smart Grid projects in 2011 and in 2012 [13]

Denmark is one of the most developed countries in European Smart Grid Industry, moreover this country is one of the world leaders in this sector. Denmark already integrates more wind energy into power system than any other country in the world. The country has a wide range of Smart Grid assets and around 60 smart grid firms. In 2012 was established the energy agreement. According to this agreement, in 2020 wind power sector will produce half of Danish electricity consumption. Also it is expected that a large amount of Danish energy consumption, including transport and heating, will be electricity based up. At the present time there are a lot of implemented and developing projects in Denmark [13]. Currently, works are underway with the development of Smart Grid technologies. «Flex Power Project» aims to develop a real-time market design that will attract a lot of small scale resources for power regulation [14]. The main idea of «EcoGrid EU» project is to develop and demonstrate a prototype of future power system containing more than 50 % renewable energy [15]. In 2010 a project «Automation and security of Supply» was initiated by Verdo Renewables Company. This project focuses on establishment DSO-Distribution-Control-Supervision at 10/0,4 kV individual stations with installed full remote control that make it possible to get an overview of the grid condition in case of fault situation [16]. Possibility to integrate a large number of photovoltaic is studied in project «Application of smart grid in photovoltaic power systems». It can be done by investigating different types of grid voltage control, developing smart grid abilities and using other services integrated into the renewable energy sources [17]. Development of an intelligent and flexible electricity system was considered in project «iPower». This kind of electricity system capable to manage millions of sustainable electricity units in decentralized power consumption and also find a way to run distribution with flexible power generation [18].

In Germany the energy market is characterized by the increasing supply of renewable energy both from wind power plants and through local generation of solar energy. Significant subsidies toward renewable energy are provided due to law «Erneuerbare Energien Gesetz». Until 2020, the share of renewable energy from the whole energy consumption will be increased to at least 35%. In 2050, approximately 80% of electricity consumption will be provided by renewable energy sources. The development of renewable energy leads to increase distributed generation and it is necessary to control these energy flows by means of smart grid technologies [19]. The project «Model City Mannheim» represents large-scale trial that has a place both in Mannheim and in Dresden. This trial includes new methods of energy efficiency improvement, grid quality and the implementation of renewable and decentralized energy sources into distribution power system. This project is focused on developing a cross-sectorial approach (including electricity, heating, water and gas) to interconnect the components of consumption with a power line infrastructure [19]. The project «eTelligence» represents intelligent system integration in consumption and generation sides. To this way the project will develop a regional market place for electricity, tariffs and incentive programs and power generation and consumption control systems [20]. The Project «MeRegio» demonstrates that a shift from today’s power supply system to «minimum emission regions» can be realized by combination of technical energy management and innovative information and communication technologies [21]. Electric mobility pilot region of Berlin-Potsdam, project «BeMobility 2.0», subproject «Micro Smart Grid» dealt with development of electric mobility with grid, shaving of power peaks and increase share of renewable energy in consumption. Moreover, in result of this project it will possible to integrate a decentralized and renewable energy into grid [22].

Spain has an important role in the Smart Grid sector; this is third country that invests in research projects. «Smartcity Malaga» is the model of the intelligent city that allows increasing energy efficiency, reducing CO_2 emissions and extending the development of renewable energy sources. The area of the smart city covers 4 km^2 with 11000 domestic and 1200 industrial and service consumers. Technologies in smart metering, communications, automation of the network, generation and storage, and smart recharging infrastructure for electrical vehicles are rolling out by consortium of several large companies. The project is planning to save over 25% in electricity consumption due to the installation of energy efficiency systems for commercial and residential customers and a 20 % decrease of CO_2 emissions (more than 4500 tons of annual emissions have been avoided) [23]. «DER IREC 22@ MICROGRID» is an industrial research project associated with development of modern products and services for distributed energy resources and electrical vehicles, investigation of energy management models located in Catalonia [24]. «Almacena» project is connected with installation of an energy storage system, which usually consist of a lithium-ion prismatic battery with power range of 1 MW and capacity of at least 3 MWh. The aim of «Almacena» is to improve the efficiency of the operation of electricity systems [25]. «PRICE» is aimed to offer innovative, public and technological solutions to provide interaction and competitiveness. It will improve the operation and maintenance of the network, optimizing process of renewable energy integration, make provision the mainstreaming of electric vehicles and also allow marketers to offer new services to their customers [26].

In France one of the important projects is «EnR-Pool» that associated with problems of balance between consumption of electricity and renewable production and ways that can solute these problems. The main purposes are to find new ways to implement renewable energy into the grid, also to create new approaches to improve the integration of renewable sources in the grid, effective use of low cost energy and development of renewable energy forecasting models [27]. «GreenLys» is development project of future electrical system that will be equipped in Lyon and Grenable. The main goals of «GreenLys» project are to decrease greenhouse gases, monitoring of energy bills, grid management, demand side control, investments and development of networks (especially DSOs) [28]. «Venteea» is innovative project focusing on the integration of wind energy into the grid. Moreover, the project dealt with study observability, controllability of wind power plants, voltage control, centralized protection and power quality. «Vinteea» will lead to improvement of grid efficiency and possibility to integrate a lot of wind energy in MV distribution networks especially in a rural area where wind power development is higher [29]. «MILLENER» is the current research project that will lead to reduction of electricity consumption for customers and allows to integrate intermittent renewable energy into distribution networks in order to provide real-time the balance between electricity demand and production. It considers the features of a non-isolated interconnected network (especially islands) and also the possibilities of consumers to manage their consumption. The base of the project will include photovoltaic panels, energy storage systems and control of power consumers. The experiments will take place in Corsica, Guadeloupe and Reunion with almost 1000 customers. [30]. «OMERE-GE» and «OMERE-IPERD» are two projects analyzing aimed to improve management in the energy balance by integrating the renewable energy sources, to develop a new software and intelligent devices and finally to test the dynamic control of the network in the substations. Renewable energy, storage, distribution and demand management will be the design basis of these projects. There are combinations of the scientific and sociological studies to investigate the relevance of communication technologies on the network at all levels (producers, distributors, manufacturers, consumers) [30]. The project «MYRTE» is based on development system and control strategy to improve the stabilization of electrical networks. According to this project, the energy will store energy by electrolyzer, which converts electricity into hydrogen and oxygen during the low consumption period. Then this energy can be returned via a fuel cell, which converts hydrogen and oxygen into electricity during the high consumption period. It will allow to examine the ability of the system to cut off a load peak and smoothing photovoltaic energy [31].

In the United Kingdom the Low Carbon London is a large-scale project, which is oriented to reduce carbon emissions up to 0,6 billion tons between 2011 and 2050. It will investigate renewable energy technologies, especially solar panels and combined heat and power plants, and its influence on the electricity network and also it will considered special issues maintaining low carbon electricity generation technologies [32]. The aim of «Hydro Active Network Management» project is to design a novel Active Network Management concept for 11 kV network in rural area, which includes several small hydro or wind generators. The idea is to develop an operational generation scheme, which helps to facilitate the management and connection of new generation units [33]. «Flexible Plug and Play» project will provide a faster and cheaper method to integrate new energy sources (wind power or solar) to Distribution System by using commercial solutions and new technologies such as Dynamic Line Rating, Remote Terminal Units, Active Voltage Control and also the first 33 kV Quadrature-booster in the world [32]. «BRISTOL» (Building, Renewables and Integrated Storage, with Tariffs to Overcome network Limitations) project considers battery storages and their potential with solar power combination used at homes and offices. New tariff with variable options will be trialed to stimulate customers to store electricity at peak times by using the battery [34]. «The New Thames Valley Vision» demonstration project is focused on management of existing network on intelligent level. The project consists of several tendencies such as forecast of low carbon technologies, network monitoring, energy storage and working out an agreement with large customers [35]. «Optimal Power Network design and Operation» will improve the design and operation of transmission systems by applying the advanced control and optimization techniques. The main idea will be associated with security of power supply in condition of uncertainties on both supply and demand sides intended to capacity utilization and transmission losses [36].

In Czech Republic the energy company ČEZ has launched the project «Smart Region» in Vrchlabi town. Around 4,5 thousands of «smart» energy meters, elements of the automation and monitoring in LV and MV grids will be installed in this town till the year 2015 [37]. The project of network control system for Prague's power grid was designed in 2012 by Siemens Infrastructure & Cities and the distribution network operator in Czech Republic. The main purpose of this project is to build new network control system in order to monitoring all operations in Czech distribution network operator. This new control system will manage the voltage level of 110 kV, 22 kV and 0,4 kV. Advanced applications will be used for protection against overload outages in the high-voltage power grid and for localization of faults and load restoration in the medium-voltage power grid [38].

There are also multinational Smart Grid projects in Europe Union. The first groups of developing countries in these projects are Spain, France, Italy and United Kingdom. The second group includes Denmark, Belgium, the Netherlands, Greece, Sweden, the Czech Republic and Austria, which collaborate mainly with the first group of countries. The biggest project is «Grid4EU» with total cost 54 million euro. «Grid4EU» was founded by consortium of 6 European energy distributors (ERDF, Enel Distribuzione, Iberdrola, CEZ Distribuce, Vattenfall Eldistribution and RWE). This project will remove some difficulties and barriers to the Smart Grids development. This aim will be reached by developing and testing innovative technologies in DSOs [39]. «E-price» is the research project aiming to design a new efficient and reliable control concept for energy market in Europe. Price control strategy will be in the center of future developments and increase the total amount of renewable energy sources. Also it will the standard framework for electrical energy trade. These goals are being made possible by introduction of Smart meters [40]. «Internet of Energy for Electric Mobility» is focused on development of hardware, software and middleware for energy grids. The Internet will be connected with the energy grids to prepare an intelligent control of energy generation, storage and distribution and it will be the background of for the widespread use of electric vehicles [41]. The main goal of «iTesla» project is to make a special toolbox that allows different TSOs to improve coordination and optimization of operation procedures. This toolbox will be responsible for the future operation of the electricity transmission network in Europe and allow to obtain operational dynamic simulations of the grids at different territorial levels (national, regional and European) and different time scales [42]. «IHSMAG» project (Integrating households in the smart grid) deals with a design development of smart grids solutions that involve consumers in the Smart Grid. According to experiences and a number of demonstration projects «IHSMAG» explores how smart grid solutions depends on consumer technologies, the electricity system and regulatory rules [43]. The basis of «Meter-ON» project is to conform the integration of smart metering technologies and infrastructures in whole Europe. The project and its analysis are based on R&D projects, large-scale demonstrators of smart meters with coordination of the regulatory framework [44]. «ENCOURAGE» is an European project that consist of intelligence and integration technologies that will lead to energy use optimization in building and active participation in the smart grid environment. It will be reached 1) by developing control strategies for different subsystems (Lighting, renewable energy generation thermal storage, 2) by developing new virtual metering technologies and some middleware applications and 3) by supporting energy exchange between buildings [45].

4.2. Smart Grid in Russian Federation

In the last years the growth of activity in the sector of Smart Grid is observed in Russian Federation. This interest appears in political and scientific areas, and also in activities of energy companies. Thus, the Russian Energy Agency and the International Development Agency of USA signed the Protocol of intent in development of cooperation for clean energy problems, Smart Grids and energy efficiency. This protocol consist of the plan of two countries activities in the direction of Smart Grid in Russian Federation.

National policies in the area of smart meters and smart grids are pursuing in the electricity sector. This development will cover some energy issues, such as energy efficiency, renewable energy and smart grids. As the Energy Strategy of Russia for period up to 2030 say [64], the main goals of this activity are to improve economic and environmental efficiency in the energy generation, transportation, distribution and consumption in Russian Federation. According to the Federal law № 261-FZ, smart meters and modern accounting systems have to be installed in all sectors of electricity and thermal markets in power plants and substations, and also in many enterprises. [65]

The two smart grid projects «Calculate, Save and Pay» and «Smart Account» are in progress in Perm city and there are related with future smart grids implementation. The main purposes of these projects are developing financial methodology for smart meters projects and new standards, building experience and changing legislation. This project leads to replace more than 50000 meters by smart meters.

The Academy of Sciences of the Russian Federation, especially Institute of Energy Research, not only carry out investigations and developments in the area of Smart Grid, but also research conceptual issues in transition of Russian power industry to intellectual energy.

Practical implementation and management of innovative projects in direction of the Smart Grid are realized by largest Russian energy holdings. The LLC «Federal Grid Company» initiated in development of «Design concepts of smart energy system with an active-adaptive grid». The LLC «Inter-Regional High-Voltage Grid Company Holding» and LLC «Inter-Regional High-Voltage Grid Company of the Center» in the first time in Russia implement the project of the «Smart city» in Belgorod [46]. The «Smart city» project includes systems of smart metering and smart accounting, «Reliable grids» (reconstruction of current distribution grids), «Smart street lighting» (new way of street lighting by using intelligent technologies) and so called «Smart House» (the automatic control for energy consumers). The main goal of Smart city project is to increase reliability of power supply, reduce power losses and reduce energy costs of consumers.

Also Smart Grid projects are developing in Astrakhan region. In accordance with information of energy companies in this region, smart meters are installed in 4900 domestic sectors, 520 in the industrial area and also 713 in HV substations. To use the remote control of these smart meters, about 2400 data transfer devices were integrated [66].

One of the Smart Grid projects evolved in the Moscow City. It is connected with electric vehicle charging infrastructure in this city. It composes installing 27 charging stations in 2012. The goal is to expand the development of electrical vehicles. Also the special intelligent control is built in these charging stations to avoid peak loads [67].

5. Current state of Ripple Control technology

5.1 Ripple Control in Czech Republic

In Czech Republic RC technology has been applying for over 50 years. Nowadays, it is used not only as a tool switching the low tariff for electric heaters and for controlling hot utility water and operation of public lighting.

Nowadays, Ripple Control technology in Czech Republic is integrated by three distribution companies (ČEZ, PRE and E-ON). Four transmitters with frequency 216,6 Hz for RC is installed in Prague. The energy company ČEZ currently has 12 transmitters with voltage level 110 kV and total capacity 800 kVA and 1600 kVa and usually with frequency 216,6 Hz (only in the northern Bohemia it is 183,3 Hz). The company E-ON owns 7 transmitters and PRE has just only two transmitters. It is almost the entire territory of Czech Republic is covered by RC signals except the North and Central Moravia and also Central Bohemia. The current estimations show that about 1,4 million RC receivers were installed in the country. The RC signal can be sent from 90 switching stations in distribution networks with 22 kV, 35 kV and 110 kV voltage levels.

In 2004 total costs for the purchase of RC systems were estimated at 5 billion Czech korunas. The RC system is used by distribution companies for reducing losses in the networks, optimizing the system load from generation to consumption and for optimum use of the networks and increase of its penetrability. Also, RC technology together with photocells is applied for controlling public lighting. RC is controlling usually 10-15 % of the total load in Czech Republic [12].

5.2. Ripple control in other relevant countries

In Slovenia, the centralized ripple control technology is based on two transmitters with 800 kVA capacity. There are located on different part of network with 110 kV voltage level. Transmitters are synchronized in operation and in such way they can support each providing the best signal level. The operation frequency of transmitters and receivers is 210 Hz, which was proposed by manufacturer and suppliers as the most convenient frequency. The main goal of RC application in Slovenia is to change tariff of electrical energy meters. Thus, the consumer can control his costs by using electricity at particular time [73].

In New Zealand the incentives of efficiency increase has been limited due to low electricity price. The current RC application in New Zealand is concentrated on managing control of how water heaters, but industrial customers have limited possibilities to switch off a load during the high price period. As results shows, RC of water heating cylinders has been successful method in managing residential load peaks of consumption in Christchurch city. Nowadays, the large distribution company Vector is maintaining and developing the policy of demand side management, especially development of RC technology [74].

In Germany, two long-wave RC transmitters located at Mainflingen and Burg. They used to transmit data throughout Germany and into large parts of neighbouring countries. The transmitters operate with the frequency of 129.1 kHz in Mainflingen and 139.0kHz in Burg. Energy distributor use RC in order to shift demand peaks and avoid the need purchasing expensive electrical energy by customers. Moreover, the grid operator can provide the reserve power by switching off flexible loads for short periods of time and offering convenient tariffs for energy customers [75].

In South Africa, RC is applied commonly for controlling domestic water heaters, hot water cylinders, boilers. It switches off these devices at consumer's side for a short time during load peaks. RC technologies were installed in different cities, such as Benoni and Sasolburg. The main purpose is to reduce the electrical energy costs in municipalities. Later, the street lighting control with timers and day/night sensors were also added to the system [8,76].

In Hungary about 230 thousand RC receivers assist in effective load control. RC Centre plays a key role in controlling street lighting, limiting consumption and maintaining load balance. The RC transmitter with 135 Hz was established in 2005 at Lakihegy, near Budapest. The main exercises of RC in Hungary are to perform peak-clipping and valley-filling of the daily load consumption [77].

Also, RC technologies are implemented in Austria, Switzerland, Belgium, Croatia, Bosnia-Herzegovina, Netherlands, Australia and other countries. According to RC current state, it can be concluded that RC is usually used for load leveling and to avoid the load peaks.

6. Overview of Siberian energy sector

6.1. Interconnected Power System in Siberia

Interconnected Power System (IPS) of Siberia is located in the Siberian Federal District. Siberian IPS covers an area of 5114,8 thousand km^2 with population of 20,1 million people (Figure 6.1). This IPS involves 10 regional power systems:

- Krasnoyarsk Territory;
- Altai Territory;
- Republic of Buryatia;
- Republic of Khakassia;
- Novosibirsk Region;
- Kemerovo Region;
- Omsk Region;
- Tomsk Region;
- Trans-Baikal Territory;
- Republic of Tyva.

The electric power system of Siberia includes 10 regional energy systems: Altai, Buryatia, Chita, Irkutsk, Krasnoyarsk, Novosibirsk, Omsk, Tomsk, Khakassia and Kuzbass. The energy system of Altai combines Altai Republic and Altai region. The energy system of Krasnoyarsk combines Republic of Tuva and Krasnoyarsk Territory [47].

Power system state is controlled by Siberian Interregional Dispatching Office (IDO), branch of JSC «System Operator of the United Energy System». Operational dispatch management of Siberian interconnection is carried out by 10^{th} regional dispatch administrations.

Figure 6.1 – The power system of Russian Federation [48]

Siberian Federal District has the highest value of the installed capacity of power plants (Figure 6.2). Energy Complex is combined by 100 thermal and hydraulic power plants with a total power 5 MW and more, having a total installed capacity of 48532 MW. HPPs of Siberia produce nearly 10% of all power generation in Unified Energy System (UES) of Russia [47].

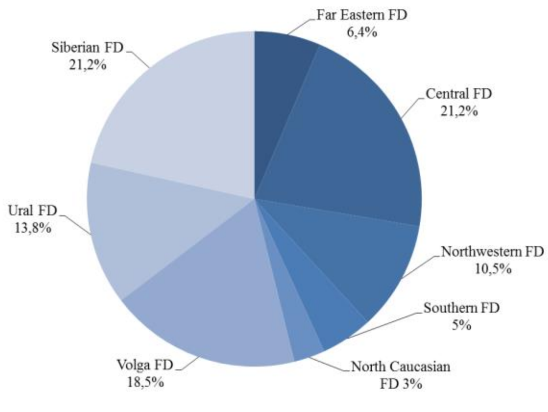

Figure 6.2 – Structure of installed power in Russian Federation [49]

As it was stated above, the Energy Complex of Siberian Region consist of HPP and TPP and compose 48,6% and 51,4% from the whole installed power, respectively (Figure 6.3).

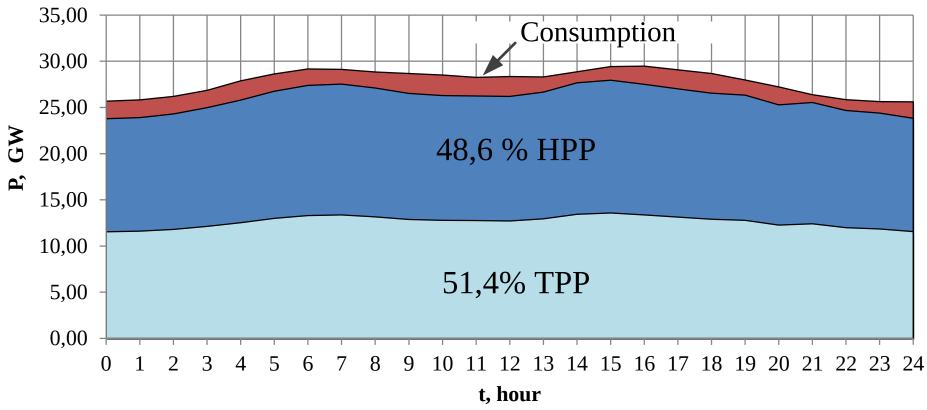

Figure 6.3 - Structure of the load diagram [49]

IPS Siberia borders with the power systems of the Urals, East, Kazakhstan, Mongolia and China, and is one of the largest IPS of Russia. Normal operation of Siberian IPS is achieved by energy flows of up to 2 million kWh transit Siberia - Ural - Center. Furthermore additional energy is consumed from East IPS (~80 GWh per year) and Kazakhstan (~6000 GWh per year) and also some amount of energy is exported to Mongolia (Figure 6.4). It provides compensation of uneven annual energy output of hydroelectric power plants due to the reserves of energy system, and also makes it possible to use the adjustment range of hydropower plants of Siberia for load control in UES of Russia.

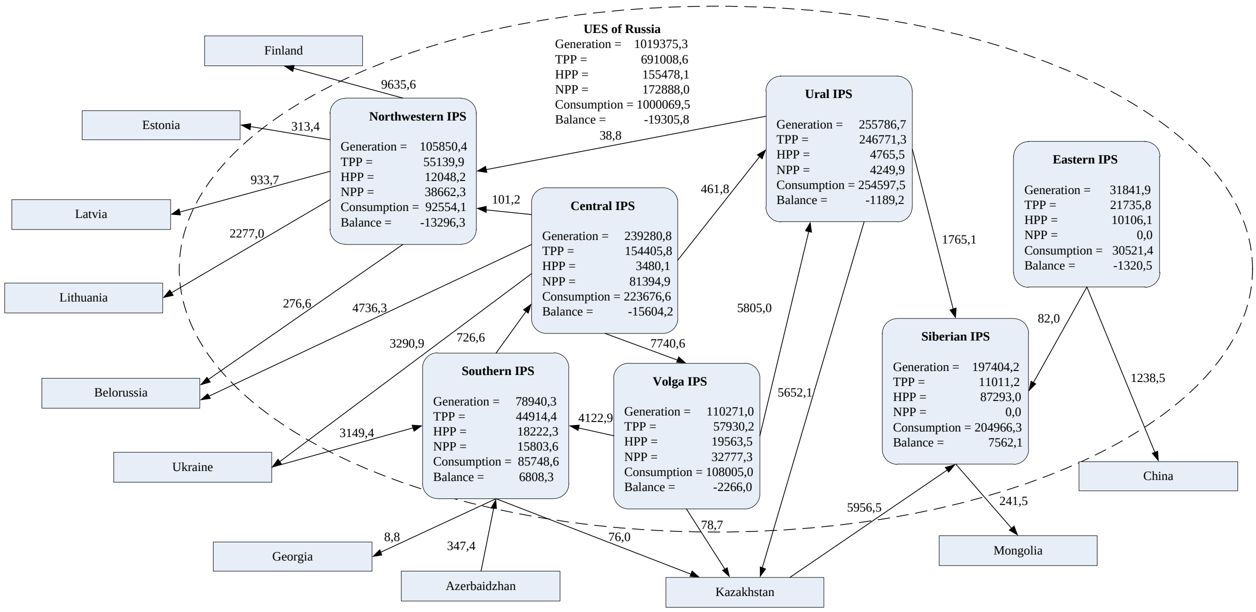

Figure 6.4 – Energy balance of Russian UES [47]

The main electrical network of IPS is formed by power lines in the voltage classes of 110, 220, 500 and 1150 kV [7]. The total length of all power lines in Siberia is 389104 km [8]. Information about length of power lines is represented in the Table 6.1.

Table 6.1 – The length of power lines in Siberian Region [50]

Siberian Region							
Voltage, kV	750-1150	500	220	110-154	35-60	3-20	0,38
Length, km	818	10194	26086	54363	38248	153542	105855

Time of Use pricing for households is dividing into three groups: on-peak, mid-peak and off-peak. The Table 6.2 includes information about tariffs for electrical energy in Siberian regions for each month. Electricity price for on-peak, mid-peak and off-peak are equal to 2,26, 1,82 and 1,3 rubles per kWh respectively [52].

Table 6.2 - Time of Use pricing for households in Siberia [53]

Time period	**On-peak, hours**	**Mid-peak, hours**	**Off-peak, hours**
January	9-12, 18-21	7-9, 12-18, 21-23	23-7
February	9-12, 19-21	7-9, 12-19, 21-23	23-7
March	9-11, 20-22	7-9, 11-20, 22-23	23-7
April	9-12, 20-22	7-9, 12-20, 22-23	23-7
May	9-14, 21-22	7-9, 14-21, 22-23	23-7
June	10-16	7-10, 16-23	23-7
Jule	10-15, 22-23	7-10, 15-22	23-7
August	10-14, 20-22	7-10, 14-20, 22-23	23-7
September	9-12, 19-22	7-9, 12-19, 22-23	23-7
October	10-11, 18-21	7-10, 11-18, 21-23	23-7
November	10-11, 18-21	7-10, 11-18, 21-23	23-7
December	9-11, 17-21	7-9, 11-17, 21-23	23-7

6.2. Analysis of Electricity Consumption

It is known that there are usually three peak hours for energy consumption: On workday in the morning (7-8 o’clock); on the holiday at the afternoon (12-14 o’clock); on workday and on holiday in the evening (19-21 o’clock).

The main loads that influence on the energy consumption at this time are the following: in the morning – water heater; at the afternoon – water heater and cooking stove; in the evening – water heater, lighting and cooking stove [51]. According to the month and day (workday and holiday) the energy consumption in Siberian Federal District were investigated.

1. Energy consumption on January

Two days were chosen for investigation of consumption, one of this is holiday, and another one is workday (Figure 6.5). As it can be seen from these diagrams, energy consumption in workday (P_{m1}=29,2 GW, P_{m2}=29,5 GW) is higher than in holiday (P_{m1}=28,1 GW, P_{m2}=29,2 GW). On the workday two extremums can be detected: the morning and the evening. In the morning the peak time is from 8 to 12 o'clock and in the evening it is between 16 and 21 o'clock. On the holiday's consumption diagram the first load peak is not expressed clearly (from 9 to 14 o'clock) and the second peak is from 17 to 22 o'clock.

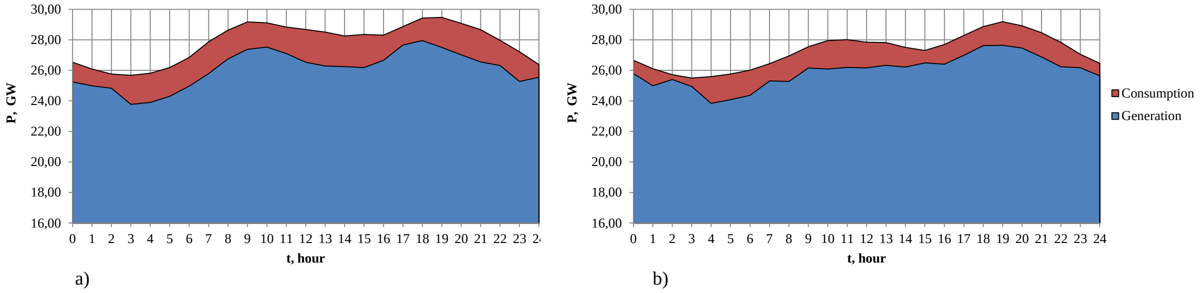

Figure 6.5 – Energy consumption a) workday (14.01.2013); b) holiday (20.01.2013) [47]

2. Energy consumption on February

Two diagrams of energy from this time of the year were investigated (Figure 6.6). Energy consumption on workday also can be specified by two peaks with maximum points P_{m1}=29,2 GW and P_{m2}=28,9 GW. In the morning the peak time is from 8 to 12 o'clock and in the evening it is between 17 and 22 o'clock. The energy consumption in holiday a little bit differs from consumption in workday. The load peak time in the morning is from 9 to 13 o'clock (P_{m1}=26,7 GW) and in the evening is from 17 to 22 o'clock (P_{m2}=27,6 GW).

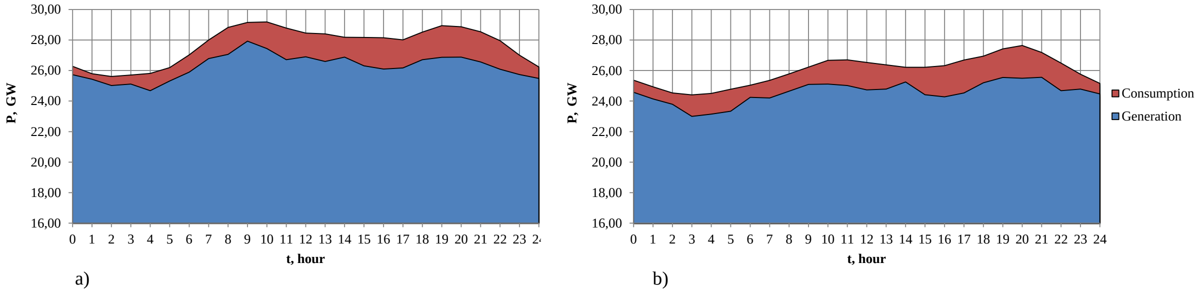

Figure 6.6 – Energy consumption a) workday (13.02.2013); b) holiday (24.02.2013) [47]

3. Energy consumption on March

The Figure 6.7 shows that the maximum points of consumption on workday are P_{m1}=26,6 GW and P_{m2}=26,9 GW. The peak time is from 7 to 13 o'clock and in the also between 18 and 22 o'clock. In case of holiday the maximum points are P_{m1}=25,9 GW and P_{m2}=26,5 GW. The first peak time is from 9 to 13 o'clock and the second one is from 18 to 22 o'clock.

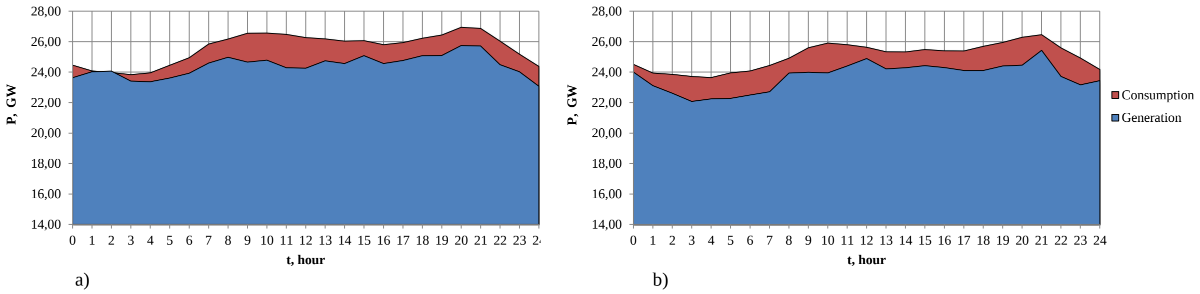

Figure 6.7 – Energy consumption: a) workday (18.03.2013); b) holiday (24.03.2013) [47

4. Energy consumption on April

As the Figure 6.8 shows the maximum points of consumption on workday are P_{m1}=24,9 GW and P_{m2}=25,2 GW. The peak time is from 8 to 12 o'clock, from 14 to 16 o'clock and between 19 and 22 o'clock. On holiday the maximum points are P_{m1}=23,9 GW and P_{m2}=24,3 GW. The first peak time is from 9 to 13 o'clock and the second one is from 19 to 22 o'clock.

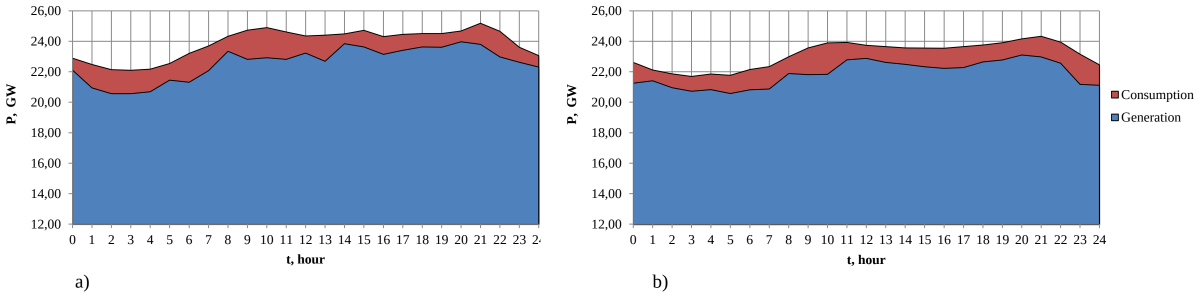

Figure 6.8 – Energy consumption: a) workday (15.04.2013); b) holiday (21.04.2013) [47]

5. Energy consumption on May

The values of maximum consumption in the morning and in the evening are equal to P_{m1}=23,4 GW and P_{m2}=23,5 GW respectively. On workday the consumption doesn't change significantly from 9 to 16 o'clock, the load peak in the evening is from 20 to 22 o'clock. On holiday the maximum points are P_{m1}=22,6 GW and P_{m2}=24,8 GW. The first peak time is from 9 to 13 o'clock and the second one is from 19 to 22 o'clock (Figure 6.9).

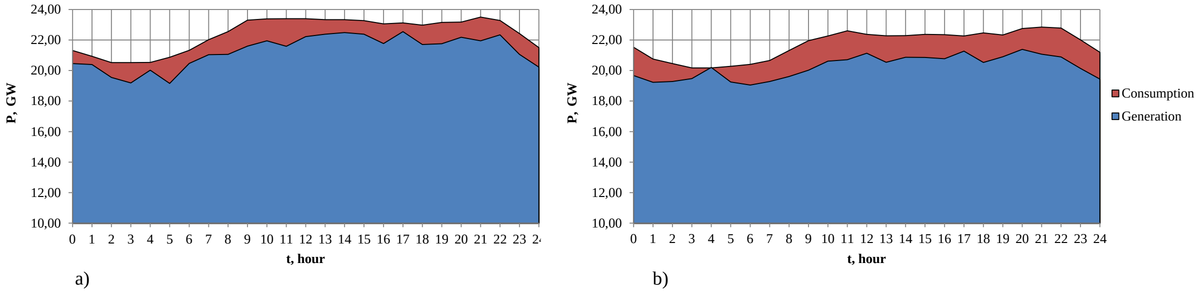

Figure 6.9 – Energy consumption: a) workday (13.05.2013); b) holiday (19.05.2013) [47]

6. Energy consumption on June

The maximum points of consumption on workday are P_{m1}=21,4 GW and P_{m2}=21,2 GW. On workday the maximum consumption points doesn't change more than 0,5 GW from 9 to 22 o'clock. On holiday the maximum points are P_{m1}=20,5 GW and P_{m2}=20,3 GW. The first peak time is from 9 to 12 o'clock and the second one is from 20 to 23 o'clock (Figure 6.10).

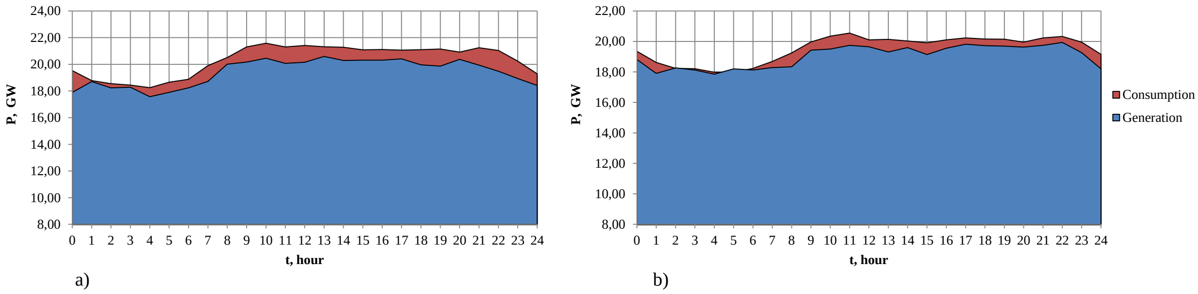

Figure 6.10 – Energy consumption: a) holiday (17.05.2013); b) holiday (23.06.2013) [47]

7. Energy consumption on July

In case of workday there are not certain load peaks. As the Figure 6.11 shows that two maximum points can be obtained (P_{m1}=21,1 GW and P_{m2}=21,1 GW). On workday the consumption almost does not change from 9 to 22 o'clock. On holiday the maximum points are P_{m1}=20,1 GW and P_{m2}=20,2 GW. There are several small load peaks from 10 to 23 o'clock.

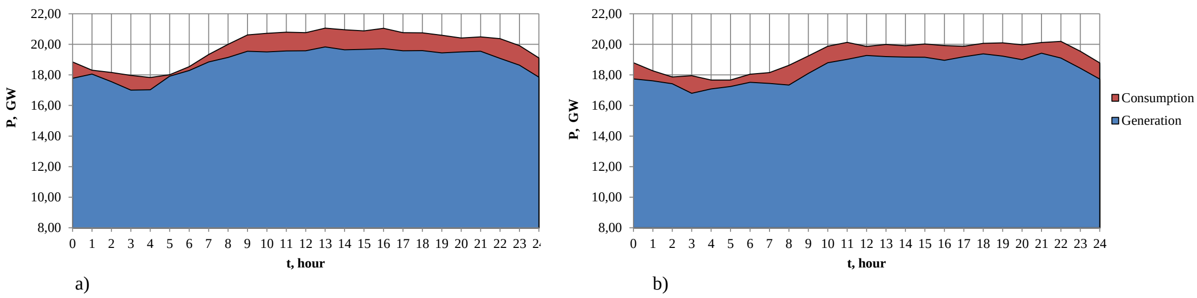

Figure 6.11 – Energy consumption: a) workday (15.05.2013); b) holiday (21.07.2013) [47]

8. Energy consumption on August

In case of workday there are not certain load peaks in the morning and in the evening; the consumption at this time is approximately the same. The maximum point is equal to 21,2 GW. On holiday the maximum points are P_{m1}=20,3 GW and P_{m2}=21,1 GW. The first load peak is from 9 to 13 o'clock and the second peak is from 19 to 22 o'clock (Figure 6.12).

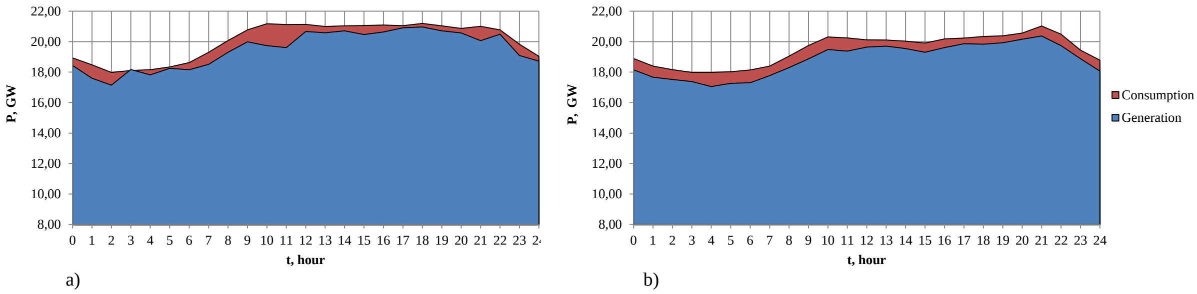

Figure 6.12 – Energy consumption: a) workday (19.05.2013); b) holiday (25.07.2013) [47]

9. Energy consumption on July

On workday the load peak in the morning is from 9 to 12 o'clock and the load peak in the evening is from 18 to 22 o'clock.. These maximum points are equal P_{m1}=23,2 GW and P_{m2}=23,7 GW. On holiday the maximum points are P_{m1}=23,3 GW and P_{m2}=24,2 GW. There are two load peak: the first one is from 10 to 12 o'clock and the second one is from 18 to 22 o'clock (Figure 6.13).

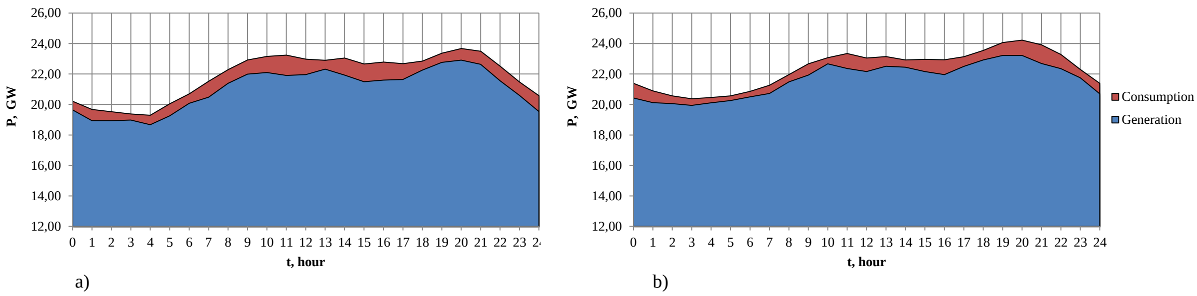

Figure 6.13 – Energy consumption: a) workday (16.09.2013); b) holiday (22.09.2013) [47]

10. Energy consumption on October

On workday the load peak in the morning is from 7 to 11 o'clock and the load peak in the evening is from 17 to 22 o'clock. These maximum points are equal P_{m1}=24,5 GW and P_{m2}=25,3 GW. On holiday the maximum points are P_{m1}=24,3 GW and P_{m2}=25,5 GW. There are two load peaks: the first one is from 9 to 14 o'clock and the second one is from 16 to 22 o'clock (Figure 6.14).

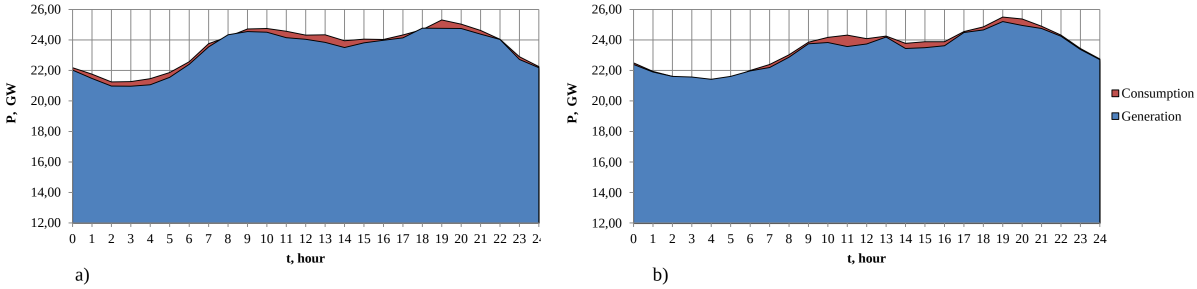

Figure 6.14 – Energy consumption: a) holiday (14.10.2013); b) holiday (20.10.2013) [47]

11. Energy consumption on November

On workday there are two certain load peaks: from 7 to 11 o’clock and from 17 to 22 o’clock. These maximum points are equal P_{m1}=25,4 GW and P_{m2}=26,2 GW. On holiday the maximum points are P_{m1}=24,9 GW and P_{m2}=25,5 GW. There are two load peaks: the first one is from 9 to 13 o’clock and the second one is from 16 to 22 o’clock (Figure 6.15).

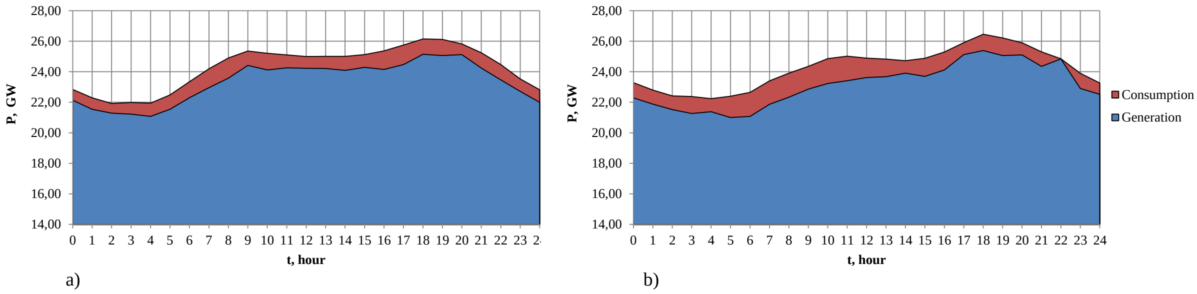

Figure 6.15 – Energy consumption: a) holiday (19.10.2013); b) holiday (25.10.2013) [47]

12. Energy consumption on December

On workday the load peak in the morning is from 7 to 11 o’clock and the load peak in the evening is from 17 to 21 o’clock. These maximum points are equal P_{m1}=27,2 GW and P_{m2}=27,5 GW. On holiday the maximum points are P_{m1}=26,6 GW and P_{m2}=27,8 GW. There are two load peaks: from 9 to 13 o’clock and from 15 to 22 o’clock (Figure 6.16).

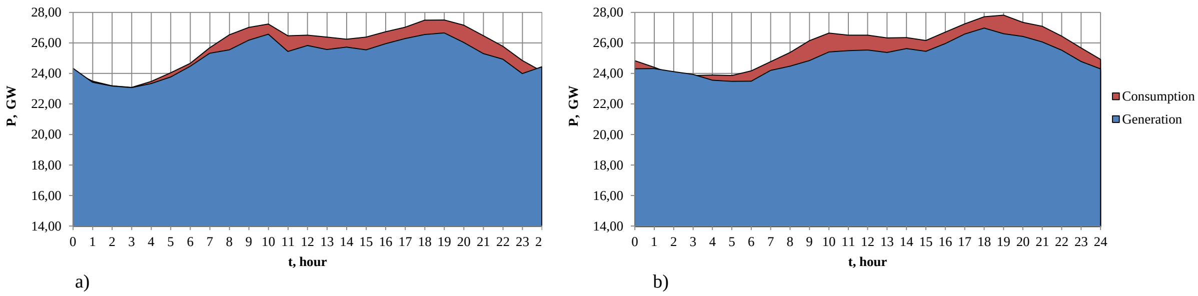

Figure 6.16 – Energy consumption: a) holiday (16.10.2013); b) holiday (22.10.2013) [47

7. Economic model of the project

7.1. Methodology of calculation

Methodology of calculations was divided into two parts: technical and economic parts. Technical part includes several calculations before and after installation of RC technology, such as finding power losses before and after RC installation and also difference between these two values. The economic part includes computations of Energy Cost Saving (ECS), ICS (Investment Cost Savings) and also Total Cost savings). All work stages are described in detail below.

1. Losses of power lines

Power generated in power plants passes through large and complex networks and finally reaches electrical consumers. It is known that some percentage power lost in transformers, overhead lines and in cables. The difference in the generated and consumed energy is power losses. The methodology includes only losses in power lines. Power losses of overhead lines depends on specific conductors, transmitting power, voltage level of the power line and resistance. The first step is to calculate the losses of power lines by using this formula [47]:

$$\Delta P_{pl} = \frac{P^2 + Q^2}{U^2} \cdot R \tag{7.1}$$

where P – transmitted active power, Q – reactive power, U – voltage class, R – resistance of power line.

The second step is to find the losses power lines after RC implementation. It can be determined by using the same formula.

2. Energy losses

The value of energy losses can say how much energy can be decreased due RC usage.

$$\Delta W = \sum_{n=0}^{24} \Delta P_n \cdot t_n \tag{7.2}$$

3. Unpaid electricity consumption or illegal electricity use

The connection or to put it direct «Stolen Electricity» accounts for certain percent from the public consumption of electricity in the country. The illegal electricity use can increase energy losses significantly. The result of this fact is increasing of energy cost. In illegal usage a consumer uses the following ways:

- Application of mechanical objects can be prevent revolution of meter. In this way, the recorded energy is reduced by slowing the disk speed.

- A subscriber can use a special magnet to change electromagnetic field of the coils. It is known that the recorded energy is proportionally associated with electromagnetic field.
- Using the external phase before meter can give free energy without recording.
- Switching the cables at the meter leads to changing of current direction. The current does not flow through the current coil of the meter and energy can be recorded.

4. Operation schedule of the power for heating

This point is confined in obtainment of the operation time for heating equipment. Heating devices should be switched off at certain time, approximately from 8 to 11 hours and from 13 to 19 hours. RC system can switch on this heating device, for instance, at night time. In other words, this procedure will lead to load leveling.

5. Difference between values of power losses

After that, it is possible to find the difference between two values of power losses before and after RC usage by using formula (7.3). This difference shows on which value the power losses per certain hour are increased or decreased due to RC operation. Obtained ΔP will be used in following calculations.

$$\Delta P = \Delta P_{pl} - \Delta P_{pl+RC} \tag{7.3}$$

6. Evaluation of the cost savings

Total costs savings (TCS) can show the profitability of the project. It consists of energy cost savings (ECS) and investment cost savings (ICS) and can be defined by using simple equation:

$$TCS = ECS + ICS \tag{7.4}$$

ECS includes information about benefits or losses, which can take a place at particular hour. It can be determined by the formula:

$$ECS = \Delta P \cdot C_1 \tag{7.5}$$

where ΔP includes power losses and illegal electricity use; C – the electricity price per MWh.

Investment costs saving (ICS) in power generation area depend on type of the power plant and specific conditions in the country. These costs include overnight costs for all technologies as well as the implied interest during construction.

$$ICS_{annual} = \Delta P \cdot C_2 \cdot a - n \cdot C_3 \cdot a \tag{7.6}$$

where ΔP – difference between values of power losses with and without RC, C_2 – investment costs of electricity per kW (Tab.3), n – amount of applied storage heaters and RC receivers, C_3 – the total price for storage heater and RC receiver, a - annuity factor.

7.2. Escalation rates

The economic model requires defining some escalation rates, such as growth of electricity price, annual growth of energy consumption and discount rate.

A growth in electricity price is a hardly predictable value and it is expected to grow together with inflation level. Historical data of inflation rate changing in Russia with current inflation rate 6,1% is illustrated in the Figure 7.1. The Central Bank of Russian Federation defined the target inflation equal to 5% [56]. A growth in electricity price is assumed to equal to 6%, because historical data shows that real inflation rate almost was not less than target inflation rate.

Figure 7.1 – Annual inflation rate from 2000 to 2014 years [57]

Analysis of Unified Energy System of the Russian Federation say that the annual growth of electricity consumption in Siberian District is expected to be 0,6 % per year. The method of its determination is based on calculations of industrial sector and non-industrial sector needs, including population needs. Combination of electrical capacity for the particular period and economic growth forecast allows obtaining the projected power consumption [63].

One of possible ways for evaluation of discount rate is to apply Capital Asset Pricing Model (CAPM). This model consists of several components: the risk-free rate and coefficient beta and market risk premium. In theory, CAPM is an expectational model, because the input parameters are expected values in future.

- Risk-free rate (r_f) is the rate of return of an investment without risk. It shows an expected interest of an investor from risk-free investment during a particular period of time. The yields on government securities are typically used as risk-free rate by financial managers. Risk-free rate of national government bond « RFLB 36 6.90» is equal to 9,1% [58].

- Market risk premium $(r_m - r_f)$ is the difference between the market return and a risk-free rate. Market risk premium for Russian Federation is taken from a special survey made by IESE Business School. The average value of this parameter is equal to 7,3% [59].
- A Beta (β) measures the sensitivity of changes in the returns of the project to changes in the returns of the market. One of possible ways to estimating Beta of the project is to identify several companies in the similar line of business as proposed project and evaluating their Betas. Hence, the value of Beta is taken from the research of Prof. Damadaran and it is equal to 1,07 for electrical equipment [60].

Then, a discount rate can be calculated by following formula:

$$r = r_f + \beta \cdot (r_m - r_f) = 9{,}1 + 1{,}07 \cdot 7{,}3 = 16{,}9\% \qquad (7.7)$$

All escalation rates are unexpected values and they can change by unpredictable way. To know how these parameters influence on the project the sensitivity analysis has developed.

7.3. Economic evaluation of the project

As it said before in the methodology, the all calculations can be divided into technical and economic parts. In case of Siberian Region this methodology has complex view due to futures of its generation and consumption. The software package Excel was used as tool finding economic evaluation of the project. The logic structure of the Excel model is represented in the Figure 7.2.

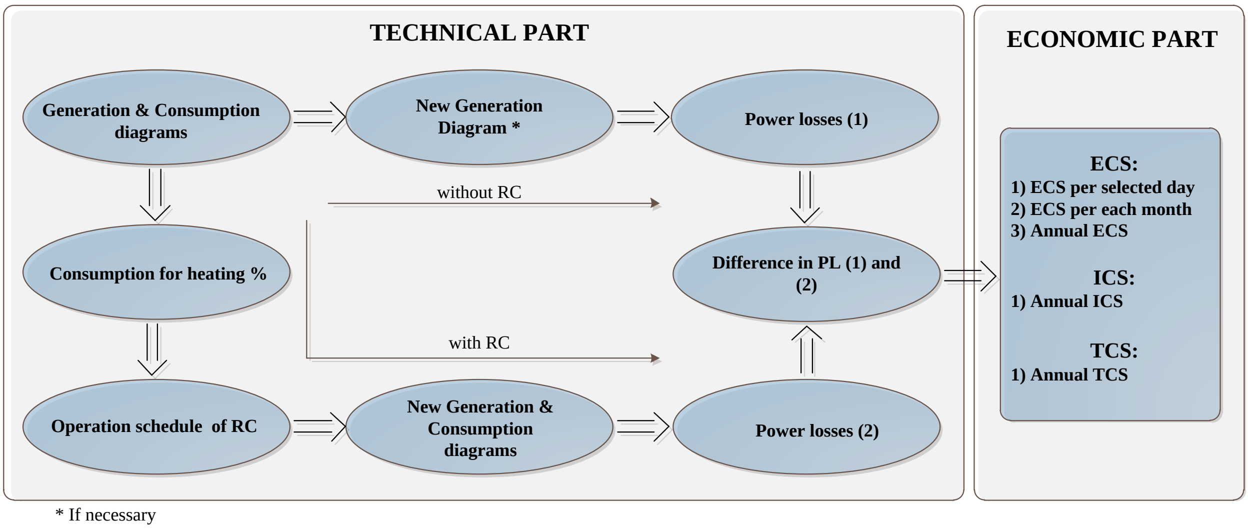

Figure 7.2 – The Structure of the Excel model

The technical part of calculations without RC comprises the computation of new generation diagram and power losses. In case of Siberian region and other regions, where the initial generation do not cover all energy consumption, it is necessary to obtain new generation diagram. The second part of technical calculation with RC technology includes estimation of electrical energy consumption used for heating, scheduling of RC operation due to time of use pricing in Siberia, finding out a new consumption and generation with built-in RC and calculating power losses. The main purpose of the technical part in the model is to find the difference between power losses before and after RC implementation. This information will be used in the economic part of the model. To know the difference of power losses it is need to evaluate ECS per selected day and afterwards annual ECS can be found ICS includes investment costs for storage heaters and also all costs for installed power. The analysis of RC installation is described below for one of the day (20th of January). Afterwards, all diagrams presented in the chapter 6.2 were investigated in the same way.

1. **Losses in power lines**

Losses in power lines were determined by using formula (7.1). In economic calculations reactive power in this formula is not significant and can be accepted to equal to 0. From the Table 6.1 it may be concluded that there are a lot of power lines with different voltage level and obviously with different resistances of power line. Accurate calculations of power losses require the scheme of whole Siberian interconnected power system and actually this is time consuming process. On the other hand, it is possible to find power losses in an alternative way by using approximations of necessary functions with some uncertain data. To use this method, the formula (7.1) can be transformed into following equation:

$$\Delta P_{Li} = P_{Gi}^{\ 2} \cdot k_1 \tag{7.8}$$

where P_{Gi} is generated power for particular hour;

$k_1 = \dfrac{R}{U^2}$ is uncertain coefficient due the complex scheme of considered IPS.

Energy losses for twenty-four hours in power lines can be described by the next equation:

$$\sum_{i=0}^{24} P_{Gi}^{\ 2} \cdot k_1 = W \cdot k_2 \tag{7.9}$$

where k_2 is coefficient indicating how much energy is lost throughout the transmission.

Energy losses throughout the transmission include energy losses in power lines and illegal electricity usage. The value of coefficient k_2 can be obtained by measuring of generated energy and consumed energy and further by finding the difference between these two energies.

The equation for calculation of power losses might be formed from equations (8) and (9),. The estimated value of energy losses was selected in accordance with statistic database of Ministry of Energy of the Russian Federation [50]. For example, k_2 is assumed to be 11% (10% - losses in power lines and 1% is unpaid power).

$$\Delta P_{Li} = \frac{W \cdot P_{Gi}^2 \cdot k_2}{\sum_{i=0}^{24} P_{Gi}^2} \tag{7.10}$$

The power losses can be easily calculated by using data from load diagram, especially from generation dependence. The results of calculations are represented in the Table 7.1.

Table 7.1 – Calculation of losses in power lines

Time, h	Generation, GW	Consumption, GW	Losses, GW
0	25,788	26,652	2,816
1	24,986	26,101	2,643
2	25,396	25,710	2,731
3	24,945	25,485	2,635
4	23,836	25,580	2,406
5	24,074	25,754	2,454
6	24,358	26,009	2,512
7	25,298	26,433	2,710
8	25,269	26,937	2,704
9	26,140	27,545	2,893
10	26,083	27,941	2,881
11	26,186	28,004	2,903
12	26,158	27,839	2,897
13	26,322	27,817	2,934
14	26,207	27,500	2,908
15	26,484	27,297	2,970
16	26,401	27,689	2,951
17	26,977	28,282	3,082
18	27,610	28,857	3,228
19	27,635	29,178	3,234
20	27,458	28,919	3,192
21	26,878	28,464	3,059
22	26,227	27,822	2,913
23	26,161	27,047	2,898
24	25,636	26,458	2,783

After calculation of power losses the value of coefficient k_1 was found by using equation (7.8). The formula shows this coefficient is variable number depending of power losses and generated power. This coefficient is equal to 0,004 for selected day.

$$k_1 = \frac{\Delta P_{Li}}{P_{Gi}^2} \qquad (7.11)$$

2. New generation diagram

As it was stated before and also as it can be seen from load diagram the consumption of Siberian Region is higher than its generation. Additional energy is importing from other regions and also from neighbor countries. Thus, new actual generation diagram must be found and in this way the whole consumption can be covered. Hence, this generation diagram includes energy generated in Siberia and also energy imported from neighbor interconnected power systems. The generated power was calculated from the following equations:

$$\begin{aligned} \Delta P_{Li} &= P_{Gi} - P_{Ci} \\ \Delta P_{Li} &= P_{Gi}^2 \cdot k_1 \end{aligned} \qquad (7.12)$$

where P_{Ci} - consumed power for particular hour.

New generated power will only depend on consumption power and coefficient k_1:

$$P_{Gi} = -\frac{\sqrt{1 - 4 \cdot P_{Ci} \cdot k_1} - 1}{2 \cdot k_1} \qquad (7.13)$$

Finally, total generated energy is equal to 786,3 GWh. New generation diagram is provided in the Figure 7.3.

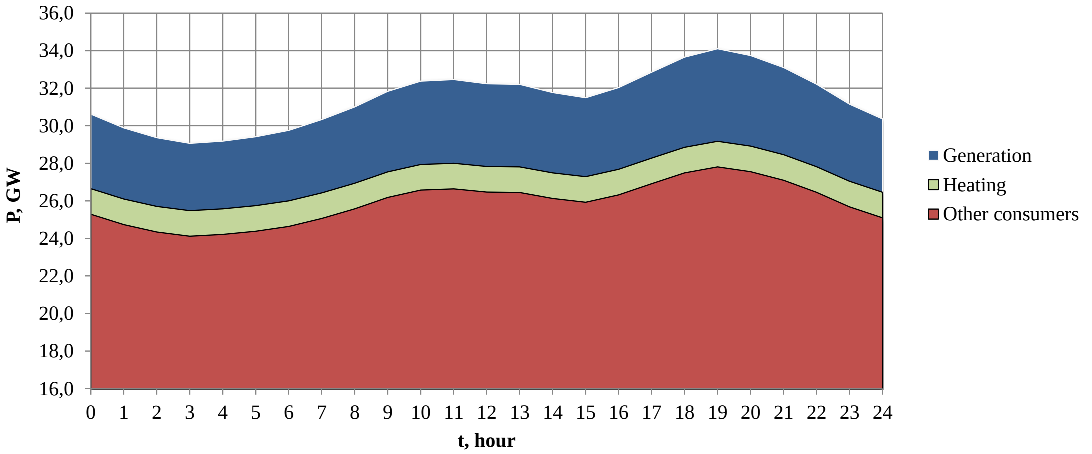

Figure 7.3 - New generation, heating and consumption diagrams with losses

New power losses were obtained by using formula (7.8). Total calculated energy losses are equal to 104,93 GWh. Also, the one more way for determination of power losses is to use the formula (7.10). But in this case, it is necessary to find the value of the coefficient k_2, because this coefficient is changing day by day. As the formula (7.1) shows, the more power is transmitted, the more losses are in power lines. In fact the percentage ratio between losses and generation power will be more than 10%. Table 7.2 shows calculated generation and losses for the whole day.

Table 7.2 - New data for generation diagram and calculated losses

Time, h	Generation, GW	Consumption, GW	Losses, GW
0	30,623	26,652	3,971
1	29,882	26,101	3,781
2	29,360	25,710	3,650
3	29,061	25,485	3,576
4	29,187	25,580	3,607
5	29,419	25,754	3,665
6	29,759	26,009	3,750
7	30,328	26,433	3,895
8	31,008	26,937	4,071
9	31,837	27,545	4,292
10	32,381	27,941	4,440
11	32,468	28,004	4,464
12	32,240	27,839	4,401
13	32,210	27,817	4,393
14	31,775	27,500	4,275
15	31,498	27,297	4,201
16	32,034	27,689	4,345
17	32,852	28,282	4,570
18	33,652	28,857	4,795
19	34,102	29,178	4,924
20	33,739	28,919	4,820
21	33,104	28,464	4,640
22	32,217	27,822	4,395
23	31,158	27,047	4,111
24	30,361	26,458	3,903

3. Energy consumption for heating.

It is not expected, what the percentage ratio of electrical energy consumption for heating in the whole Siberian consumption can be. It is known that the values of consumption for heating in workdays and off days will be different. In workdays, there is no need to maintain the particular temperature level in the houses, because in most cases all people work and they are not at home. In weekend, this is reverse situation: people mostly stay at home and obviously that maintaining the temperature level in the house is important. The average value of household electrical energy consumption is around 12% [68]. According to this information, the consumption for heating is proposed to equal to 5% for off days and 4% for workdays. The value of heating consumption for each hour is can be found from average consumption:

$$P_{HC_i} = k_3 \cdot P_{Cav} \tag{7.14}$$

where k_3 - coefficient that shows the percentage value of heating consumption.

Coefficient k_3 has not to be the constant value for the whole year, because the heating needs are known to be different in each month. For instance, the electricity consumption for heating in the winter period is significantly higher than in summer time. In this way one more coefficient k_4 will be used. This coefficient shows how much energy is consumed for heating in the selected month. The formula for determination this coefficient:

$$k_4 = \frac{(T_{max} - T_{av.})}{(T_{max} + |T_{min}|)} \tag{7.15}$$

where T_{max} is the maximum temperature in the year;

$T_{av.}$ is average temperature in the month;

T_{min} is minimum temperature in the year.

These temperatures can be found by using data about average temperature in Siberian region. Average temperature of the large towns in Siberia such as Novosibirsk, Omsk, Tomsk, Barnaul, Kemerovo, Irkutsk, Ulan-Ude, Chita, Abakan, Krasnoyarsk were taken to account in this investigation. The results of this investigation are illustrated in the Table 7.3.

Table 7.3 – Information about average temperature for cities and towns in Siberia [72]

Cities	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
Novosibirsk	−16,5	−14,8	−7,6	2,3	11,8	17,1	19,4	16,6	10,2	3,1	−6,9	−14
Omsk	-16,3	-15	-7,3	3,7	12,5	18	19,6	16,9	10,4	3,5	-7,3	-13,8
Tomsk	-17,1	-14,7	-7	1,3	10,4	15,8	18,7	15,7	9	1,7	-8,3	-15,1
Barnaul	-15,5	-13,7	-6,5	3,8	12,8	17,7	19,9	17,4	11	3,8	-6,3	-12,9
Kemerovo	-17	-14,7	-7,3	1,9	11,2	16,5	19	16,2	9,6	2,4	-7,4	-14,5
Irkutsk	-17,9	-14,6	-6,5	2,5	10,2	15,4	18,2	15,8	9,1	1,7	-7,7	-15,4
Ulan-Ude	-23,4	-17,9	-7,4	2,4	10,6	16,9	19,8	17,1	9,6	0,7	-10,1	-19,3
Chita	-25,1	-19,2	-9	1,6	9,7	16,4	18,7	16	8,7	-0,4	-12,6	-21,9
Abakan	-17	-15	-4	3	11	17	19	17	10	2	-8	-16
Krasnoyarsk	-15,5	-12,8	-5,7	2,5	10,9	16,2	19,1	15,7	9,9	2	-7,2	-13,4
Average	**-18,3**	**-15,3**	**-6,7**	**2,5**	**11,0**	**16,7**	**19,1**	**16,4**	**9,7**	**1,9**	**-8,3**	**-15,8**
Coefficient	**1,00**	**0,92**	**0,69**	**0,44**	**0,22**	**0,07**	**0,00**	**0,07**	**0,25**	**0,46**	**0,73**	**0,93**

Then, the formula for determination of electricity consumption for heating will have following format:

$$P_{HC_i} = k_3 \cdot k_4 \cdot P_{Cav} \tag{7.16}$$

The average consumption power in considered day is 27,3 GW, the coefficient k_3 is 5% from the whole consumption and the coefficient k_4 is equal to 1 for January (Table 7.3). Hence, electricity consumption for heating will is equal to 1,4 GW.

4. Operation schedule of Ripple Control.

RC sends a special signal to customer in peak time that the heating devices must be switched off. After that, this heating energy should be added in night time, when the electricity price is less. According to Time of Use pricing presented in the Table 6.2 the operation schedule of RC for the selected day (20^{th} of January) was developed. The heating consumption was switched off at peak time from 9 to 12 and also from 18-21 hours. Realized power was switched on at off-peak (night) time from 23 to 7 hours, when electricity price is less, than the price during the day. Consumption for heating in middle peak time has not been changed and it means that some amount of storage heaters will work in this period of time.

5. New generated power and power losses with RC implementation.

If compare diagrams of consumption from Figure 7.3 and Figure 7.4 the consumption before RC integration is higher in peak times than the consumption in case of RC operation. It is known that the higher energy transmit through the power line, the higher part of power will lost. In such way power losses is decreased due to RC usage. The formulas for calculation of generated power and power losses are represented above (Formulas 7.13, 7.8). Total generated energy is equal to 786,1 GWh and total energy losses are equal to 104,7 GWh (Table 7.4).

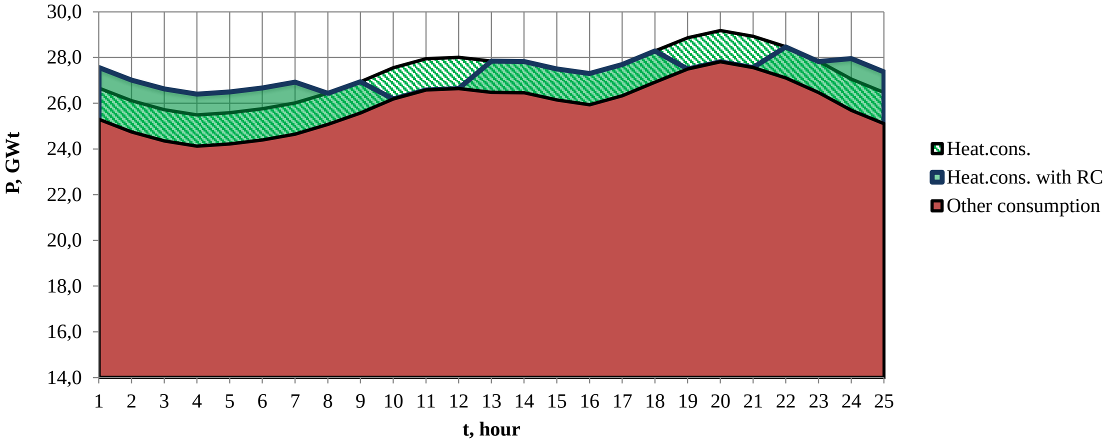

Figure 7.4 - Consumption for heating without and with RC and other consumption

As it seen from the Figure 7.4 the consumption for heating was switched off in peak time and was shifted into night time. In this case, power losses are less than in the model without RC usage and also daily costs for consumption for heating are reduced.

6. Difference between power losses for each hour before and after RC.

This difference can be easily found by using proposed formula (7.3).The Table 7.4 includes information about generation, consumption, consumption for heating, obtained losses also difference in losses after RC integration during the day. The negative sign of this difference say that power losses increased for particular hour due to RC integration and conversely the positive sign shows that power losses decreased. In mid-peak time the difference between power losses is equal to 0, because power consumption for heating and obviously the whole power consumption haven't changed.

Table 7.4 - Calculated data for Siberia with RC

Time	Generation, GW	Consumption, GW	Heating, GW	Losses, GW	Difference, GW
0	31,858	27,56	2,271	4,298	-0,327
1	31,107	27,009	2,271	4,097	-0,316
2	30,577	26,618	2,271	3,959	-0,309
3	30,274	26,393	2,271	3,881	-0,305
4	30,402	26,488	2,271	3,914	-0,307
5	30,637	26,662	2,271	3,974	-0,31
6	30,982	26,917	2,271	4,064	-0,315
7	30,328	26,433	1,363	3,895	0
8	31,008	26,937	1,363	4,071	0
9	29,991	26,182	0	3,809	0,483
10	30,523	26,578	0	3,945	0,495
11	30,608	26,641	0	3,967	0,497
12	32,24	27,839	1,363	4,401	0
13	32,21	27,817	1,363	4,393	0
14	31,775	27,5	1,363	4,275	0
15	31,498	27,297	1,363	4,201	0
16	32,034	27,689	1,363	4,345	0
17	32,852	28,282	1,363	4,57	0
18	31,768	27,494	0	4,273	0,522
19	32,208	27,815	0	4,392	0,532
20	31,852	27,556	0	4,296	0,524
21	33,104	28,464	1,363	4,64	0
22	32,217	27,822	1,363	4,395	0
23	32,401	27,955	2,271	4,445	-0,335
24	31,593	27,366	2,271	4,226	-0,323
Total	**786,047**	**681,320**	**34,066**	**104,727**	**0,207**

After that, energy losses should be computed by the formula (7.2). The result shows that energy losses decreased on 0,2 GWh due to RC implementation.

7. Evaluation of the costs saving.

Energy costs savings (ECS) from formula (7.4) can be defined by following formula:

$$ECS = \sum_{i=0}^{24} \Delta P_i \cdot C_{1i} \quad (7.17)$$

where ΔP_i is the difference in power losses at particular time;

C_{1n} – the electricity price per kWh.

As it said above electricity price are divided into three types: peak time, mid-peak time and off-peak time. To know this information and also difference between power losses the twenty-four energy costs were found. The obtained value of energy cost savings are equal to 3,2 million rubles per selected day. It is obviously that the magnitude of ECS will change depending on the day, month and year. This is the reason why additional parameters, such as annual consumption growth, growth of electricity price and also operation schedule of RC were investigated and included in the model of the project.

ECS for particular month can be obtained:

$$ECS_n = ECS_{workday} \cdot N_{work\ day} + ECS_{offday} \cdot N_{off\ day} \quad (7.18)$$

where $ECS_{workday}$ - energy cost saving in workday;

$ECS_{off\ day}$ - energy cost saving in off day;

$N_{workday}$ - amount of workdays in the considered month;

$N_{off\ day}$ - amount of off days in the considered month.

The results of ECS calculations for all months during 40 years are illustrated in the Appendix 1. In the proposed methodology it is need to find out the annual ECS that can be computed by this way:

$$ECS_{annual} = NPV_{ECS} \cdot a \quad (7.19)$$

where a - annuity factor;

NPV - the sum of present values of each year’s ECS for the whole period.

To know possible ECS for each year of the project, NPV for proposed period of the project (40 years) can be defined by following equation:

$$NPV_{ECS} = \sum_{n=0}^{40} \frac{ECS_n}{(1+r)^n} \tag{7.20}$$

where ECS_n - energy cost savings depending on the year;

r – discount rate.

Next step is to find annuity factor. Annuity factor was found out for 40 years:

$$a = \frac{r}{1-(1+r)^{-n}} \tag{7.21}$$

Excel model allows determining ECS-s not only for each month, but also for each year during the whole period of the project (Appendix 1). To know information about year's ECS, the PV, NPV and annual ECS can be determined. In consequence of executed computations, NPV_{ECS} is equal to 7,4 billion rubles, $ECS_{an.}$ is 1,2 billion rubles.

ICS can be found by applying the formula (7.6). As it stated above in the methodology, ICS in power generation area depend on type of the power plant, certain conditions in the country, storage heaters and their quantity. The investment costs of electricity (C_2) in the first part formula for several power plants in Russian Federation are represented in the Table 7.5.

Table 7.5 - Investment costs of electricity per kW [10].

Type of power plant	Investment costs, USD/kW	
	min	max
Nuclear	2500	3000
Thermal	1400	2000
Hydro	1840	2760
Wind	1200	2400
Solar	3500	4000
Smale-scale Hydro	2000	4000

As far as Siberian power plant do not cover all consumption, it is necessary to import additional energy from neighbor regions and countries. In this case, the first part of investment costs saving ($\Delta P \cdot C_2$) is equal to 0, because imported energy is not included to investment costs of installed power.

The second part of the formula (7.6) consists of investment cost for storage heaters. The price for storage heaters with installed power 3,4 kW is about 250-300 euro [69]. The price for RC receivers is 45-65 euro [78]. It was assumed that one RC receiver is used for two storage heaters. Thus, the amount of RC receivers depends on the number of storage heaters. In this case, the total price is assumed to equal to 300 euro (~15000 rubles). The amount of storage heaters can be calculated, if the maximum hourly consumption for heating is known. In accordance to previous calculation (Table 7.4) the maximum hourly consumption for heating is equal to ~2,3 GW. In the methodology this value (for 20th of January) is assumed to be the maximum for the year, because energy consumption for heating in this season is expected to be higher, than in other seasons due information about average temperature. Hence, the necessary amount of storage heaters can be computed by the formula:

$$n = \frac{P_{max.heat}}{P_{sh}} \tag{7.22}$$

where $P_{max.heat.}$ is average daily consumption for heating, P_{sh} is average consumption of storage heater per hour. The determined amount of storage heaters is 670 thousand.

Finally, it may be concluded that the annual energy cost savings of the project are 1,25 billion rubles, the annual investment costs savings (ICS_{annual}) are 1,7 billion rubles and consequently the total cost savings are equal to -450 million rubles.

7.4. Sensitivity analysis

Sensitivity analysis is applied to investigate how sensitive the project is to changes in some parameters. Results of the sensitivity analysis can help to learn a model of the project in detail by changing the uncertainties, which are associated with parameters of the project. A lot of parameters in the project model are values, which are difficult or impossible to measure and predict in the real world. Some parameters are changing year by year and also during the whole year. These parameters are uncertain values, but they must be estimated. Sensitivity analysis provides a possibility to determine, what level of accuracy is need for certain parameter to make the project sufficiently useful and profitable [61].

In sensitivity analysis influence of the uncertain factors on total investment costs was investigated. These factors are discount rate, ratio of power losses, energy consumption for heating, electricity price growth, annual energy consumption growth and price of storage heater (include the price for receiver).

7.4.1. Sensitivity analysis for discount rate

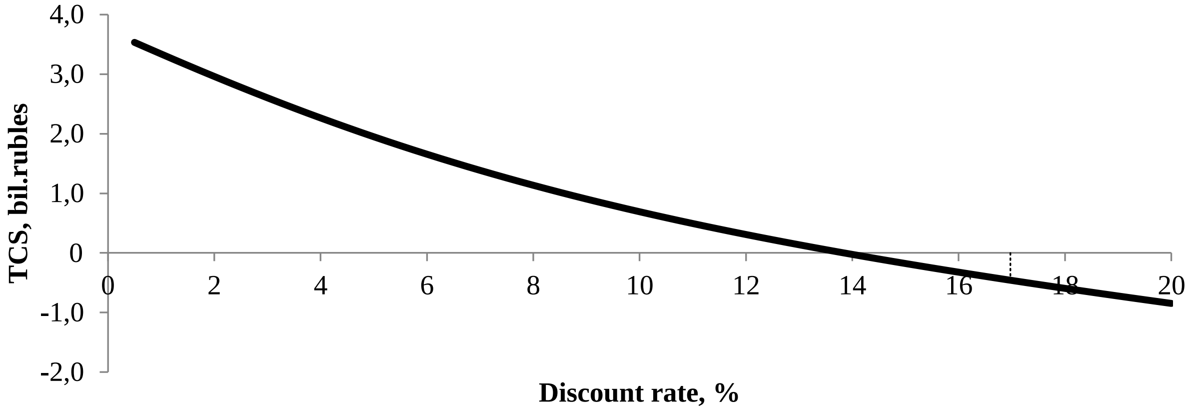

Figure 7.5 - Dependency of TCS on discount rate

The Figure 7.5 shows a strong dependence of TCS to the discount rate, which can be used for long-time project. It can be seen that increasing of discount rate lead to decreasing of TCS. The optimal value of discount rate has to be less than ~14%. Only in this case TCS will have positive value.

7.4.2. Sensitivity analysis for value of power losses

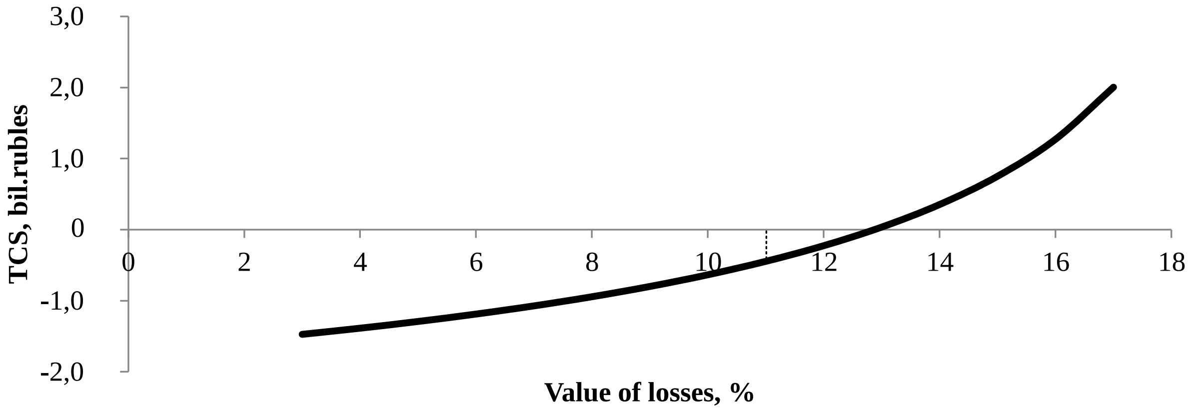

Figure 7.6 - Dependency of TCS on value of power losses

Figure 7.6 is focused on the dependence of TCS to the value of power losses. It can be concluded that if power losses are higher than ~13 %, TCS will be positive value. The reason of this dependency is that growth of power losses increase the difference between power losses before and after RC integration and consequently ECS and TCS.

7.4.3. Sensitivity analysis for energy consumption for heating

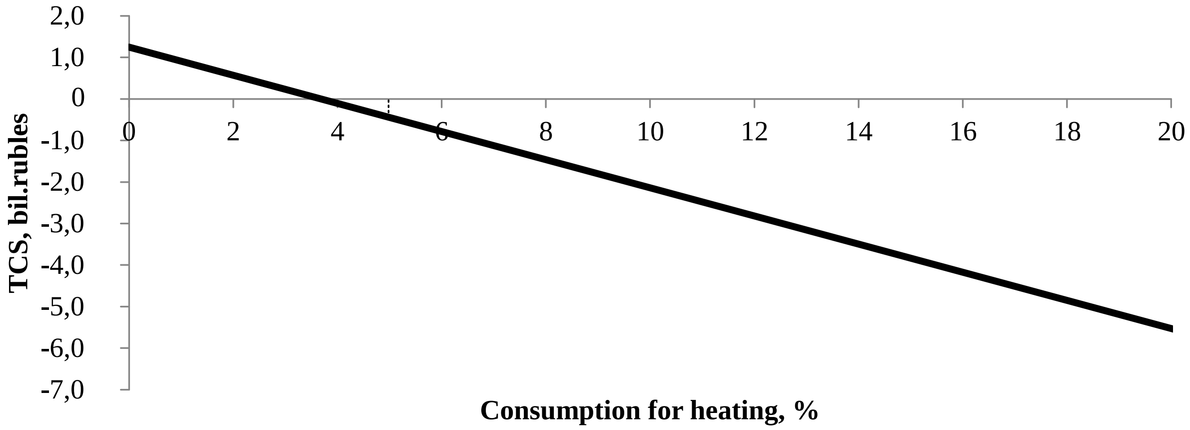

Figure 7.7 - Dependency of TCS on consumption for heating

Within the Figure 7.7 is contained the dependency of TCS on consumption for heating. It has declining type, because the growth of total consumption for heating leads to the growth of maximum hourly consumption for heating at night time after RC integration. According to previous calculations, ICS depends on the quantity of storage heaters and their price, in turn the maximum hourly consumption for heating influence on the quantity of storage heaters. In other words, increase of hourly consumption for heating will increase the quantity of storage heaters and, obviously, ICS. This is the reason why TCS is decreasing due to consumption for heating increase. It can be seen, that the project is useful, if value of energy consumption for heating will be less than ~ 4%.

7.4.4. Sensitivity analysis for annual consumption growth

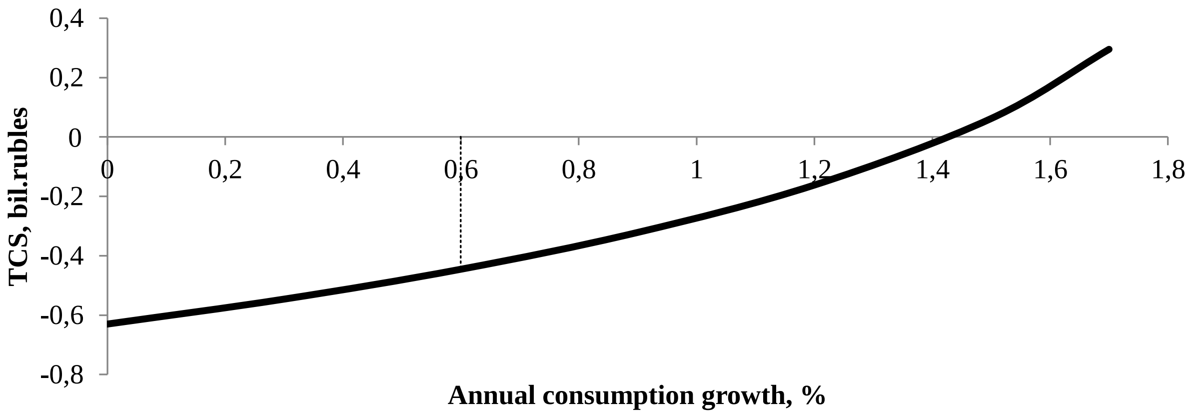

Figure 7.8 - Dependency of TCS on value of annual consumption growth

Figure 7.8 shows influence of annual consumption growth on TCS. Obviously, the higher consumption growth in Siberian region is, the higher power losses throughout power transmission are and therefore it will influence on the final results of ECS and TCS. If annual consumption growth will be a little bit higher than ~1,4 %, the project will be profitable.

7.4.5. Sensitivity analysis for electricity price growth

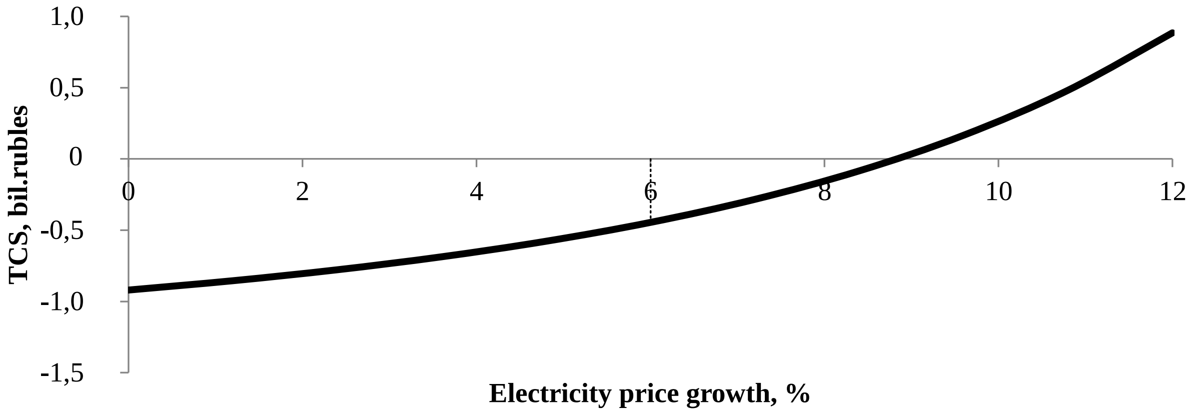

Figure 7.9 - Dependency of TCS on value of electricity price growth

Electricity price growth will influence on ECS and TCS (Figure 7.9). If electricity price grows, the value of ECS will increase and TCS also will increase. In this case, the most convenient value of electricity price growth (if other parameters have not been changed) is ~9%.

7.4.6. Sensitivity analysis for price of storage heater and RC receiver

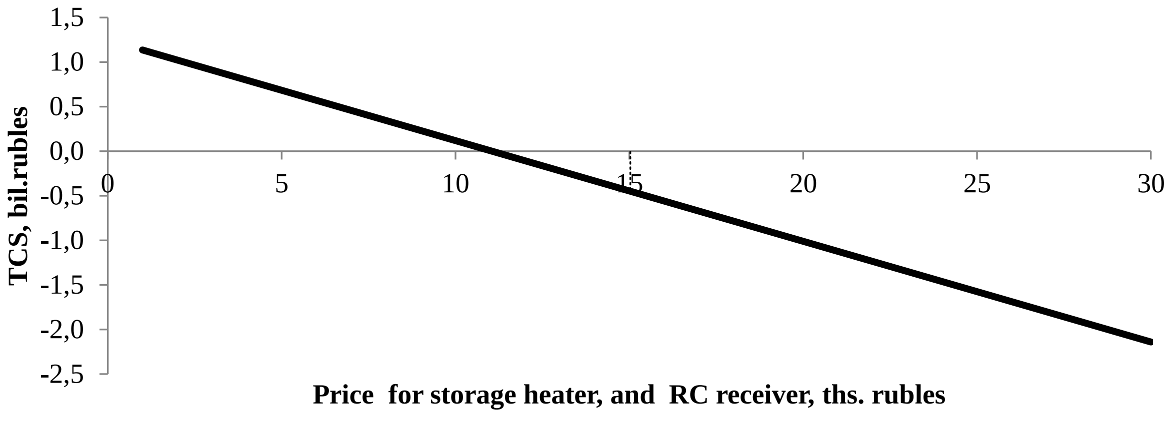

Figure 7.10 - Dependency of TCS on price of one storage heater

The current combined price for storage heater and RC receiver is about 15000 rubles, but if this price will decrease from 15000 to about 11000 rubles, the project will have a positive TCS. The reason is that the price is associated with ICS. The decrease of this price leads to ICS reduction and consequently TCS grows.

7.4.7. Sensitivity graph

Sensitivity graph shows TCSs of the project for changes in an input variable with unchanged all other input data. The slope of the line shows the sensitivity of the TCS of the project to each variable parameter. The steeper slope of the line indicates on the high sensitivity. The Figure 7.11 represents the sensitivity graph for all considered parameters. The most likely parameters are illustrated as reference point (0 on the graph). It was assumed that all data changes on 10%.

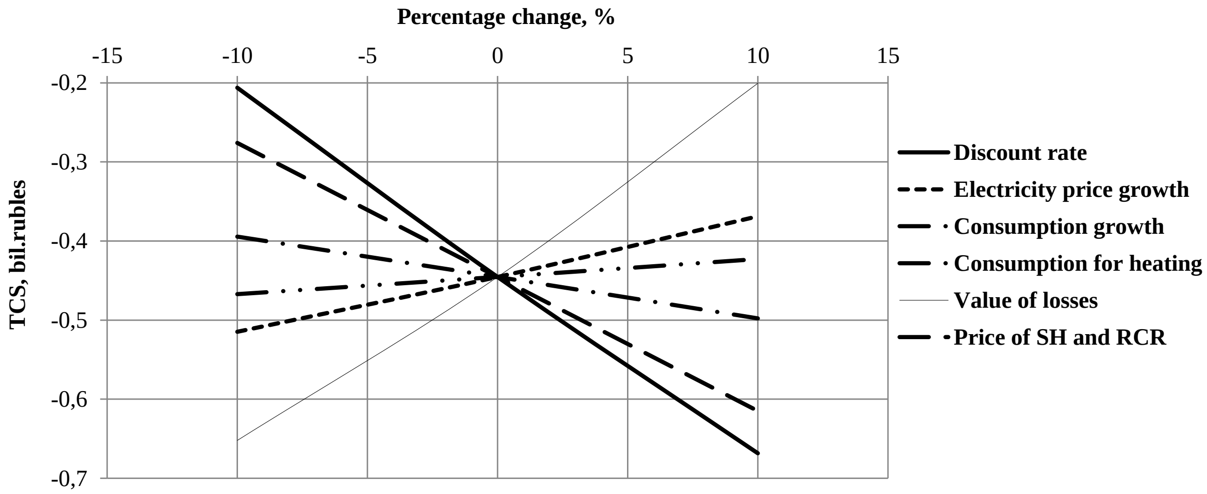

Figure 7.11 – Sensitivity graph

As it can be seen the TCS of the project is most sensitive to changes in discount rate, value of power losses and price of storage heater and receiver, followed by consumption for heating, electricity price growth and annual consumption growth. Thus, a small error in forecasting or small change of discount rate or value of power losses or price of storage heater can result in a larger error or larger change in TCS of the project, than with similar situation of any other parameters.

Sensitivity analysis has several major advantages. One of these strengths is that it helps to identify the input variables affecting a TCS of the project. This method indicates on the parameters that can lead to the most damage of the project. Hence, before any decision making, these parameters have to be investigated with the high accuracy. The second plus of this analysis is that all results can be easily interpreted. It is a simple picture of possible results on in the future without any probability estimations. Moreover, sensitivity analysis can provide information about risk of the project. Information about risk is important and useful especially if several projects are being compared with one another. In such way, the project with steeper sensitivity lines is more risky than the project with flatter sensitivity lines.

Nevertheless, sensitivity analysis has some disadvantages and limitations. First of all, this analysis does not include probabilities of possible future events associated with input parameters. One more minus of this method is that it shows impact on TCS (or NPV) only in one parameter. Also, sensitivity analysis does not provide any information about acceptance or rejection of projects.

7.5. Scenario analysis

Scenario analysis is a risk analysis method often used to estimate what will be with profitability estimates (for example NPV) under several different conditions of assumptions. It is a kind of sensitivity analysis, but unlike sensitivity analysis, scenario analysis describes the impact on final result of several changes in input variables (uncertain parameters). There are infinite options of different existing conditions, but scenario analysis usually consists of three scenarios: optimistic, most likely and pessimistic. In the optimistic scenario all variables are considered as better option than the most likely variant. In other words, if change in the initial values by certain way increase the final result (for example NPV) this is optimistic point of view. In this case, for instance, operating revenue will be increased and operating cost will be decreased. In the pessimistic scenario inversely, all variables are worse than the most likely values. For example, inflation rate and tax rate will be greater than expected and these conditions will decrease the final value. Optimistic and pessimistic scenarios are like possible forecast deviations from the most like scenario [62].

In the considered project the most likely scenario have the same parameters as assumed values in proposed methodology. In the optimistic and pessimistic scenarios the initial data vary from the values of most likely scenario on 20 %. It was assumed, because all uncertain initial parameters are hardly predictable. According to sensitivity analysis described above, the project will be profitable, if one group of parameters decrease and another group increase. The first group of uncertain parameters includes discount rate, consumption for heating, amount of storage heaters, price of storage heater. The second group is formed by electricity price, annual consumption growth and value of power losses. In this case, the optimistic scenario has to lead to high benefits and the pessimistic scenario is the opposite side of the optimistic scenario. To know this information the Table 7.6 was prepared.

Table 7.6 – Scenario analysis

Initial data	Scenarios		
	Pessimistic	Most likely	Optimistic
1. Discount rate, %	20,3	16,9	13,5
2. Electricity price growth, %	4,8	6	7,2
3. Consumption growth,%	0,5	0,6	0,7
4. Consumption for heating, %	6	5	4
5. Value of losses, %	8,8	11	13,2
6. Price of SH and RCR, rubles	18000	15000	12000
Final results			
ICS, mil. rubles	**2 900**	**1 700**	**870**
ECS, mil. rubles	**850**	**1 250**	**2 080**
TCS, mil. rubles	**-2 050**	**-450**	**1 210**

If the probabilities of all scenarios are known, the expected TCS and standard deviation can be obtained. It was assumed that the probability of most likely, optimistic and pessimistic scenarios are equal to 0,6; 0,2 and 0,2 respectively. Hence, the expected value of TCS can be found by using following formula:

$$TCS_{exp.} = TCS_{MLS} \cdot P_{MLS} + TCS_{OS} \cdot P_{OS} + TCS_{PS} \cdot P_{PS} \quad (7.23)$$

where TCS_{MLS}, TCS_{OS} and TCS_{PS} are total cost savings of each scenario (Table 7.6),

P_{MLS}, P_{OS} and P_{PS} are probabilities of these scenarios. The expected TCS is equal to – 440 million rubles.

The standard deviation of the TCS is 1 billion rubles due to the next formula:

$$\sigma_{TCS} = \sqrt{P_{MLS} \cdot (TCS_{MLS} - TCS_{exp.})^2 + P_{OS} \cdot (TCS_{OS} - TCS_{exp.})^2 + P_{PS} \cdot (TCS_{PS} - TCS_{exp.})^2} \quad (7.24)$$

The coefficient of variation is equal to 2,3 due to the formula:

$$CV_{TCS} = \frac{\sigma_{TCS}}{|TCS_{exp.}|} = \frac{1000}{|-440|} = 2,3 \quad (7.25)$$

The coefficient of variation can be used for comparison with other average risks of similar projects. If the coefficient of variation is higher than this average risk, it can be concluded that the current project has a high risk.

Scenario analysis has two basic benefits. Firstly, it analyzes a range of future results. Scenario analysis includes not only most likely case, but also possible pessimistic and optimistic outcomes. The knowledge about these scenarios can avoid any variants of the unexpectedness and sometimes the project has to be rejected due to worst results. The second advantage is that this method helps to define the expected TCS of the project, deviation of this value and also coefficient of variation. This statistical information can be used for evaluation of the project's risk.

Also scenario analysis has several weaknesses. It is limited by few results (pessimistic and optimistic), but actually many other results can exist. One problem is that it is hardly to evaluate the probabilities for each scenario. Another difficulty is approach of the best and the worst cases. In reality the combination of all good parameters together and all worst parameters together is unlikely event. As well as sensitivity analysis do not provide any decision making rules «accept or reject the project». It only provides useful information for making any budgeting decisions, but ultimately, the decision depends on confidence of the investor.

Conclusion

Smart Grid technologies are intensively developing in many countries in the world. A Smart Grid allows not only integrating new applications into network, but also improving efficiency of power delivery, providing comprehensive control and monitoring capabilities. The present work illustrates that there are many developing Smart Grid projects distributed throughout the Europe Union. It shows the interest of other countries in improving the energy sector by modern intelligent devices and technologies.

The diploma thesis is associated with the studying one of the parts of Smart Grid – Ripple Control. Application of Ripple Control technology in power system leads to reduction of power losses and obviously to reduction of energy costs. Integration of Ripple Control technology and its influence is investigated for Siberian region, Russian Federation. The analysis of electrical energy generation and consumption in Siberian region has been carried out by using real data, which were obtained from specialized energy company «System Operator of the Unified Energy System».

During the investigation of Ripple Control and current state of Siberian Region the methodology of necessary calculations was developed. This universal methodology allows evaluating technical and economic benefits of Ripple Control project in any possible areas. The methodology has been divided into several parts enabling to analyze possible influences of Ripple Control as step-by-step process.

From technical point of view, the results of the project show that the implementation of Ripple Control into Siberian Interconnected Power System can lead to reduction of energy losses in power lines and consequently improve the stability and performance of the power system without any technical changes in the network. As the results show, energy losses can be reduced on 0,2 GWh for one selected day due to Ripple Control implementation.

From economic point of view, the project is not effective, but it can provide economic benefits with particular conditions. To find these possible conditions, the influence of uncertain parameters on total cost savings has been investigated in sensitivity and scenario analysis. According to obtained results, it can be concluded, that total cost savings can be positive value, if one of considered below factor will change:

- discount rate will be less than ~14%;

- value of power losses will be higher than ~13%;

- annual consumption growth will be higher than ~1,4%;

- annual electricity price growth will be more than ~9%;

- total price of storage heater and receiver will decrease up to 11000 rubles.

Also, as the sensitivity graph show, the value of total cost savings is most sensitive to changes in some parameters, such as discount rate, value of power losses and price of storage heaters. Thus, small change in these parameters can result in larger change of total cost savings.

Scenario analysis is based on sensitivity analysis. The pessimistic and optimistic scenarios were simulated. It was assumed that all parameters will be changed on 20% in particular way due to these uncertainty and unpredictability. It is unlikely that all parameters will change in particular direction and at the same time, but to know the exact values of these changes in the future, the possible benefits and even risk can be estimated.

In addition, the present project can be used as foundation for further research in Ripple Control sector. The developed methodology is universal and can be applied not only for Ripple Control projects in Russian Federation, but also in other countries.

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Appendix 1 – ECS for each month, year and PV from ECS for year

Year	ECS, thousand rubles													
	January	February	March	April	May	June	Jule	August	September	October	November	December	Total	PV
2013	74 593	66 586	70 003	37 612	24 009	7 334	-	7 146	21 495	34 577	58 136	81 722	483 214	483 214
2014	81 553	72 782	76 500	41 109	26 411	7 989	-	7 856	23 361	37 569	64 000	88 771	527 900	465 104
2015	89 511	79 559	83 068	44 935	29 054	8 703	-	8 587	25 545	41 059	69 464	97 033	576 517	447 516
2016	98 249	89 980	90 203	49 416	31 563	9 514	-	9 278	27 936	44 836	75 396	106 726	633 095	432 975
2017	107 032	95 086	98 594	54 347	34 289	10 400	-	10 142	30 739	48 513	82 429	117 389	688 960	415 132
2018	116 612	103 963	108 473	59 063	37 492	11 407	-	11 088	33 823	52 570	90 126	128 340	752 956	399 723
2019	127 542	113 677	119 346	64 190	40 996	12 512	-	12 195	36 776	57 229	99 257	139 468	823 188	385 023
2020	139 509	129 100	129 639	70 190	45 404	13 592	-	13 412	39 988	62 492	108 542	151 569	903 436	372 292
2021	153 755	135 945	140 826	76 756	49 656	14 863	-	14 581	43 749	68 200	117 856	165 747	981 933	356 505
2022	168 205	148 683	153 982	84 448	53 968	16 254	-	15 853	47 867	74 254	128 900	182 380	1 074 794	343 801
2023	183 349	162 627	168 381	92 915	58 658	17 776	-	17 338	52 693	80 754	140 992	200 688	1 176 172	331 475
2024	199 879	184 049	186 530	100 423	64 167	19 567	-	19 076	57 663	87 918	155 339	218 181	1 292 792	321 001
2025	218 729	194 613	204 004	109 853	70 648	21 336	-	20 988	62 732	95 884	171 153	237 213	1 407 153	307 835
2026	240 258	212 920	221 705	120 180	77 788	23 266	-	22 960	68 663	104 645	185 928	259 510	1 537 823	296 402
2027	263 919	232 971	240 953	131 489	85 117	25 454	-	24 975	75 161	114 164	201 988	283 927	1 680 118	285 307
2028	288 883	263 755	263 593	145 602	91 969	27 851	-	27 168	82 774	124 553	221 033	314 464	1 851 644	277 031
2029	313 967	278 993	290 256	158 387	100 653	30 570	-	29 729	91 162	135 997	241 896	344 109	2 015 719	265 704
2030	343 747	305 352	319 631	172 306	110 167	33 556	-	32 724	99 232	148 501	266 657	374 318	2 206 193	256 218
2031	376 392	334 236	349 758	188 591	121 365	36 612	-	36 024	108 028	162 192	293 965	407 207	2 414 371	247 041
2032	413 650	379 962	377 865	206 436	133 710	39 952	-	39 204	118 315	176 780	317 250	445 730	2 648 852	238 792
2033	454 624	400 579	413 562	227 345	145 469	43 734	-	42 667	129 596	193 080	347 335	490 910	2 888 900	229 453
2034	496 203	438 606	452 676	250 388	158 272	47 879	-	46 712	142 804	211 257	380 313	540 698	3 165 808	221 535
2035	541 662	480 296	498 749	272 544	173 324	52 579	-	51 146	157 368	231 281	416 467	592 025	3 467 442	213 779
2036	593 442	544 221	549 545	296 686	191 047	57 574	-	56 660	170 432	252 863	462 659	640 540	3 815 668	207 265
2037	652 504	576 135	597 863	324 933	210 598	62 865	-	62 052	186 771	275 947	503 170	701 507	4 154 345	198 818
2038	717 498	631 114	650 474	355 912	230 708	68 853	-	67 573	204 704	301 106	547 265	768 365	4 543 571	191 579
2039	786 352	691 423	712 377	392 215	251 167	75 421	-	73 591	224 387	329 300	599 570	846 767	4 982 571	185 098
2040	859 018	783 833	785 310	429 710	273 462	82 863	-	80 623	248 850	361 986	656 956	933 233	5 495 843	179 879
2041	938 559	830 194	865 774	468 061	299 686	91 044	-	88 851	271 284	396 136	725 091	1 016 450	5 991 130	172 764
2042	1 029 097	909 875	948 502	512 939	330 580	99 481	-	97 927	295 782	433 586	800 355	1 107 205	6 565 328	166 801
2043	1 132 290	997 338	1 032 632	562 195	364 696	108 719	-	107 324	324 405	473 335	871 097	1 213 472	7 187 501	160 886
2044	1 245 942	1 131 249	1 124 324	619 926	397 294	119 165	-	116 286	355 851	516 716	948 176	1 338 082	7 913 011	156 056
2045	1 362 224	1 198 796	1 232 236	683 650	432 848	130 633	-	127 479	392 639	567 465	1 039 627	1 475 611	8 643 206	150 180
2046	1 489 652	1 314 592	1 359 417	745 212	474 689	143 612	-	139 769	433 269	623 419	1 140 064	1 617 871	9 481 566	145 149
2047	1 634 610	1 441 791	1 499 868	812 416	520 654	157 895	-	154 156	472 806	682 969	1 259 357	1 763 648	10 400 170	140 273
2048	1 793 975	1 642 151	1 634 024	891 071	578 528	172 241	-	170 043	516 039	745 931	1 381 443	1 922 812	11 448 257	136 041
2049	1 981 719	1 735 117	1 780 375	977 495	634 755	188 927	-	185 449	566 526	814 723	1 504 819	2 109 161	12 479 065	130 650
2050	2 175 569	1 903 918	1 952 660	1 078 815	692 121	207 263	-	202 277	622 062	892 918	1 651 236	2 327 666	13 706 506	126 431
2051	2 381 422	2 089 494	2 141 953	1 190 782	754 765	227 416	-	221 948	687 002	982 177	1 812 207	2 569 084	15 058 250	122 377
2052	2 607 375	2 373 120	2 380 304	1 291 669	828 541	250 832	-	244 984	754 616	1 080 680	2 003 473	2 802 896	16 618 492	118 991
2053	2 864 225	2 518 009	2 611 905	1 417 907	915 583	274 614	-	270 447	824 456	1 185 222	2 215 211	3 058 466	18 156 045	114 536