Czech Technical University in Prague

Faculty of Electrical Engineering

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FAKULTA ELEKTROTECHNICKÁ ČVUT V PRAZE

Power supply system for an isolated consumer in the North

Master's Thesis

Study program: Electrical Engineering, Power Engineering and Management
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Scientific supervisor: Ing. Miroslav Vitek, CSc.

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MASTER'S THESIS ASSIGNMENT

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Demand and needs of electricity consumer, his position, used appliances, daily and annual load curve
Design of variants of power supply for this isolated customer in climatic conditions of North
Investment and operating expenses of variants
Recommendation of the optimal variant in terms of economic efficiency

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VAN LOO, Sjaak a Jaap KOPPEJAN. The handbook of biomass combustion and co-firing. Vyd. 1. Washington, DC: Earthscan, 2010. ISBN 18-497-1104-6.
RICHARD A. BREALEY, .. STEWART C. MYERS, .. FRANKLIN ALLEN, .., Richard A. Brealey, .. Stewart C. Myers, .. Franklin Allen, .. Principles of corporate finance. 9th ed. [international edition]. Boston, Mass: McGraw-Hill, 2008. ISBN 00-712-6675-5.

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III. Assignment receipt

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Date of assignment receipt

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I hereby declare that this master’s thesis is the product of my own independent work and that I have clearly stated all information sources used in the thesis according to Methodological Instruction No. 1/2009 – “On maintaining ethical principles when working on a university final project, CTU in Prague”

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ABSTRACT

This paper describes a solution to the problem of power supply of an enterprise in the North. The objectives of this work are to study various options for power supply of the enterprise and select the most economically and technically beneficial one. To achieve the goals, the power supply sources market was researched, advantages and disadvantages of each source of energy were examined. Result of the work includes scientific selection of one of the previously proposed power sources and its reasonable explanation. Current work can be used to implement similar projects in the north.

KEYWORDS

Overhead transmission line, photovoltaic power plant, renewable energy sources, biomass, diesel fuel, diesel generator set, hybrid system, organic Rankine cycle.

CONTENTS

LIST OF APPENDICES

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AC Alternating current

Ah Ampere-hour

CapEx Capital expenditures

Czk Czech koruna

DPP Diesel power plant

EAA Equal annual annuity

Hz Hertz

EMF Electromagnetic force

ICE Internal combustion engine

kV Kilovolts

kVA Kilovolt-amps

kW Kilowatts

OpEx Operational expenditures

ORC Organic Rankine cycle

OTL Overhead transmission line

PPP Photovoltaic power plant

PV Photovoltaic

RES Renewable energy sources

Rub Russian ruble

Ths Thousand

Introduction

The Russian Federation has a vast territory. Many production facilities, such as oil and gas, timber, mining and other industries, are located far from large settlements and do not have access to a unified power supply system, that is, they are isolated. Construction of individual power lines for such consumers is impractical in most cases, since it is associated with high costs, and the payback period at standard market prices for electricity can exceed the payback period of electrical installations. Then the question arises: how should supply of electrical energy to these consumers be ensured? In this case, autonomous sources of energy come to the rescue. Examples of decentralized sources of electrical energy are diesel power plants, micro hydroelectric power plants, wind generator power plants, photovoltaic power plants and other facilities that are not connected to the unified power supply system. Low-power sources used for autonomous power supply, as a rule, have low technical and economic indicators. In addition to this, rising fuel prices and increasing transportation tariffs (which is especially true in remote areas) lead to high costs of electricity production - several times higher than the average for centralized power supply systems. Shortages of fuel entail long power outages.

Additional difficulties arise in the energy supply of facilities in the far north. This is mainly associated with cold temperatures, sudden changes in temperature, icing of equipment, inaccessibility of some regions, remoteness from regional centers. The solution to the problem of power supply of an isolated consumer in the Far North will be described in this master's thesis.

A description of the process of power supply of an isolated consumer will be carried out on the example of a logging enterprise with a set of production mechanisms.

1 Description of the area conditions

1.1 Terrain description

By joint choice of the student and the supervisor, it was decided to consider Parabelsky district as the place where the logging company will be located. Parabelsky district is a part of Tomsk region. Figure 1 is a satellite photograph of the area. The logging enterprise is located close to Parabel village, in the center of the Parabelsky district. The relief of the selected area is predominantly flat with a significant predominance of forests. The area is swampy and impassable.

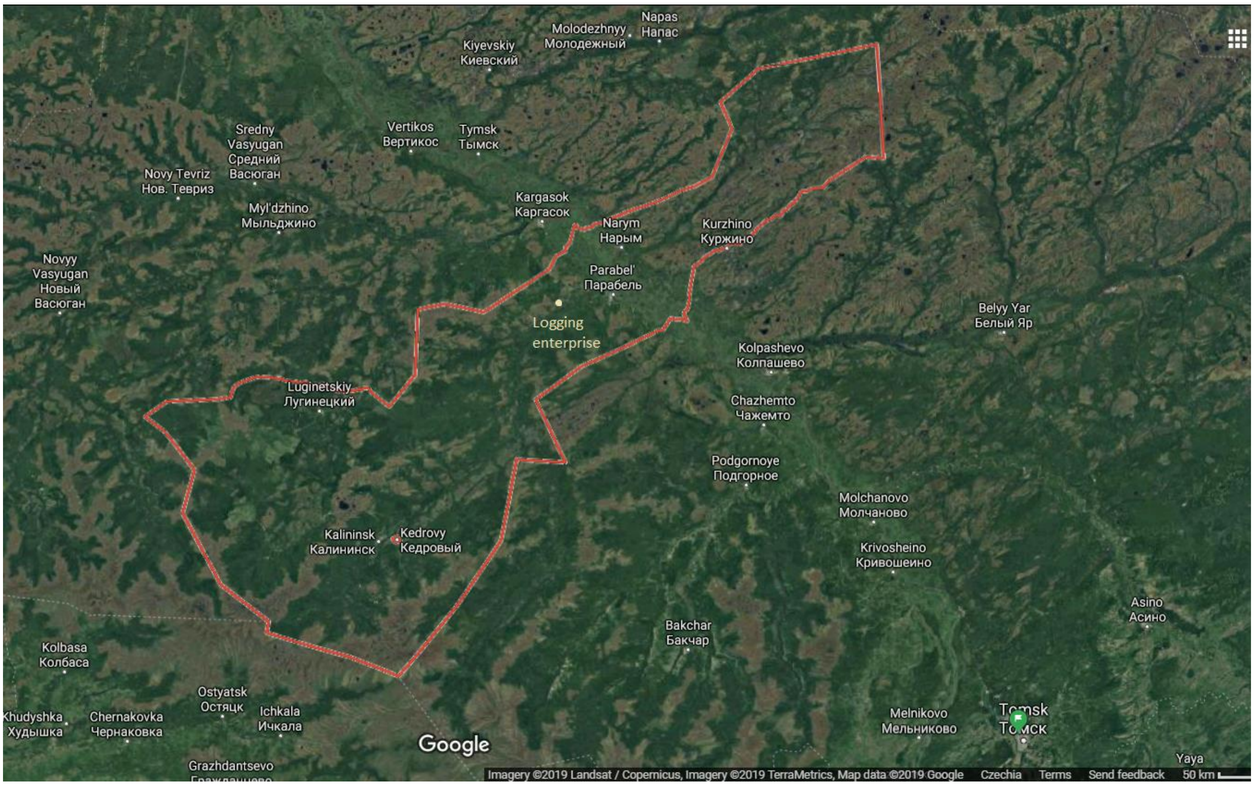

Figure 1 – Parabelsky district and the logging enterprise on the map of Tomsk region. [1]

Figure 2 – Overview of the area. [2]

1.2 Climatic conditions of the area

The climate is estimated as temperate continental. The average temperature in July is + 18˚C, January –19.2˚C. The selected region is characterized by large temperature differences during the year. In winter, the ambient temperature can reach -50°C, while in summer it reaches +40°C. There is no predominance of clear or cloudy days. A distinctive feature of the climate is long duration of the cold period, which is about 200 days out of 365 days a year. Since the weather conditions of the area can vary significantly over several days or even hours, it is important to choose the equipment that is possible to withstand severe climatic conditions.

2 Overview of electric power sources

2.1 Introduction to electric power sources

Modern development of electric power industry in Russia is characterized by an increase in the cost of energy production. The greatest increase in the cost of energy is observed in remote regions of Siberia and the Far East of Russia, Kamchatka, and the Kuril Islands where decentralized power supply systems based on diesel power plants operating on imported fuel are mainly used. The total cost of electricity in these areas often exceeds the world price level and reaches 0,25 or more US dollars per one kWh.

World experience shows that a number of countries and regions are successfully solving energy supply problems today through the development of renewable energy. In order to intensify the practical use of renewable energy in these countries, various privileges for green energy producers are legally established. However, the decisive success of renewable energy is ultimately determined by its effectiveness in comparison with other more traditional energy installations of the fuel industry. Development of technical and legislative framework for renewable energy and a steady growth trends in the cost of fuel and energy resources already today determine the technical and economic advantages of power plants using renewable energy resources. Obviously, in the future, these advantages will increase, expanding the scope of renewable energy and increasing its contribution to the global energy balance. [3, page 3]

In this work, I will consider several traditional and alternative sources of power energy.

2.2 Overhead transmission line

According to the subject of the current master's thesis, the consumer is isolated from high voltage lines. It means that it is not possible to use central power supply for providing the company with electricity. Nevertheless this type of power supply should be compared to others in order to ensure its economic inconsistency.

An electric transmission line, consisting of wires (cables) and auxiliary devices (insulators, couplings, etc.), is an electrical installation for transmission of electricity over a distance. [4]

Figure 3 – Overhead transmission power line. [5]

A simple description of power supply using overhead transmission lines is shown in the Figure 4.

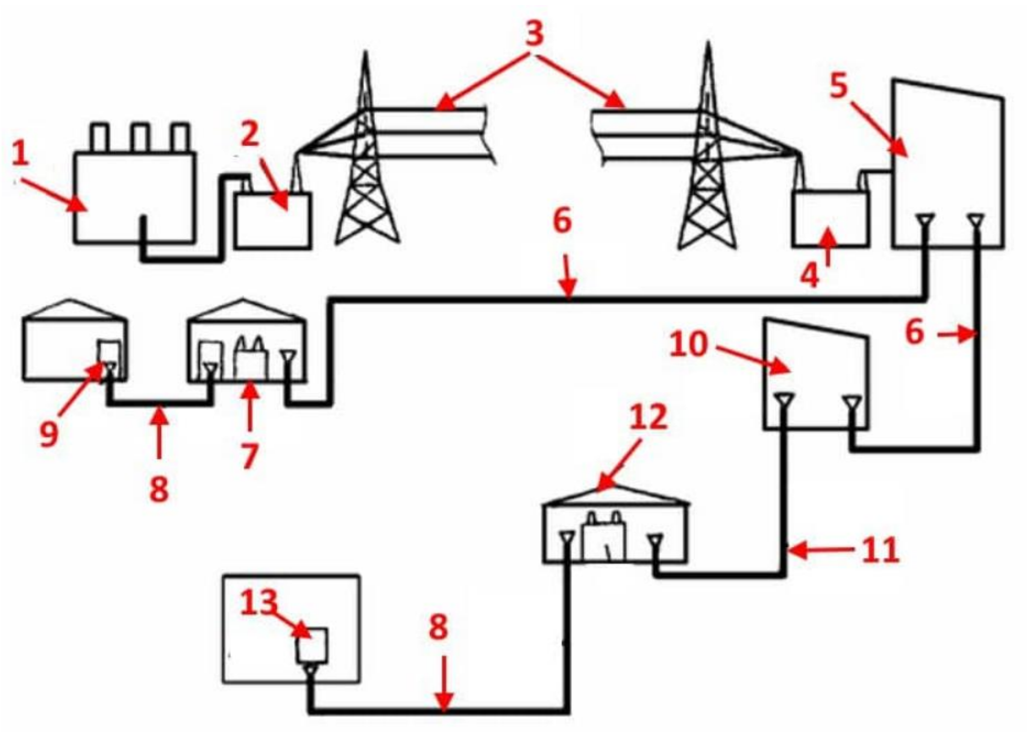

Figure 4 – Scheme of power supply using overhead transmission power lines.

A proper description of the significant parts of power supply via transmission lines is given below.

1 – Power plant where electricity is generated

2 – Voltage boosting substation to provide high efficiency transmission of electricity over long distances

3 – Power line with a high voltage (35 - 750 kilovolts)

4 – Substation with step-down functions (6-10 kilovolts in the output)

5 – Electricity distribution point

6 – Power line cables

7 – Central substation at an industrial facility serving to reduce voltage to 0.4 kV

8 – Radial or trunk cable lines

9 – Main switchboard in a workshop

10 – District distribution substation

11 – Cable radial or trunk line

12 – Substation lowering voltage to 0.4 kV

13 – Main switchboard of a residential building, used to connect an internal electrical network. [4]

Electricity is mainly generated by burning coal, gas or fuel oil as well as using energy of water or nuclear energy at power plants. Using voltage boosting substations the voltage is increased up to 35-750 kV. Electricity is transmitted to step-down substations via overhead transmission lines. At step-down substations, the voltage of electricity is transformed into a lower value (in Russia, it is usually transformed from 35-750 kV to 6-10 kV). Then the electricity flows to smaller substations which reduce the value of voltage to 0,4 kV. The electricity of 0,4 kV (three phase current) is transmitted to three-phase consumers using overhead transmission lines or cables. In case of one-phase consumers, one of the three phases of transmission lines should be used.

2.3 Combination of a wind and photovoltaic power plant

Wind energy is the most developed area of practical use of natural renewable resources (also known as alternative sources of energy). An alternative source of electrical energy is a method, device or structure that allows to receive electrical energy (or another type of energy) using technologies that differ from traditional ones.

The widespread use of wind power plants is explained by their relatively low specific capital investments compared to other renewable energy sources.

The operation principle of all wind motors is to rotate the wind wheel with blades under the pressure of wind. The torque of the wind wheel through the transmission system is transmitted to the generator shaft, generating electricity.

The kinetic energy W of the air flow is equal to:

$$W = \rho \frac{V^3 S}{2}$$

Where ρ is density of air, kg/m^3;
S is the cross-sectional area, mm^2;
V is the velocity of wind, meters/second.

Mechanical energy of a wind turbine W_{wt} is determined by utilization of wind energy, which depends on the type of wind turbine and its operating mode:

$$\xi = \frac{W_{wt}}{W}$$

The electric power of the generator of a wind power installation can be determined by the formula:

$$P_{el} = \pi\rho V^3 \frac{R^2}{2} \xi\eta$$

Where R is the radius of the wind wheel;
η is an efficiency of the electromechanical energy converter
ρ is a density of air, kg/m^3;
S is the cross-sectional area, mm^2;
V is the velocity of wind, meters/second;
ξ is an utilization coefficient of wind energy. [6, 47]

The principle of operation of a wind power plant is as follows. Under the influence of mechanical force of the wind applied to the blades of the wind wheel, the wind wheel is driven. The wind wheel and the rotor of the wind generator are connected by a shaft, so that the rotor is driven by rotation of the blades. The mechanical energy of the wind is converted into electrical energy due to the presence of a stator winding. The controller controls battery charging. As the charge decreases, rotation of the blades slows down, while the battery charge decreases, the rotation speed of the wind wheel increases. Electric power in the form of direct current stored in batteries is converted into electric power of alternating current using inverters and supplied to the consumer through cables and wires.

I will assess feasibility of using this source of electric energy in relation to a logging enterprise. To do this, I will consider the advantages and disadvantages of wind power plants in relation to this region.

The advantages include low price for the equipment. Wind farms have become widespread in Russia over the past five - ten years, which created competition in the market and led to the emergence of inexpensive and high-quality solutions for the power supply of households and small enterprises. [7, 37]

The disadvantage in our case is difficulty of installing electrical equipment, due to the inaccessibility of the enterprise, marshland and need for deforestation. To install the tower of a wind farm, it is necessary to prepare a solid foundation. Making the foundation in wetlands leads to a rise in the cost of the process associated with the need to fill the soil with rubble, sand, and gravel. Use of this source of electricity is complicated by a need to install a high mast, since the forest does not pass wind, acting as a kind of barrier. Transportation of bulky equipment in the cramped conditions of forest roads creates additional difficulties. In addition, evaluating the wind energy potential of the Tomsk Region, I can conclude that the installation of a wind farm is impractical due to the low average annual wind speed.

Fundamentally, solar power plants can be of two types: thermodynamic and photovoltaic. Thermodynamic solar power plants are based on heating the heat carrier with solar radiation using special optical systems with the further conversion of thermal energy into mechanical energy and then into electrical energy. Photovoltaic power plants (PPP) use the effect of direct conversion of solar radiation into electricity.

Let us consider the principle of operation of the simplest photovoltaic station. The principle of operation of a photovoltaic plant is based on the phenomenon of a photoelectric effect. The essence of the photoelectric effect is that light photons, as the basis of solar radiation, can knock electrons either from the surface of bodies (external photoelectric effect) or only from the crystal lattice inside the semiconductor (internal photoelectric effect), as well as the occurrence of incident radiation at the boundary of the metal-semiconductor pair of some EMF, causing the appearance or change in the external circuit connecting the specified pair (photoelectric effect of the barrier layer, or gate photoelectric effect).

The resulting electrical energy in the form of direct current is stored in batteries. In order to provide the batteries with a certain current and voltage, battery charge controllers are used. The consumers are powered by rechargeable batteries without conversion (for direct current consumers) and by converting direct current to alternating current using inverters (for alternating current consumers).

Consider the positive and negative sides of the possibility of using this source of electric energy in relation to a well-known enterprise. The advantages include the presence of a large number of technical solutions in the market for the implementation of the project.

The main disadvantage of photovoltaic power plants is the low specific power generation, since the output power of one square meter monocrystalline photovoltaic elements usually does not exceed 200 watts. This leads to the fact that for the production of large amounts of electric energy it is necessary to spend huge territories, which is impossible in the conditions of the production activity of a logging enterprise. Forests located near the enterprise will prevent the penetration of sunlight, which will not allow the proper functioning of solar panels. In addition, dust, grass, the remains of the crown of trees settling on solar panels will create the need for continuous cleaning of the panels. Due to the presence of an impressive number of solar photocells, transportation costs for delivery to the place of operation will increase. In addition, the generation of electrical energy by this method largely depends on the intensity of solar radiation, which will not allow the generation of electrical energy during the night. [8]

It is also possible to supplement the system with a back-up diesel generator or a permanently working diesel generator. Generated electricity can be used by one consumer or transmitted to several consumers using a grid.

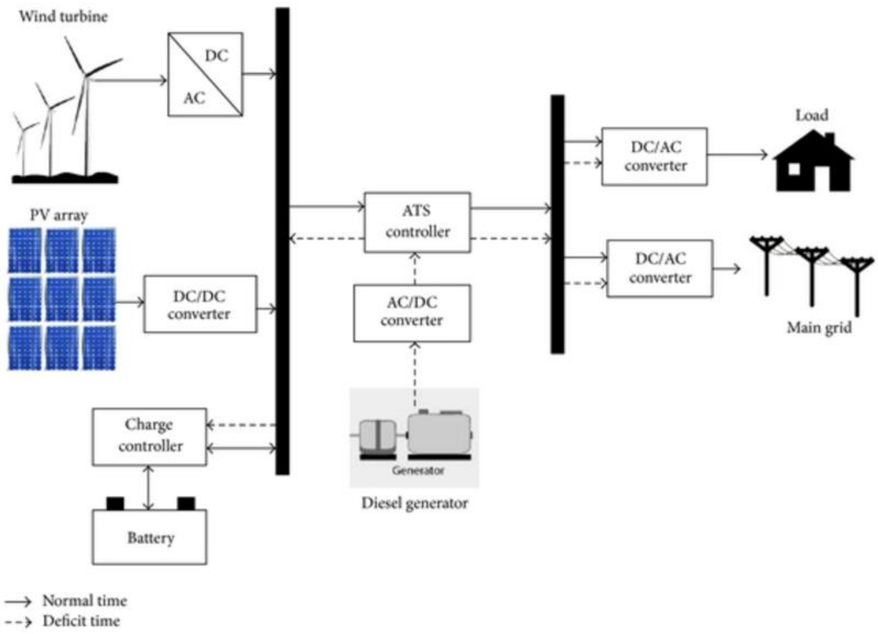

Figure 5 – Hybrid wind and solar power plant supplemented with a diesel generator and accumulators. [9]

2.4 Biofuel gasification power plant

A gas-generating electric power plant is one of the methods for generating electric and thermal energy by conversion from biofuels. There are two main types of electric energy production from biofuels: pyrolysis and biomass gasification technology. The biomass gasification technology based on burning wood in the absence or lack of oxygen has become more widespread. Under the influence of heat, chemical bonds in the molecules of complex hydrocarbons contained in wood are broken, resulting in the formation of methane, methyl gas, hydrogen, carbon dioxide and carbon monoxide, wood alcohol, carbon, water and many small additives. The amount of methane can reach up to 25%. Methane has a high calorific value and can be used instead of natural gas. Methyl gas can be burned directly or after conversion to methanol, which is a high-quality synthetic liquid fuel suitable for use in internal combustion engines. [6, 153-154]

The principle of operation of the biomass gasification unit is as follows. The wood remaining during the production process is crushed with a wood chipper. The chips are placed in a chip drying installation, where they are drained to the required moisture percentage. On an inclined skip lift, the drained wood chips enter a gas generator (reactor), where it is burned. Gases, which are the products of burning wood chips, through the gas preparation system enter the gas-diesel (gas) engine. To generate electricity, the gas obtained is used as fuel in one or several generation modules based on gas-diesel engines operating on a mixture of generator gas (70 ... 85%) and conventional diesel fuel (15 ... 30%), or on the basis of gas engines operating on 100% generator gas.

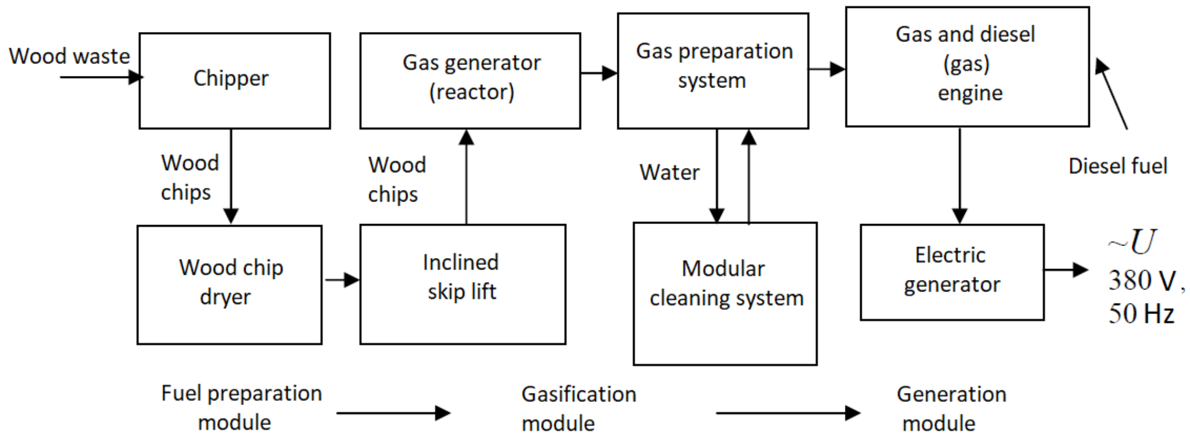

Figure 6 – Operation principle of a gas generating plant. [6, 155]

There some disadvantages of such a facility. Firstly, the installation requires specific type of fuel. Wood chips should be of a specific size otherwise the output energy may be lower or the installation may be out of operation. Secondly, wood chips should be properly dried before use despite the fact that the facility itself has a wood chip dryer.

2.5 Diesel generator power plant

Diesel generator power plant is a device generating electrical energy by burning diesel fuel. The expansion energy of the gases generated during combustion of the fuel ignited by compression in a diesel internal combustion engine is converted by means of a crank mechanism into the mechanical energy of rotation of the crankshaft. The rotor of the generator driven by the engine, rotating, excites an electromagnetic field that creates an induction alternating current in the generator winding, which is supplied to the consumer. [10]

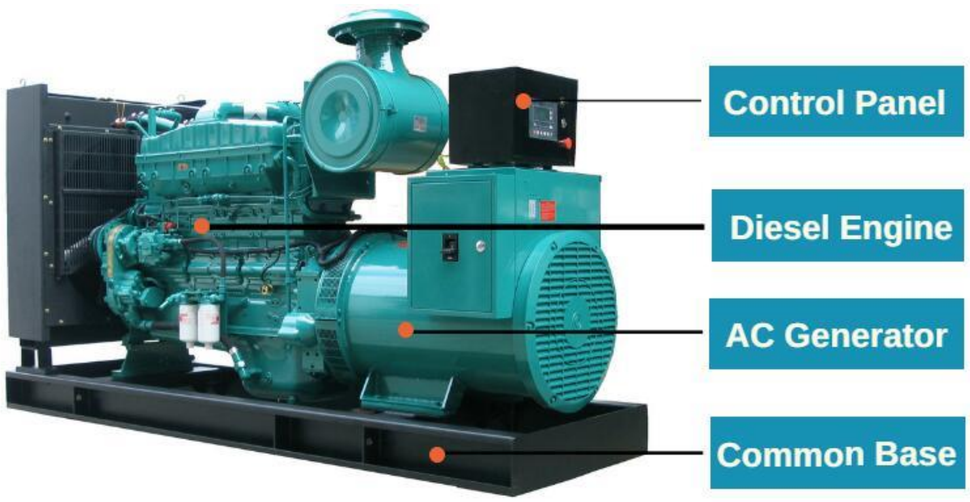

Figure 7 – Diesel generator and its main parts.

The main components of a diesel generator set include:

- Control panel
- Diesel engine
- AC generator
- Common base [11]

This type of power supply has become widespread as a backup source of responsible consumers. It is also used as the main power source for remote consumers.

Considering this type of power supply, it is important to estimate its advantages and disadvantages in comparison with the other sources of power supply. The main advantage is low capital expenditures. The second one is easier maintenance. Regarding the flaws, it is important to mention high prices for diesel fuel and its transportation. Diesel fuel should be kept in warm conditions to prevent it from freezing as well as it should be stored in special tanks. One more disadvantage that makes this source less attractive to us is its non-environmental friendliness. It pollutes environment with gases from burning diesel fuel which have bad impact on the atmosphere. One more disadvantage of a diesel generator facility is that operation costs of the facility are mainly dependent on the price of diesel fuel.

2.6 Organic Rankine cycle

The Rankine cycle is a thermodynamic cycle that converts heat into work. The heat is supplied to a closed loop, which typically uses water as working fluid. The Rankine cycle based on water provides approximately 85% of worldwide electricity production.

The organic Rankine cycle's principle is based on a turbogenerator working as a conventional steam turbine to transform thermal energy into mechanical energy and finally into electric energy through an electrical generator. Instead of generating steam from water, the ORC system vaporizes an organic fluid, characterized by a molecular mass higher than that of water, which leads to a slower rotation of the turbine, lower pressures and no erosion of the metal parts and blades.

The ORC turbogenerator uses medium-to-high-temperature thermal oil to preheat and vaporize a suitable organic working fluid in the evaporator (4>5). The organic fluid vapor rotates the turbine (5>6), which is directly coupled to the electric generator, resulting in clean, reliable electric power.

The exhaust vapor flows through the regenerator (6>7), where it heats the organic liquid (2>3) and is then condensed in the condenser and cooled by the cooling circuit (7>8>1). The organic working fluid is then pumped (1>2) into the regenerator and evaporator, thus completing the closed-cycle operation.

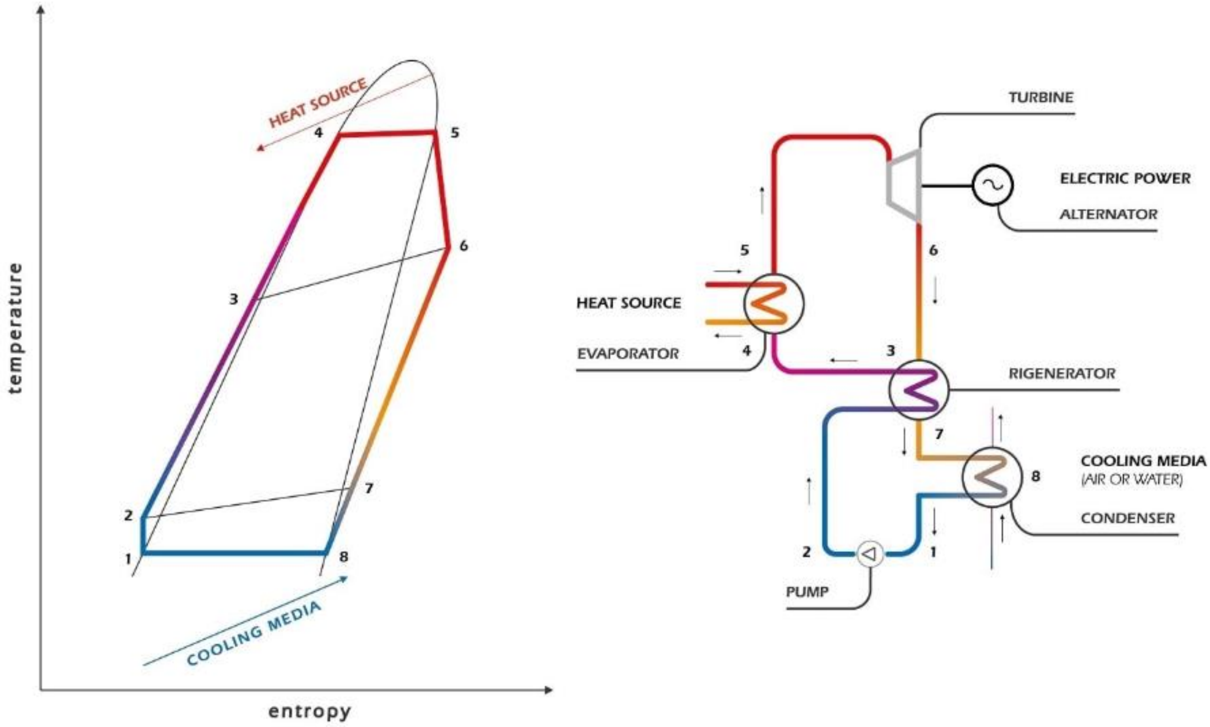

Figure 8 – Organic Rankine cycle technology. [12]

This technology is a relatively new one. So it leads to the disadvantage that a power engineer of the logging company should be taught how to operate this facility by an engineer of the supplying company. One more disadvantage is that the fluids used in an ORC cycle are combustible and if leakages occurred an environmental hazard could result.

3 Description of the company

3.1 Main information on the company

The company is located among the forests of Parabelsky district in Tomsk region. It produces industrial forest for selling. The company employs 29 people. It has two teams for forest harvesting, each includes four members. Sixteen employees are engaged in woodworking. The enterprise also has two drivers, two cooks and a security guard.

Table 1 – Staff of the company

№	Staff category	Number of people
1	“Taiga SMD-2” disk multisaws’ operators	6
2	“Kedr-5” band sawmils’ operators	10
3	Harvesting teams	8
4	Short log truck driver	1
5	Tractor driver	1
6	Cooks	2
7	Security guard	1
Total:		**29**

3.2 Operation process of the company

The operation principle of the company is divided into three steps. The first step is cutting. Two brigades consisting of 4 people each one cut the forest and transport it to the main store. The four of people in the brigade perform different operations. The first person cuts a tree, the second one cuts the tree into the pieces of 6 meters, the third one cuts the branches of the tree and the fourth worker transports the pieces to the main storage. The first three workers have electric jigsaws “Husqvarna 436 Li”. The fourth person is a driver of TT-4, a skidder which main aim is to carry the trees to the storage.

The second step is wood processing. The wood from the storage is treated in order to obtain industrial wood. During this operation, 40 percent of wood is lost as wood chips and sawdust. To perform the second step, the company uses five band sawmills “Kedr-5” and three disk multisaws “Taiga SMD-2”. Sixteen persons are engaged in this operation.

The third step is transportation to a consumer. Industrial forest is delivered directly to the consumer using a short log truck “KAMAZ 43118-3027-50” equipped with hydraulic manipulator (grapple) “VM 10L74”.

Harvesting of forest residuals is carried out using the MTZ-82 tractor equipped with a Palms-530 loader crane. Processing of chopping residues into wood chips is implemented using the Farmi-260 wood chippers. The whole technological process is performed by one person, the MTZ-82 driver.

Security guard works during days off and holidays only.

3.3 Calculation of the logging base

In order to ensure electricity supply to the logging enterprise, it is necessary to have the data on the logging base of the enterprise, daily production output, data on production mechanisms, number of employees, etc. I will introduce primary data based on a comparative analysis of enterprises in this industry in the Tomsk region.

Firstly, let us determine the number of working days in 2019 by the following algorithm:

$$D_W = D_C - (D_{W.H.} + D_R + D_{Cl}),$$

where D_C– number of calendar days;

$D_{W.H.}$ – number of holidays and weekends during the year;

D_R – number of days to redeploy the brigade;

D_{Cl} – number of days of inactivity due to climatic conditions.

$D_C = 365$, $D_{W.H.} = 118$, $D_R = 5$, $D_{Cl} = 7$

$$D_W = 365 - (118 + 5 + 7) = 235\ days.$$ [13]

The working schedule will look as follows:

Table 2 – Approximate annual working schedule

Month	Number of days in the month	Working days	Days off and holidays
January	31	13	18
February	28	13	15
March	31	20	11
April	30	22	8
May	31	18	13
June	30	19	11
July	31	23	8
August	31	22	9
September	30	21	9
October	31	23	8
November	30	20	10
December	31	21	10
Total	**365**	**235**	**130**

It is assumed that daily production of untreated forest by two brigades is 90 cubic meters. The logging base equals to:

$$90 \cdot 235 = 21150 m^3.$$

I assume that the company harvests 21150 cubic meters of forest each year. The value of industrial wood equals to 60 % of the initial amount of wood. [14]. Approximately 20% of remains is sawdust and the other 20% is woodchips and not-industrial wood.

That gives the amount of usable wood per year:

$$21150\ m^3 \cdot 0{,}6 = 12690\ m^3.$$

3.4 Main equipment of the company

Selection of a power source is always based on the load level. So it is essential to describe all the main power consumers. I created a list of all the company's equipment which uses electrical energy during the day. Knowing the number of working hours and using the formula of electric active power, I can calculate electric power consumption of each device.

I created an approximate schedule of activities for every electric appliance of the company.

Table 3 – Daily working schedule

Equipment and electrical appliances	Working hours	Number of hours
Disc multisaws	9:00-13:00 14:00-18:00	8
Band sawmills	9:00-13:00 14:00-18:00	8
Tractor TT-4	9:00-13:00 14:00-18:00	8
Electric jigsaws	9:00-13:00 14:00-18:00	8
Short log truck	9:00-13:00 14:00-18:00	8
Tractor MTZ	9:00-13:00 14:00-18:00	8
Gadgets	19:00-21:00	2
Mobile phones	20:00-21:00	1
TV's	8:00-9:00 13:00-14:00 18:00-19:00 21:00-22:00	4
Refrigerators	Around the clock	24
Lamps 10W (inside)	7:00-9:00 18:00-00:00	8
Lamps 40W (outside)	21:00-9:00	12
Water pump	19:00-19:30	0,5
Electric stoves	6:00-8:00 11:00-13:00 16:00-18:00	6

Electric power is equal to:

$$P_{el} = \frac{P_{nom}}{\eta}$$

Where P_{nom} is the nominal power of a device, kW;
η is efficiency of a device;

The formula for power consumption is written below:

$$W = P_{el} \cdot t$$

Where P_{el} is the electric power of a device, kW;

t is the number of working hours of the device, hours.

Main equipment of the company can be put into action by using electricity or by using diesel fuel. The short log truck, skidders and tractor are driven by diesel fuel. The rest of the equipment uses electric energy.

Using the software package MS Excel, I create a list of electric consumers used by the company and its workers. Using the two previous formulas, I obtain the values of active power and power consumption of each appliance. The results are put into the Table 4.

Table 4 – Electric power consumption of the equipment during working days

Equipment	**Average active power of one appliance, kW**	**Number of electrical appliances or equipment, units**	**Number of working hours, hours**	**Average active power consumption, kW·h per day**
Disc multisaws	14,586	3	8	350,055
Band sawmills	6,748*	5	8	269,916
Gadgets	0,06	28	2	3,36
Mobile phones	0,004	28	1	0,109
TV’s	0,051	6	4	1,229
Refrigerators	0,055	8	24	10,55
Lamps (inside)	0,01	30	8	2,4
Lamps (outside)	0,04	10	12	4,8
Water pump	0,929	1	0,5	0,464
Electric stoves	7	1	6	42
Electric jigsaws’s batteries	0,756	6	3	13,599

*As the band sawmills have the maximum power during the cutting period and 10% of the power during the period of rest, I need to choose between the two powers. The steady power is better for calculation of power consumption so I choose this case. Installed active power of this appliance is 16,854 kW.

The following figure shows the shares of daily power consumption during working days for each of the appliance.

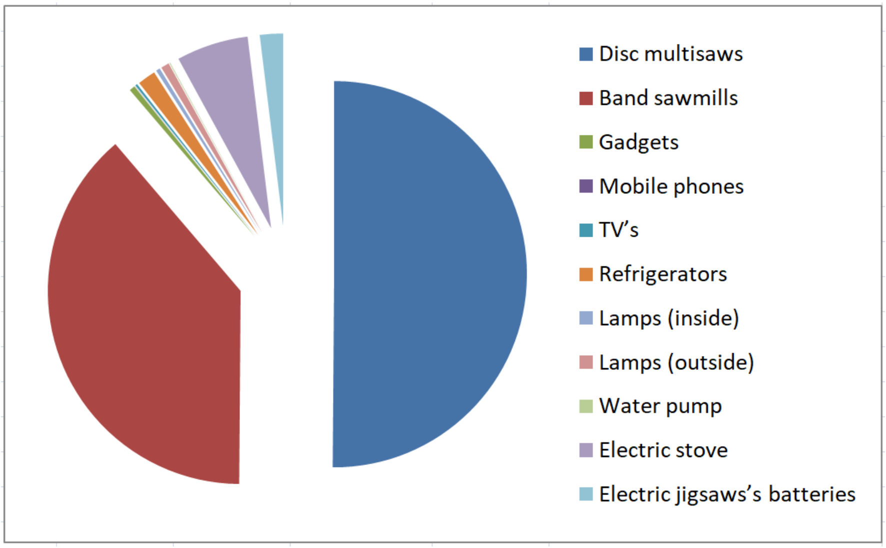

Figure 9 – Daily shares of electric power consumption for each electric appliance.

We may see from the previous figure that the highest power consumption is

Using the table of electric power consumption of the equipment, it is possible to build a load graph. The graphs are shown in the Figures 9 and 10.

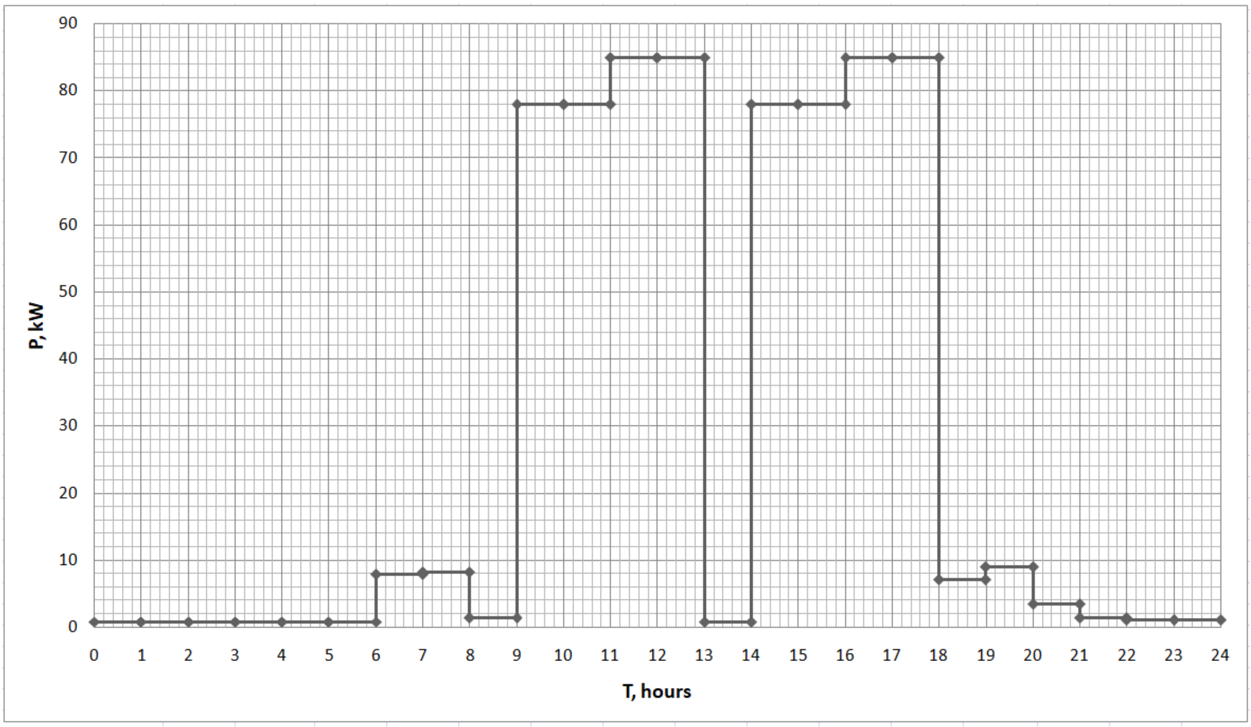

Figure 10 – Apparent power load graph during working days.

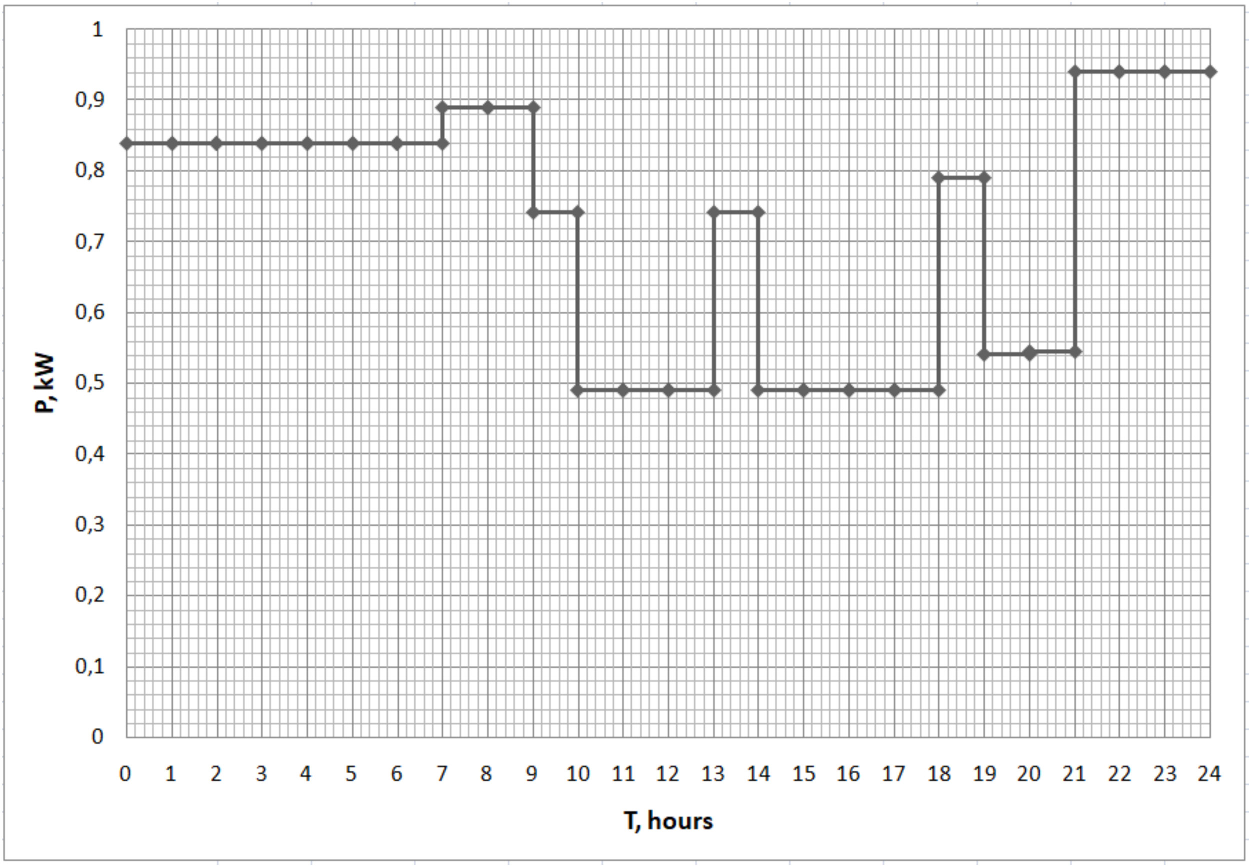

Figure 11 – Apparent power load graph during days-off and holidays.

It can be seen from the graphs that the load level is not constant and changes significantly several times a day. It is important to remember the load graphs are constructed approximately. It is obvious that the graphs can significantly change from day to day. The electricity power supply source should withstand the conditions of load change and should be designed to ensure stable power supply during load peaks and the time of load minimum.

Daily power energy consumption during working days is 698,996 kWh, during days off is 17,271 kWh. Having the information on daily energy consumption, I can estimate annual electric power energy consumption during working days (W_{wd}) and days off (W_{do}):

$$W_{wd} = W_{1wd} * n_{wd} = 698{,}996 \cdot 235 = 164264{,}051\ kWh/year$$

$$W_{do} = W_{1do} * n_{do} = 17{,}271 \cdot 130 = 2245{,}256\ kWh/year$$

Where W_{1wd} = 698,996 kWh is electric power energy consumption during a working day;
W_{1do} = 17,271 kWh is electric power energy consumption during a day off;
n_{wd} = 235 is the number of working days during a year;
n_{do} = 130 is the number of days off and holidays during a year;

Total power energy consumption during a year is the sum of consumptions during working days and days off and holidays. It gives the value of 166,509 MWh/year.

Basing on the Table 2 and previous calculations, I can draw the graph of approximate power consumption during the year.

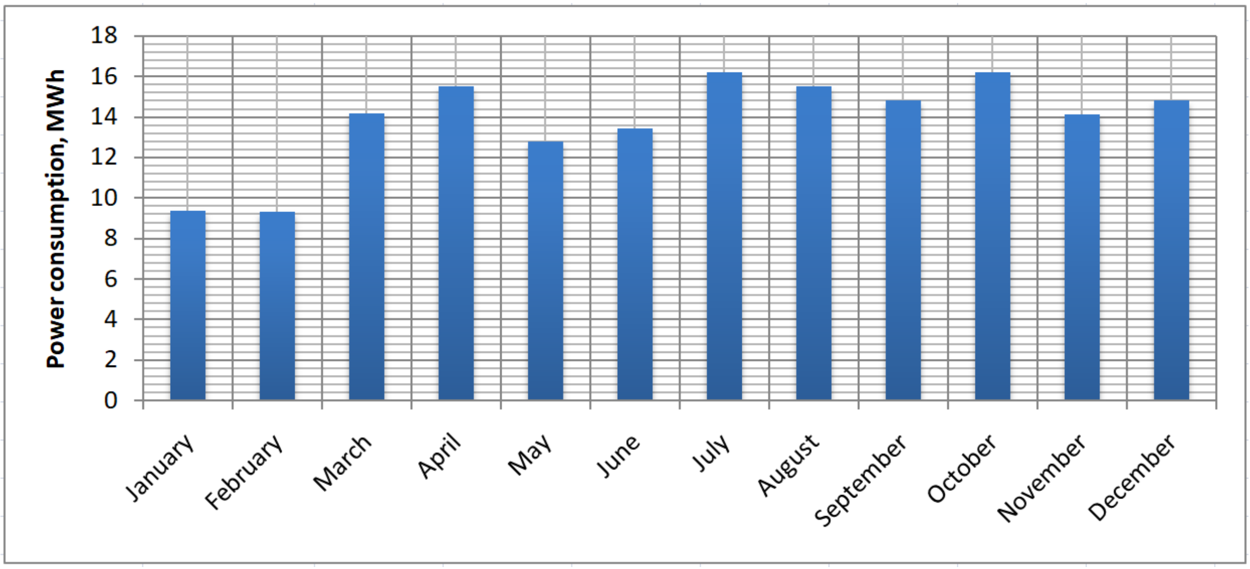

Figure 12 – Power consumption by months.

We may see that power consumption is unequal during the year. The highest consumption is in July and October.

4 Implementation of motor soft starters

To begin with evaluation variants of power supply, it is important to estimate the load. The load has several induction motors that have huge starting currents. Big starting currents made us choose generators of a bigger nominal power. To avoid this, I will install motor soft starters for the biggest consumers in our enterprise, namely, band sawmills and disc multisaws.

A motor soft starter is an electrical device used in induction motors that allows to keep the motor parameters (current, voltage, etc.) within safe limits during startup. Its use reduces starting currents, reduces likelihood of motor overheating, and eliminates jerks in mechanical drives, which ultimately increases the life period of the electric motor.

Each of the disc multisaws has an apparent power of 14,586 kW (as they work at 60% of maximum power) and nominal current of 42 A and each of the band sawmills has the power of 16,854 kW and nominal current of 30 A. To ensure soft start of our equipment, I install motor soft starters with reserve in nominal current and active power. I decided to equip all the band sawmills and disc multisaws with Siemens 3RW4036-1BB14 motor soft starters. Their nominal power is 22 kW and nominal current of 45A. The soft starters ensure stable work of equipment under heavy start conditions even if starting current exceed nominal ones 8-10 times. The price for the soft starter is 35090 RUB per each one.

Figure 13– Motor soft starter which will be applied to the equipment. [15]

5 Economic evaluation of the variants of power supply

5.1 Introduction to the chapter

In this chapter, I am going to compare several variants of power supply and decide which one will be implemented in case of the logging enterprise. These variants were briefly considered in the chapter 2.

Economic evaluation of the project will be fulfilled by evaluation of operating expenditures and capital expenditures.

Economic assessment is based on the assumption that all the power supply sources should provide the same level of quality and reliability.

5.2 Capital expenditures of the power supply variants

Capital expenditures refer to funds that are used by a company for the purchase, improvement, or maintenance of long-term assets to improve the efficiency or capacity of the company. Long-term assets are usually physical, fixed and non-consumable assets such as property, equipment, or infrastructure, and that have a useful life of more than one accounting period.

Also known as CapEx or capital expenses, capital expenditures include the purchase of items such as new equipment, machinery, land, plant, buildings or warehouses, furniture and fixtures, business vehicles, software, or intangible assets such as a patent or license.[16]

5.3 Operating expenditures of the power supply variants

An operating expense is an expense a business incurs through its normal business operations. Often abbreviated as OpEx, operating expenses include rent, equipment, inventory costs, marketing, payroll, insurance, step costs, and funds allocated for research and development. One of the typical responsibilities that management must contend with is determining how to reduce operating expenses without significantly affecting a firm's ability to compete with its competitors. [17]

5.4 Salary of the power engineer

Having a considerable amount of electrical equipment, the company needs a specialist to carry out repairs, maintenance and inspection of the equipment. During implementation of this project, two options were considered: to attract a specialist from an external organization or to have an employee with the appropriate qualifications. It was decided to hire a specialist in the field of electric power industry to perform a wide range of work, since an appropriate specialist may be required at any time of production activity and third-party companies will not always be able to provide an employee in the right time.

The power engineer will be included in the operating expenses of each of the options, since he/she will be involved in work regardless of the selected source of electricity.

To estimate the amount of money spent on the power engineer, it is important to know where the money goes to. The budget for the power engineer is given in the Table 3

Table 5 – Salary payment for the employee

Indicator	Value, rub	Notes
1. Gross salary	90000	Before taxation
1.1. Personal income tax	11700	13% from the gross salary
2. Net salary	78300	After taxation (net profit of the employee)
3. Insurance	38571,43	30% paid before the gross salary payment
Total (monthly)	128571,43	Amount of money spent by the company monthly
Total annual expense	1542857,14	Amount of money spent by the company annually

5.5 Overhead transmission line installation

5.5.1 Description of the installation

Overhead transmission line is chosen to be the first variant to consider. Overhead power transmission line (OTL) is a device designed to transmit or distribute electric energy through wires located in the open air and attached with traverses (brackets), insulators and fittings to supports or other structures (bridges, overpasses).

Construction of power transmission lines includes design, production work, installation, commissioning, and maintenance.

Installing a new power line is a laborious, lengthy and costly process. It is carried out by specialized organizations that provide a range of services: from the sale of components to design and installation of overhead lines. Construction of power lines involves use of various equipment, including drilling rigs and cranes.

Installation of power lines is carried out in two stages. First, necessary preparatory measures are carried out, including a site survey, project development, budgeting, and approval of documentation. The preparation of clearing also applies to preparatory work if there are disturbing trees on the line path. Access of equipment is provided.

The second stage in construction of power lines is on-site work. All necessary materials are transported to the site. Unloading is carried out by a crane, which facilitates the work of installers.

The main components of power lines are poles and wires, but in addition to them, a large list of other components is used, namely:

- insulators;
- fittings;
- grounding conductors;
- traverses, brackets;
- additional equipment and stuff.

Development of pits is carried out using drilling rigs. The depth of the pit along the support depends on several parameters. The height of the support, the type of soil where it is installed, as well as the number of wires attached matters. All necessary elements are installed on the support before it is installed in the ground. The last step is the installation of wires. [18]

The cost of constructing an overhead power line consists of the price of materials and the cost of work, which includes:

- delivery of materials;
- unloading;
- drilling;
- distribution of supports throughout the territory;
- installation;
- installation of traverse, mount;
- wiring.

The greater the length of the power lines, the more expensive its cost.

Installation of electrical wiring must also be included in the list of investment costs, since it is understood that the enterprise does not have access to electricity.

After the area exploration, it was estimated that to supply the company with electricity it is needed to install the overhead transmission line of the length of 39 kilometers. It was decided to pave the line over the bridge as it is much more expensive to build the construction over the river and swamps.

Figure 14 – Path of the overhead transmission line.

In addition, 15 out of 39 kilometers of the line are located among forests. It means that additional amount of many will be spent on forestry work. One kilometer of the line goes through swamps. It also increases the price of the OTL.

5.5.2 Capital expenditures of the project

The project is implemented by a Saint-Petersburg's company PSV-Energo. It includes all project and managerial works, ground preparation work, purchasing of equipment as well as on-site work and installation. The steps of overhead transmission line construction are given in the Table 6. Prices of each step are also given in the Table 6.

Table 6 – Cost estimate for OTL installation (CapEx)

Step	**Cost (mln rub)**
Project work	0,2
Installation of the line	49,14
Forestry work (15 km)	13,047
Development of swamp roads	3,388
Circuit breakers installation	0,476
Package transformer substation installation	0,28
Commissioning	0,2
Relay protection and additional equipment	0,2
Payment for technological connection	0,014
Installation of electrical wiring	0,3
Total (mln rub)	**67,245**

The procedure of technological connection and price list for the service is properly described in the source [19].

Table 6 represents capital expenditures needed for the overhead line construction. To evaluate the project properly, it is important to estimate its operating expenses.

5.5.3 Operating expenses of the project

The operating expenses of the project are shown in the Table 5. Salary for the power engineer, costs of maintenance and repair of the line are included into the list of operational expenditures. Annual charge for maintenance and repair is 0,5% of initial investment. Tariff for electricity consumption is 2,45 rub/kWh. It is a single-rate tariff which is used for consumers that utilize electric stoves instead of natural gas ones. The cost of electric power energy includes payments for power consumption and power losses in the line and transformer as well.

Table 7 – Annual expenses for maintenance of the line (OpEx)

Action	**Cost (mln. rub)**
Salary payment for the power engineer	1,543
Maintenance and repair	0,336
Cost of power energy	0,451
Total (mln. rub)	**2,33**

5.6 Installation of a hybrid source of power energy

5.6.1 Analysis of use

Proposed hybrid source of power supply includes a photovoltaic power plant, a park of wind generators, accumulators and a diesel generator. PV panels and a wind generator are used to satisfy power consumption during the time when solar radiation is high and the wind speed is big enough to produce sufficient amount of electricity. The accumulators are used to store electrical energy and use it while generation from PV panels and the wind generator is not enough to satisfy the consumer's needs. A diesel generator is used when the previously mentioned sources cannot satisfy the consumer's needs.

As the hybrid system has three sources of power energy and accumulators to store it, it is important to find the balance between the sources. The main goal is to increase the share of RES in total power generation and to decrease the share of power production of the diesel generator.

To define whether it is possible to use the system, it is important to analyze the situation. Figure 15 represents the volume of solar radiation during the year basing on the data from the source [20]. As we may see, the highest irradiance is in June and July. It means that generation during this time will be the highest and it is necessary to store and consume as much energy as possible from PV panels.

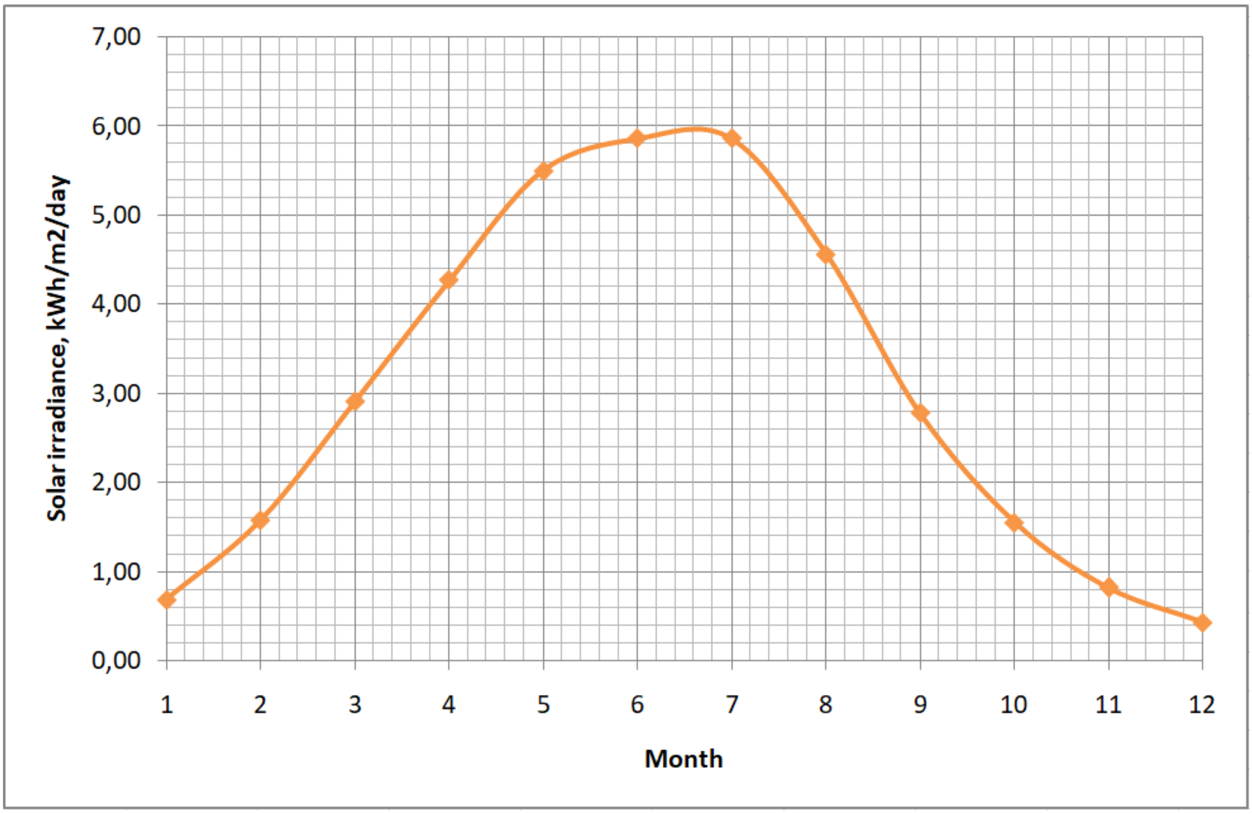

Figure 15 – Graph of solar irradiance during the year. [29]

The graph represents the average wind speed during the year in the Parabelsky district. According to the graph, it may be seen that the wind speed in summer is the lowest in the year while the highest wind speed is in spring. Spring is the best time for the consumer to use wind energy.

Figure 16 – Graph of the average wind speed in the selected region. [21]

5.6.2 Description of the installation

I decided to consider three sub variants of the hybrid system. For the first variant, I decided to exclude the wind turbine generator and concentrate my attention on PPP, batteries and DPP. The second variant includes the wind turbine generator, DPP and a set of batteries. The last sub variant includes all the components of the proposed hybrid system namely PPP, DPP, batteries and a wind turbine generator.

The distributor of a photovoltaic power plant is an Ukrainian company "Alteco". The power plant includes photovoltaic modules with the total installed power of 10,2 kW, a grid inverter, mounting equipment as well as cables and wires.

Batteries are purchased from the company "EnergyWind". The batteries have the capacity of 200 Ah. and the price is 34,3 ths. rub. per each one.

Wind generators will be purchased from the company "EnergoStok".

The system also includes a diesel power plant. I decided to use AKSA AJD-132 diesel power plant in the project. The main aim of the installation is to operate during peak loads and supply the company with electric power energy during the days with low solar and wind potential.

Let us start with the first sub variant. The first sub variant includes a diesel power plant, a battery set and a PPP. According to the source [6], the time of use of maximum production from PPP for the Tomsk region is about 1000 hours/year. Using this value, I calculated installed power of PPP which is needed to ensure stable power supply:

$$P_{instPPP} = \frac{P_{avg}}{k_u} = \frac{29{,}125}{0{,}114} = 255{,}135\ kW$$

$$k_u = \frac{T_{max}}{8760} = \frac{1000}{8760} = 0{,}114$$

Where P_{avg} is the average power during a working day;

k_u is coefficient of use of maximum load;

T_{max} is the time of use of maximum load.

The batteries for the project are assumed to cover at least half of the daily load. It is about 350 kWh per each working day. So I need approximately 150 “Challenger G12-200” batteries for all the sub variants of the hybrid system.

I do the same for the second variant. Basing on several tests, the time of use of maximum production from wind generator power plant is assumed to be 600 hours/year. I calculate installed power of wind turbine generators:

$$P_{instWPP} = \frac{P_{avg}}{k_u} = \frac{29{,}125}{0{,}068} = 425{,}225\ kW$$

$$k_u = \frac{T_{max}}{8760} = \frac{600}{8760} = 0{,}068$$

Where P_{avg} is the average power during a working day;

k_u is coefficient of use of maximum load;

T_{max} is the time of use of maximum load.

For the third variant, I decided to combine the previous sub variants and use a half of production from the PPP and the second half from the wind power plant. The installed powers should be as follows:

$$P_{instPPP3} = \frac{P_{instPPP}}{2} = \frac{255{,}135}{2} = 127{,}568\ kW$$

$$P_{instWPP3} = \frac{P_{instWPP}}{2} = \frac{425{,}225}{2} = 212{,}613\ kW$$

I choose the following equipment for the hybrid system sub variants:

Table 8 – Equipment for the sub variants

Variants	Equipment
Variant 1	PPP of 255 kW installed power, a DPP, batteries
Variant 2	Wind power plant of 430 kW installed power, a DPP, batteries
Variant 3	PPP of 132,6 kW installed power and a wind power plant of 210 kW installed power, a DPP, batteries

The following graphs are based on the source [22]. They represent theoretical possible electric power production using the three proposed variants of hybrid system.

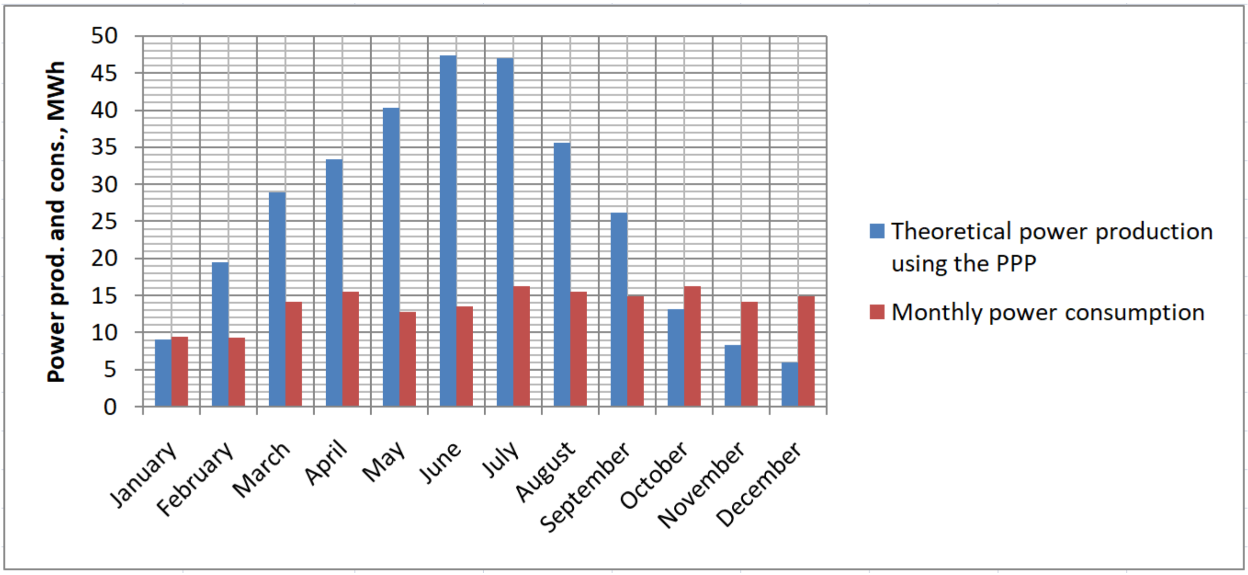

Figure 17 – Theoretical power production using a 255-kW photovoltaic power plant.

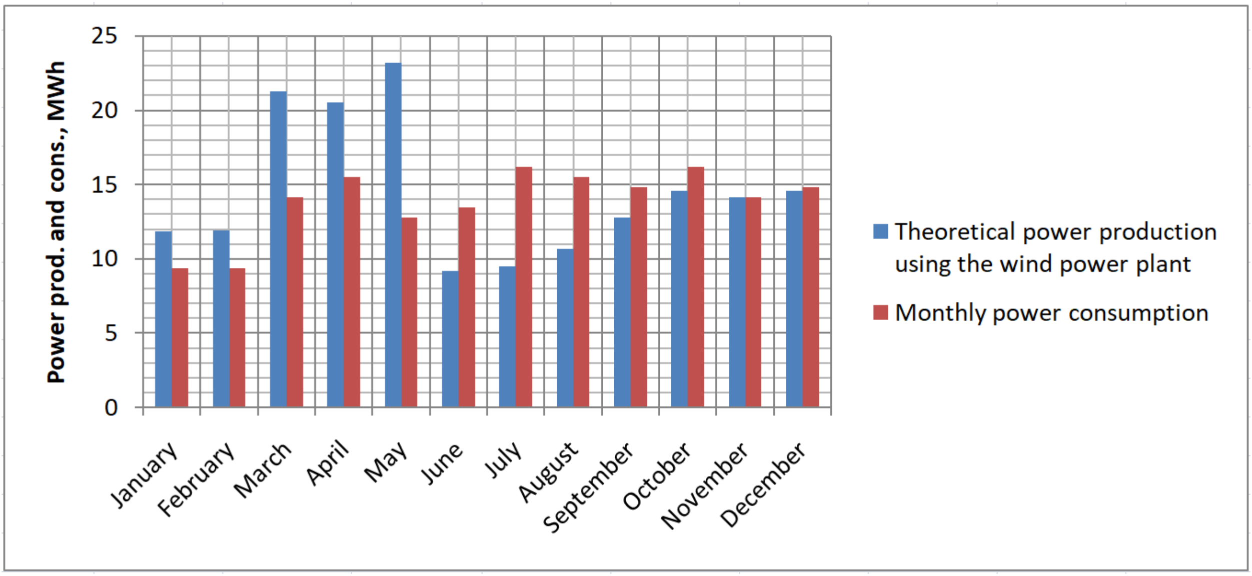

Figure 18 – Theoretical power production using a 430-kW wind turbine power plant.

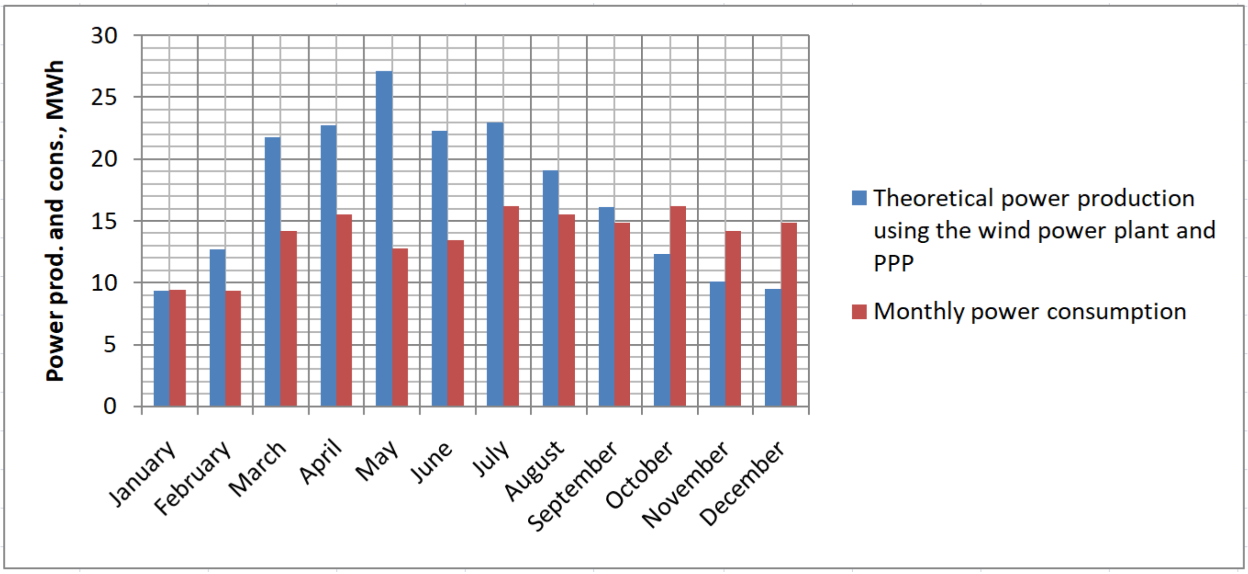

Figure 19 – Theoretical power production using a 132,6-kW photovoltaic power plant and a 210-kW wind turbine power plant.

We may see from the previous three graphs that power consumption exceeds power production during some months. To satisfy the needs of the enterprise during daily peaks and the time when energy production is not sufficient, I decided to install a diesel power plant as well as to use a battery set.

5.6.3 CapEx of the hybrid system

Capital expenses of the project with the hybrid system are shown in the Table 9.

Table 9 – CapEx of the project

Item	Investment 1 (mln. rub.)	Investment 2 (mln. rub.)	Investment 3 (mln. rub.)	Notes
Photovoltaic power plant	40,96	0	22,852	Investments include purchase of the main facilities, solar trackers, batteries, racks for the batteries, containers to store the batteries, bypass equipment, power inverters, mounting equipment as well as delivery and commissioning costs
Wind power plant	0	47,46	24,335	
Diesel power plant	2,892	2,892	2,892	This item includes purchase of the diesel generator, a container for it, costs of delivery and commissioning
Batteries	7,169	7,169	7,169	Purchase of batteries
Additional equipment	3,498	5,423	4,488	Purchase of an automatic transfer switch and the systems of uninterruptable power supply, electric connection of the consumers, purchase of the frequency regulators
Total	**54,519**	**62,944**	**61,736**	

5.6.4 OpEx of the hybrid system

Operating expenses are shown in the Table 10.

Table 10 – OpEx of the project

Item	Cost 1 (mln. rub)	Cost 2 (mln. rub)	Cost 3 (mln. rub)
Power engineer’s salary	1,543	1,543	1,543
Maintenance	0,22	1,03	0,761
Diesel generator fuel	0,397	0,425	0,199
Total OpEx	2,16	2,998	2,503

As we may see from the tables of capital and operating expenses, the first variant has lower costs. The first variant will be compared to the other projects of power supply.

Photovoltaic power plant, DPP and wind turbine generators are assumed to have lifetimes of 25 years. Batteries can serve for 5 years only so the company will need additional investments into the batteries (7,169 mln. rub each 5 years). The investments into batteries are assumed not to grow as costs of technology tend to decrease.

5.7 Installation of a gas generating power plant

5.7.1 Description of the installation

Gas generating power plant is a device whose operating principle is to generate combustible gas (pyrolysis gas) from solid fuel which is further used to generate electrical energy. A distinctive feature of this installation is that the fuel used for operation of this device is sawdust and wood chips, which are formed during normal activities of the company. These materials are absolutely free. This means that the cost of acquiring fuel will be zero, and, consequently, will lead to a decrease in the operational costs of the enterprise for implementation of the project.

The market of gas generating power plants is not diverse. There are few companies which produce gas generating power plants of good quality. I selected the company of Allpowerlabs and their flagship Power Pallet 30.

The reason for choosing this company is that the appliance has a high level of reliability as well as a simple way of operation. But the main advantage of this installation is that the operation of the installation is not based on the pyrolysis of wood, but the conversion of wood. Gas generation technology is a complex process of thermochemical conversion of fuel. It differs from pyrolysis in that the pyrolysis gases come out of the woods with water and resin. This process adversely affects the environment and makes it more difficult to use the installation.

Figure 20 – Biomass gasifier genset system Power Pallet 30 by Allpowerlabs. [23].

According to the Power Pallet's datasheet, the installed power of the appliance is 22 kW at a frequency of 50 Hz. Usually, power plants work at the level of 75-85% that gives us about 18 kW of power so the company needs six units of the device.

5.7.2 Investment in the project

One unit of the device costs 50 ths. dollars US. 6 units will cost 300 ths. dollars to the company. Delivery provided by the company PEK will cost approximately 50 ths. rubles. Commissioning cost is about 200 ths. rubles and the cost for wiring is 300 ths.rub. It was decided to use a diesel generator during days off as it is much simpler in operation for a security guard who will be in the company during weekends and holidays. Total capital expenditures are expressed in the following table.

Table 11 – CapEx in the gasifier project

Step	Cost (mln.rub)
Purchase of six gasifiers	24
Delivery of the installation	0,07
Commissioning	0,2
Wiring	0,3
Purchase of 6 containers	2,962
Delivery of the containers	0,75
Purchase of a diesel generator and its delivery	0,048
Motor soft starters	0,281
Additional expenses	0,5
Total CapEx	**29,111**

5.7.3 Operational expenditures the project

The operational costs of this project include several items. Firstly, this includes the planned costs of replacing consumables, namely the replacement of engine oil and filters. The biofuel gasifier generators have a lifetime period of 15 years and the containers, where the generators are placed, have a lifetime period of 25 years. The salary for the power engineers is also an item of operating expenses. The company needs additional investment into the internal combustion engine (ICE) on the 7^{th} , 14^{th} and 21^{st} year.

Now I have full information about operational expenditures. Annual costs are presented in the Table 12.

Table 12 – Operational expenditures of the project

Item	Cost (mln. rub)
Power engineer’s salary	1,543
Expendable materials	0,21
Diesel generator fuel	0,189
Total OpEx	1,941

5.8 Installation of a diesel generating power plant

5.8.1 Brief description of the diesel generating power plant

Diesel generator installation is the most common option for the selected region. This option is distinguished by its practicality, since the market for diesel generators is huge, prices are relatively low, and the operation process of the installation is not difficult.

Figure 21 – Diesel generator facility AKSA AJD 132. [24]

To implement the project, I selected three different diesel generator installations with different nominal powers.

Table 13 – Chosen diesel generator facilities

Diesel generator facility	Installed power, kW	Notes
AKSA AJD 132 [24]	105	The equipment is used to cover power consumption during the working hours
FUBAG DS 14000 [25]	10	The installation is used to cover the average level of power consumption (up to 10 kW)
FUBAG DS 3600 [26]	2,7	The diesel generator facility is used by the security guard during holidays and days off when the operation of the company is paused. It is also used to ensure power supply during low level of consumption during working days

5.8.2 Capital expenses in the project

Capital expenses of the project consist of purchasing of initial equipment, delivery, project and commissioning work as well as on-site work. The estimate cost is presented in the next table.

Table 14 – CapEx of the project

Step	Cost (mln.rub)	Notes
Investment into AKSA 132	2,892	Including purchase of the installation, delivery, purchase of containers as well as commissioning
Investment into FUBAG DS 14000	0,795	Including purchase of the installation, delivery, purchase of containers as well as commissioning
Purchase of an automatic transfer switch	0,112	Switching between the diesel installations
Purchase of diesel tanks	0,034	The operation is fulfilled to store the fuel
Investment into FUBAG DS 3600	0,048	Including purchase and delivery
Installation of an electrical wiring	0,3	Connection of the power consumers to the power source
Purchase of motor soft starters	0,281	Soft starters are used to reduce the influence of starting currents
Total CapEx	**4,462**	

5.8.3 Operational expenditures the project

Operating expenses of the project are presented in the Table 15.

Table 15 – OpEx of the project

Item	Cost (mln. rub)
Power engineer's salary	1,543
Expendable materials	0,2
Diesel generator fuel	2,71
Total OpEx	4,453

The company has to invest into the ICE's of diesel power plants each 7 years.

5.9 Facility on the basis of organic Rankine cycle

5.9.1 Description of the project

Equipment on the basis of organic Rankine cycle is a relatively new technology. The market of ORC equipment is small and the equipment costs much. In this work, I decided to choose 6500B produced by ElectraTherm. This facility allows operating at the power consumption level of 120 kW. In addition, it can normally operate even when the load is only 20 kW. This fact allows the company to install one facility only. The design life is expected as 25 years.

Figure 22 – Facility on the basis of ORC produced by ElectraTherm. [27]

5.9.2 Capital expenses in the project

Capital expenses in the project include purchase of the equipment that can work during the full period of working days. In addition, it is important to ensure stable electricity generation during the other days. So it is necessary to buy a diesel generator as an additional source of energy for holidays.

Table 16 – CapEx of the project

Step	Cost (mln.rub)
Purchase of the ORC facility 6500B	33,922
Commissioning	0,3
Shipping costs	0,5
Wiring to prepare for power consumption	0,3
Purchase of a diesel generator and its delivery	0,048
Purchase of motor soft starters	0,281
Additional expenses	0,5
Total CapEx	**35,851**

5.9.3 Operational expenditures the project

Operating expenses of the project are presented in the Table 17.

Table 17 – OpEx of the project

Item	Cost (mln. rub)
Power engineer’s salary	1,543
Expendable materials	0,2
Annual revision	0,3
Diesel generator fuel	0,189
Total OpEx	2,232

6 Economic comparison of the proposed variants of power supply

6.1 Inflation

The inflation rate is the percentage increase or decrease (deflation) in prices during a specified period, usually a month or a year. The percentage tells us how quickly prices rose during the period. Inflation reduces the purchasing power of each unit of currency, which leads to increases in the prices of goods and services over time.

Predicted Inflation rate is calculated as geometric mean of the inflation rates during the last 10 years in the Russian Federation. The formula of geometric mean for inflation rate calculation looks as follows:

$$r_{geom} = ((1 + r_1) \cdot (1 + r_2) \cdot \ldots \cdot (1 + r_n))^{1/n}$$

Where $r_1, r_2 \ldots r_n$ are inflation rates during the first, second…n-th year;
n is the number of years.

Predicted inflation rate equals to 6,69%. Historic Inflation rates were examined in the range from 2010 till 2019.

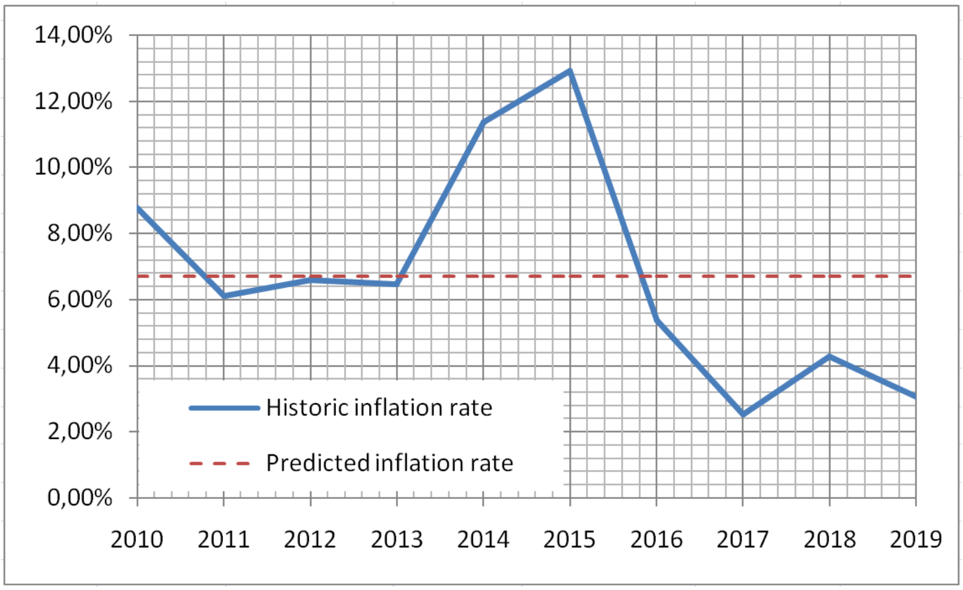

Figure 23 – Historic and predicted inflation rates for the Russian Federation. [28]

6.2 Escalation rate

Escalation rate is the rate of change in price for a particular good or service associated with an asset (as contrasted with the inflation rate, which is for a specific basket of goods and services).

In the current work, I assumed escalation of 7%. The escalation value was obtained through research on the Russian annual inflation rate, price change in diesel fuel, expendable materials and price of technologies.

6.3 Discount rate

The discount rate can be estimated as opportunity costs from alternative investments. I assume that the discount rate equals to 7,2%. It is a nominal rate which is based on risk-free asset namely governmental bonds. Taking into account inflation of 6,69%, I obtain the real value of the discount rate

$$r_{real} = \frac{r_{nom} - i}{1 + i}$$

Where r_{nom} is a nominal discount rate;
i is an expected inflation rate.

Real value of discount rate equals to 0,476%.

6.4 Net present value calculation

Net present value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows over a period of time. The formula is as follows:

$$NPV = \sum_{t=0}^{T} \frac{CF_t}{(1+r)^t} = \sum_{t=1}^{T} \frac{CF_t}{(1+r)^t} - Investment$$

Where CF_t is net cash inflow-outflow during a single period of time;
r is a discount rate or return that could be earned in alternative investments;
t is a number of a time period;
Investment is initial investments into the project. [29]

The cash flows are adjusted to the inflation value. The discount rate is chosen as 0,476%.

Table 18 represents the values of NPV for the given projects.

Table 18 – Net present values of the projects

Project	**NPV, mln. rub**
OTL	-151,096
Hybrid system	-116,732
Gasification system PP	-79,443
Diesel power plant	-91,987
ORC technology PP	-86,754

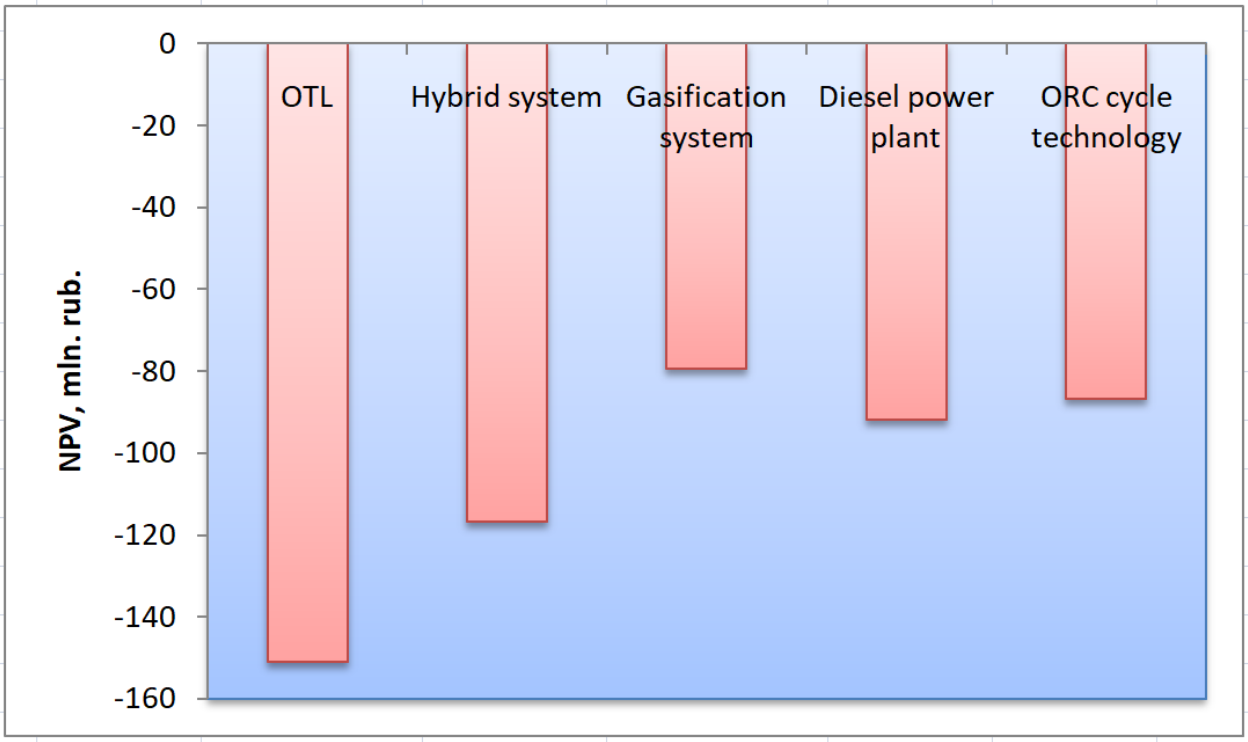

Figure 24 – Net present values comparison.

As we may see from the Table 18 and Figure 24, the net present values of the projects are negative. This happens due to the fact that revenues of the company are not included into the calculations. It may be seen from the bar chart that the gasification system project requires less cumulative payment over the lifetime of the project.

The NPV values are calculated according to the lifetimes of the projects. It is wrong to judge about the projects using NPV as it does not show the real situation. A better way to estimate the projects is to calculate equal annual annuities (EAA).

6.5 Equal annual annuity calculation

Calculation of equal annual annuities gives a better understanding of the economic situation of the projects with different lifetimes. The formula of equal annual annuity looks as follows:

$$EAA = NPV \cdot a_T$$

$$a_T = \frac{1}{PVAF} = \frac{(1+r)^T \cdot r}{(1+r)^T - 1}$$

Where *NPV* is a net present value of the project;

a_T is the annuity factor;

PVAF is the present value annuity factor;

r is the discount rate;

T is the number of periods. [30].

Using the previous formulas, I calculated the equal annual annuities of the projects. The calculations are performed using Excel software package.

Table 19 – Equal annual annuities of the projects

Project	**Lifetime period**	**Year of additional investment**	**EAA, mln. rub**
OTL	40	No additional investment	-4,157
Hybrid system	25 (5)	5, 10, 15, 20	-4,964
Gasifier system	25	7,14,21	-3,378
Diesel power plant	20	7,14	-4,833
ORC technology	25	No additional investment	-3,689

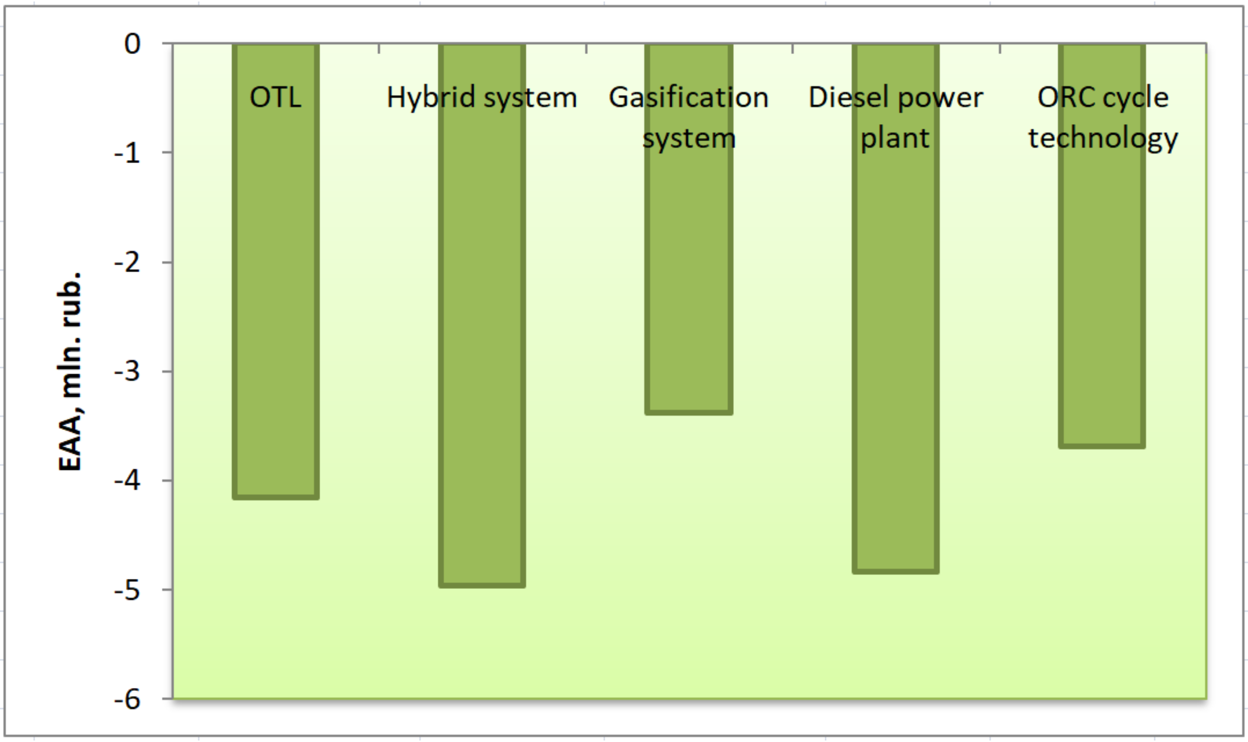

Figure 25 – Equal annual annuities comparison.

It can be seen from the bar chart that EAA is higher for the project of gasification system so this variant is the best solution for the logging enterprise.

The main disadvantage of the EAA method is assuming that a project can be replicated an infinite number of times. Moreover, its cash flows and cost of capital remain stable, but such a scenario is unlikely in practice.

6.6 Sensitivity analyzes of NPV and EAA on the real discount rate

The value of discount rate may vary significantly over time. So it is necessary to know how the net present values and equal annual annuities change depending on the level of discount rate. I performed sensitivity analyzes for all of the projects. The graphs of dependences of NPV's on the discount rate are shown in the Figure 26.

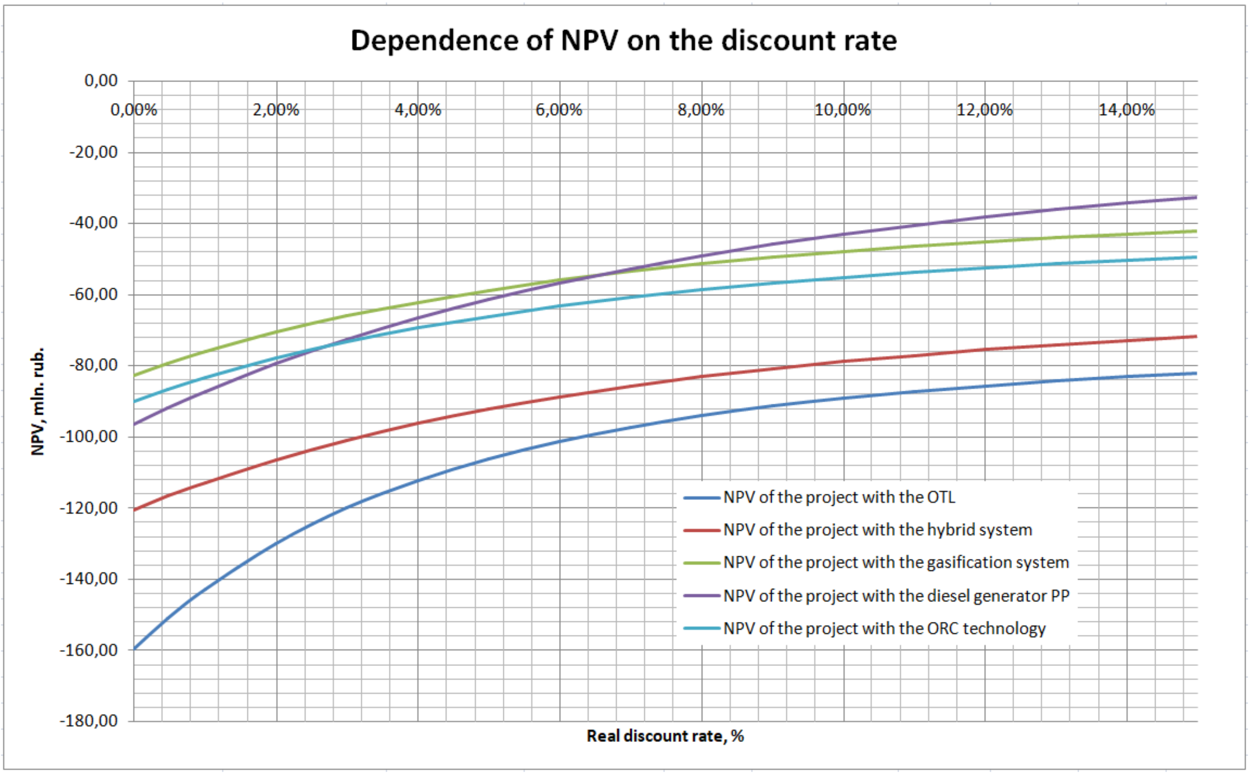

Figure 26 – Dependence of the net present values on the discount rate.

As we may see from the graphs, the dependence of the net present values in non-linear. The project of installation of the biofuel gasification system shows the best result on the range from 0% til approximately 6,5% as it has higher levels of NPV. The results are performed on the range from 0 till 15%. It does not make sense to consider a higher discount rate level as it does not seem to be real.

The Figure 27 represents a dependence of the EAA's on the discount rate.

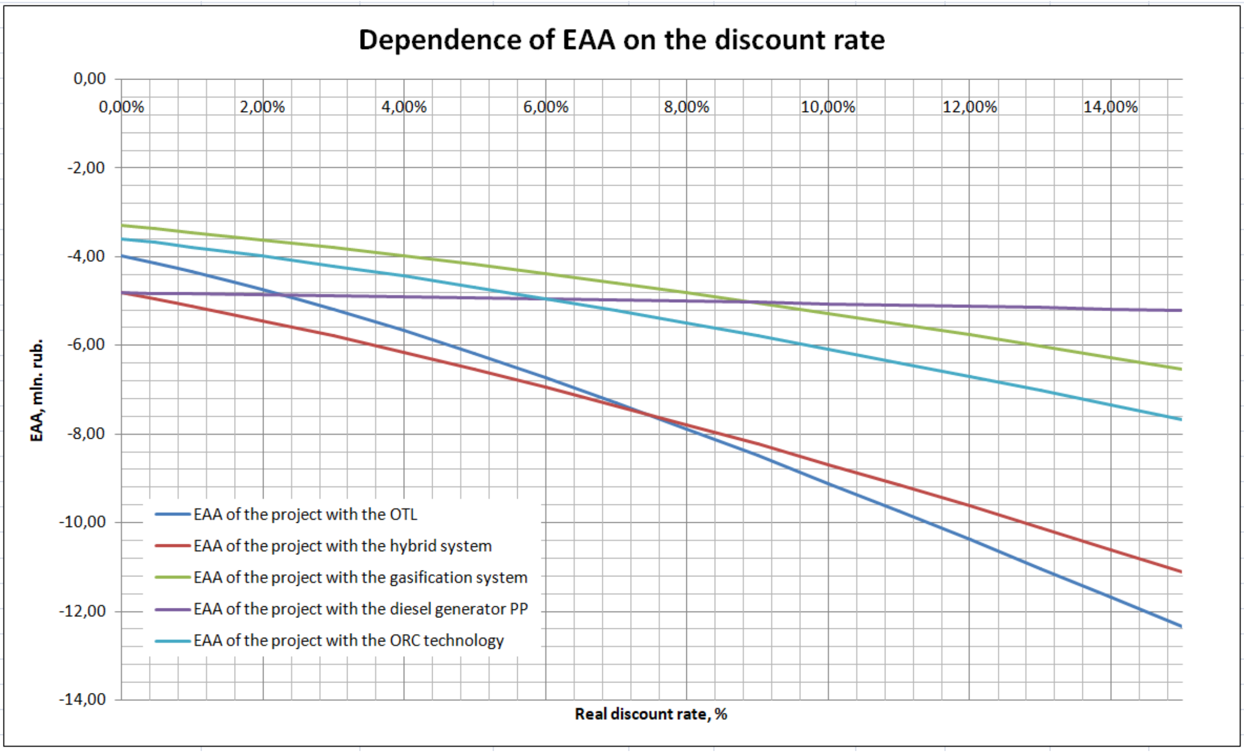

Figure 27 – Dependence of the equal annual annuities on the discount rate.

The dependences are also non-linear. In the range from 0% to 15% of the discount rate, the equal annual annuity of the gasification system is higher than the curves of the other types of electricity sources from0% till 9% of the real discount rate. It means that annual cash outflows are less and the project is more effective as well.

As we may see from the previous analyzes, economic parameters of the project with the biofuel gasification system are higher so this project will be implemented for the logging enterprise.

6.7 Sensitivity analyzes of the biofuel gasification system project

I would like to make some sensitivity analyzes of the biofuel gasification system project. The following graph shows dependence of NPV of the biofuel gasification system project on initial investments.

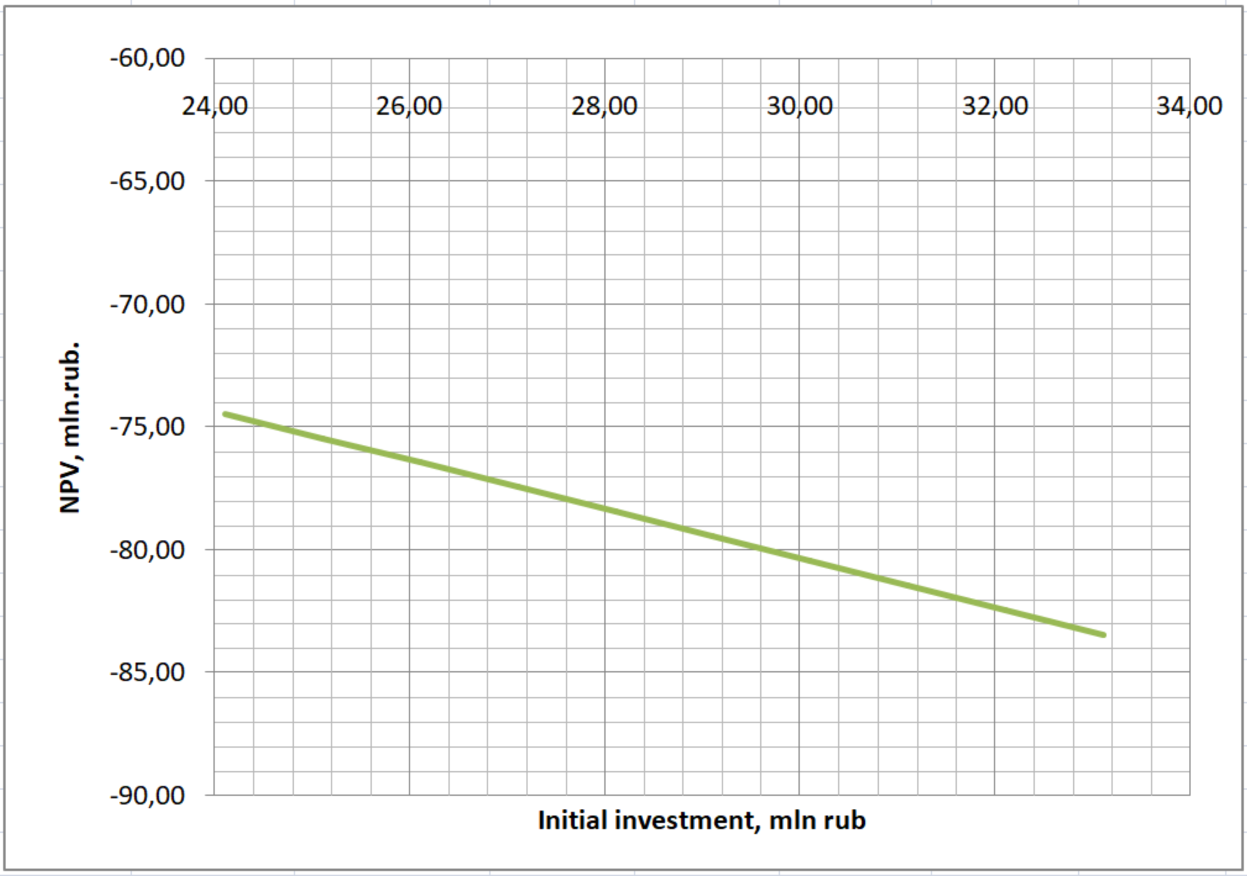

Figure 28 – Dependence of NPV of the biofuel gasification system project on initial investment cost.

We may see from the Figure 28 that the dependence of NPV on biofule gasification system investments is linear. It happens due to the fact that initial investment cost is not discounted in the net present value calculation.

Tomsk region has a plenty of isolated consumers. Diesel power plants are mainly used to provide electric power supply to isolated consumers. So it is important to compare this variant to the one proposed by me. The following graph represents dependence of the diesel power plant and biofuel gasification system projects on the output price of fuel.

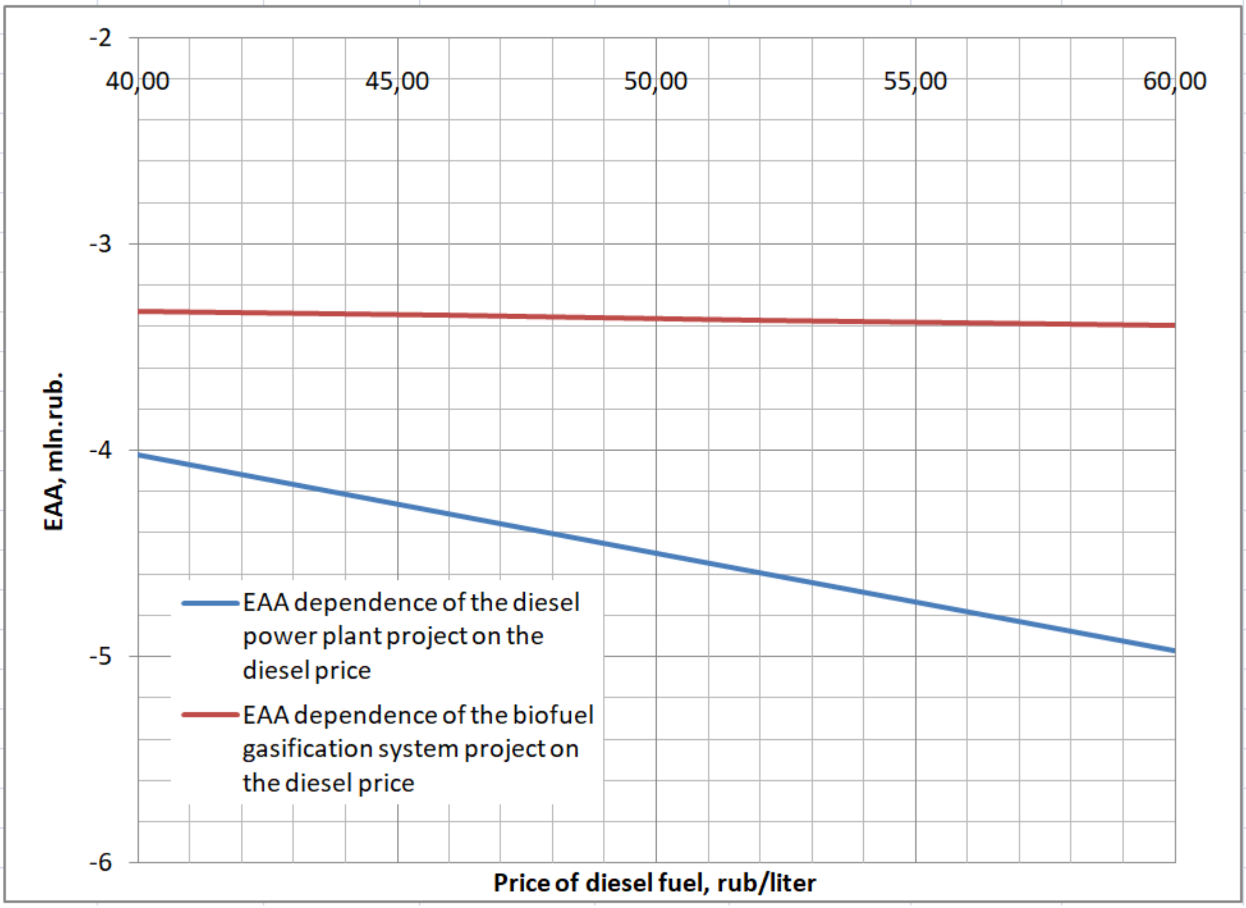

Figure 29 – EAA comparison of the project on the price of diesel fuel.

From the Figure 29, we may see that equal annual annuities of the diesel power plant project are lower in all the points. It means that even if I find a distributor of diesel fuel who offers the price of 40 rub per one liter of diesel fuel the diesel power plant project is still less economically efficient than the biofuel gasification system project. We may also see from the graph that the biofuel gasification system project is also dependent on diesel fuel price. It is due to the fact that the security guard uses a low-capacity diesel power set to satisfy his/her electricity needs during weekends and holidays.

6.8 Bank loan for the project

I assumed that the company needs 30 mln. rub. for implementation of the project. The company already has a half of this value and it needs a loan of 15 mln. rub. The loan is based on equal annual payments and it can be borrowed with the following conditions:

Table 20 – Loan conditions

Item	Value
Value of loan	15 mln. rub.
Interest rate	12,9%
Duration of the loan	10 years

To understand how much the company should pay in total, we need to evaluate the amount which the company would pay each month firstly. It can be done using the formula of present value annuity factor. The interest rate is divided by 12 as payments are fulfilled once a month.

$$PVAF = \frac{1-(1+\frac{r}{12})^{-T\cdot 12}}{(1+\frac{r}{12})-1} = \frac{1-(1+\frac{12,9\%}{12})^{-10\cdot 12}}{(1+\frac{12,9\%}{12})-1} = 67,24$$

Where r is the bank interest rate;

T is the loan duration.

Now it is possible to find the value of monthly payment:

$$PV = PMT \cdot PVAF$$

$$PMT = \frac{PV}{PVAF} = \frac{15000000}{67,24} = 223082,24\ (rub. per\ month)$$

The company must pay to the bank during 10 years the following sum:

$$Repayment = PMT \cdot 12 \cdot T = 223082,24 \cdot 12 \cdot 10 = 26769869,18 \text{ rub.}$$

Where PMT is a monthly payment;

T is duration of the loan.

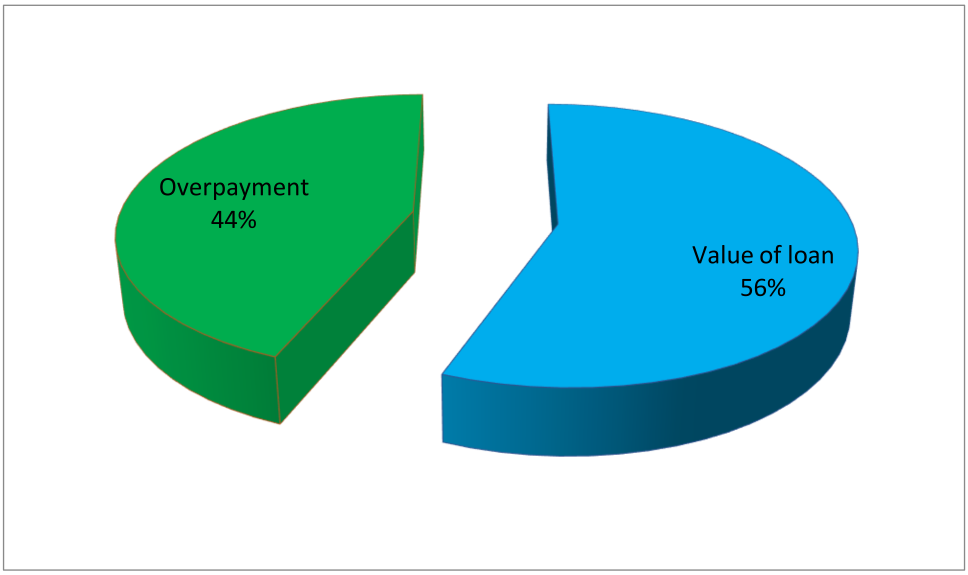

Figure 30 – Shares of loan and overpayment.

The company have to pay 223082,24 rubles each month and 26769869,18 rub during the loan period of ten years. The payment strategy is shown in the Figure 31.

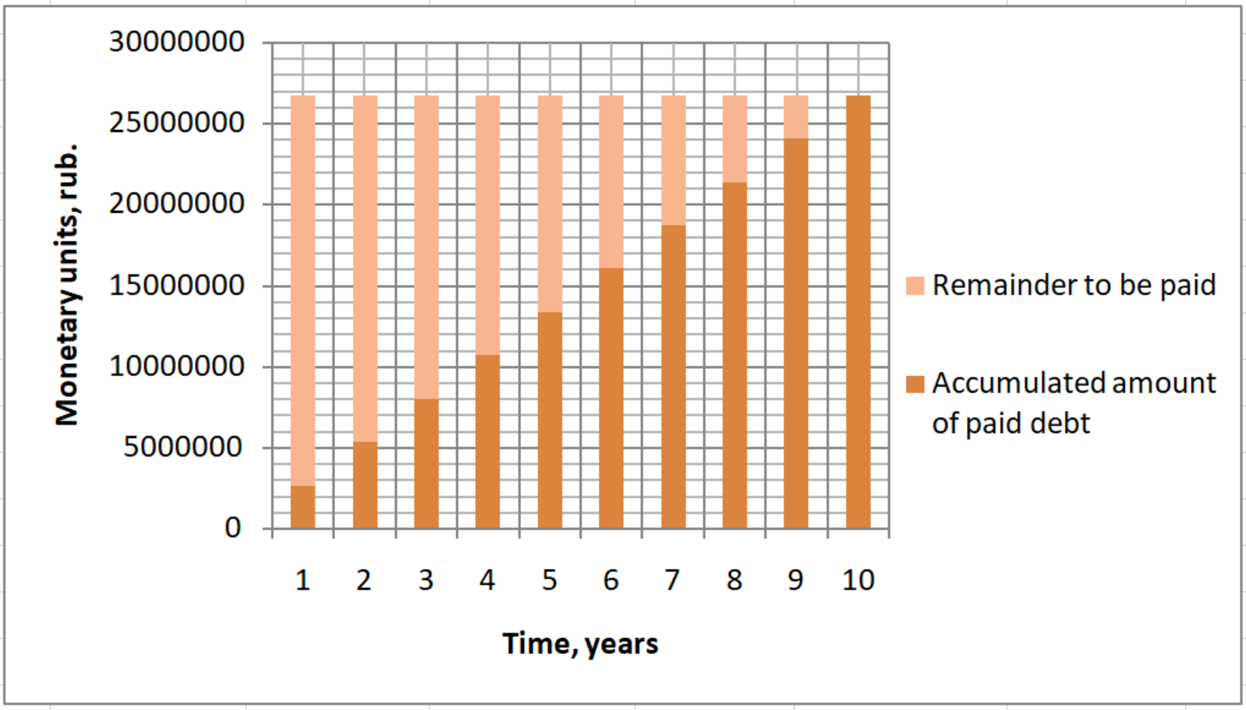

Figure 31 – Debt payment strategy.

7 Recommendations on optimization for the logging enterprise

According to the research from the previous chapters, the best from the proposed decisions for the logging enterprise is to implement the project with the biomass gasification system. In this chapter I am going to propose some ways for optimization of that project.

The first suggestion refers to use of the gasifiers. To satisfy needs of the company, I decided to install six gasification systems. According to the datasheet, each of them can ensure a power level of 22 kW in a continuous 50-Hertz operation mode. Real power value may be a little lower due to quality of woodchips and their humidity. Usually this level is about 75-85% of the nominal value. To ensure high level of power generation, I would propose to properly dry the woodchips before use in the gasification systems. To dry the woodchips properly, it is needed to leave them in dry conditions for several months. It would be a good idea to build a wooden warehouse to store the woodchips. The woodchips will be protected from humidity and rain drops.

As the second suggestion, I advise to properly share working period between the installations during low load periods. According to the final load graph, it may be seen that there are high (from 9 am till 13 pm and from 14 pm till 18pm) and low (from 18 pm to 9 am and 13 pm till 14 pm) load levels. One set is enough to ensure power supply during low load time. The question is which one to choose. I propose to share the low level load time equally between the sets. It will help not to overload the equipment and will reduce the number of possible failures of the equipment.

CONCLUSIONS

The goal of the work was to provide the logging enterprise with a high-quality and reliable source of electric energy which can guarantee a stable process of work. Performing my Master's thesis, I fulfilled several steps. Firstly, I examined the logging enterprise location area. The area factor is significant. Some of the electrical energy sources were not included in the list of sources as their use is not possible in severe weather conditions. The company had to install additional equipment to withstand the weather conditions (arctic containers, heaters and heating systems and others).

The second step, I estimated daily energy consumption of the enterprise. It is the most significant step in the work. Selection of a power source is always based on the load. I estimated load during working days as well as during days off and holidays. Annual power consumption was also evaluated

The third step is selection of a power source. I proposed five sources to consideration basing on the assumption that all of them have the same level of quality and reliability. I estimated their investment costs and operating expenses with a certain annual escalation.

The fifth step is economic evaluation of the proposed variants. Net present values and equal annual annuities were calculated to compare the projects. I also made several sensitivity analyzes of the projects. According to the results, the project with the biofuel gasification system turned out to be the most economically efficient variant. This source of power supply will be implemented in the logging enterprise.

The result of the work is installation of a biofuel gasification system as a source of electric power energy for the enterprise.

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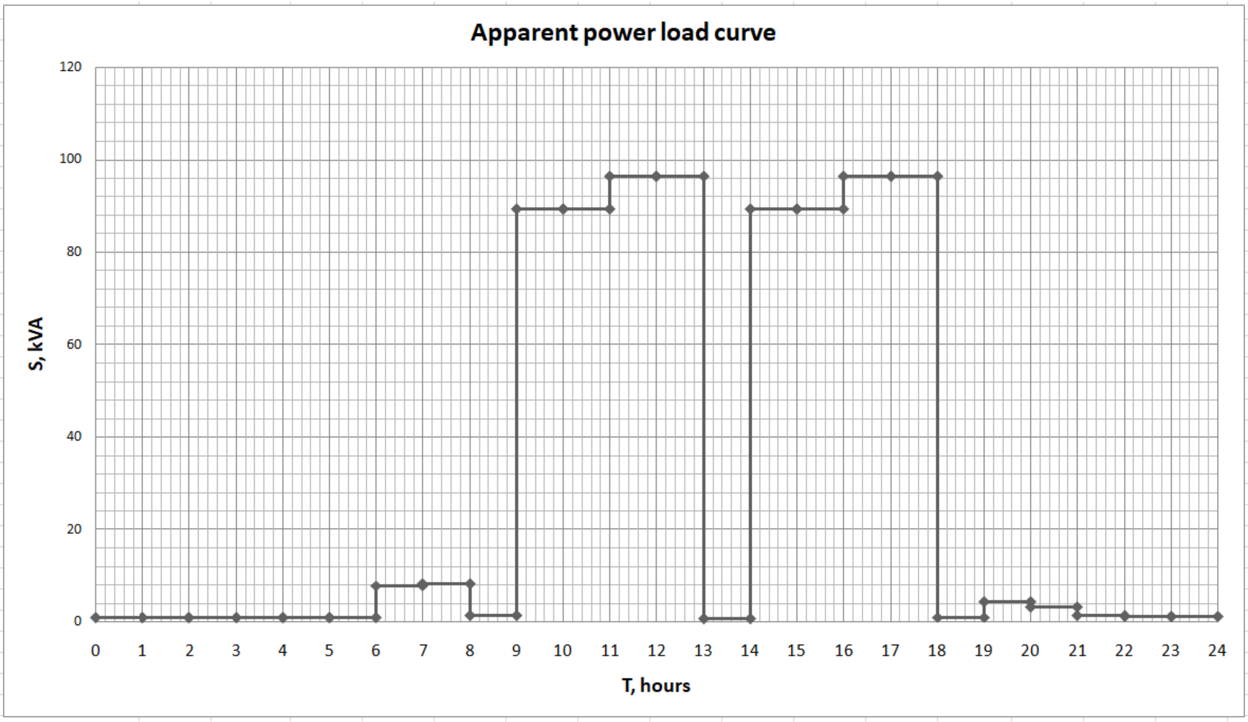
APPENDICES

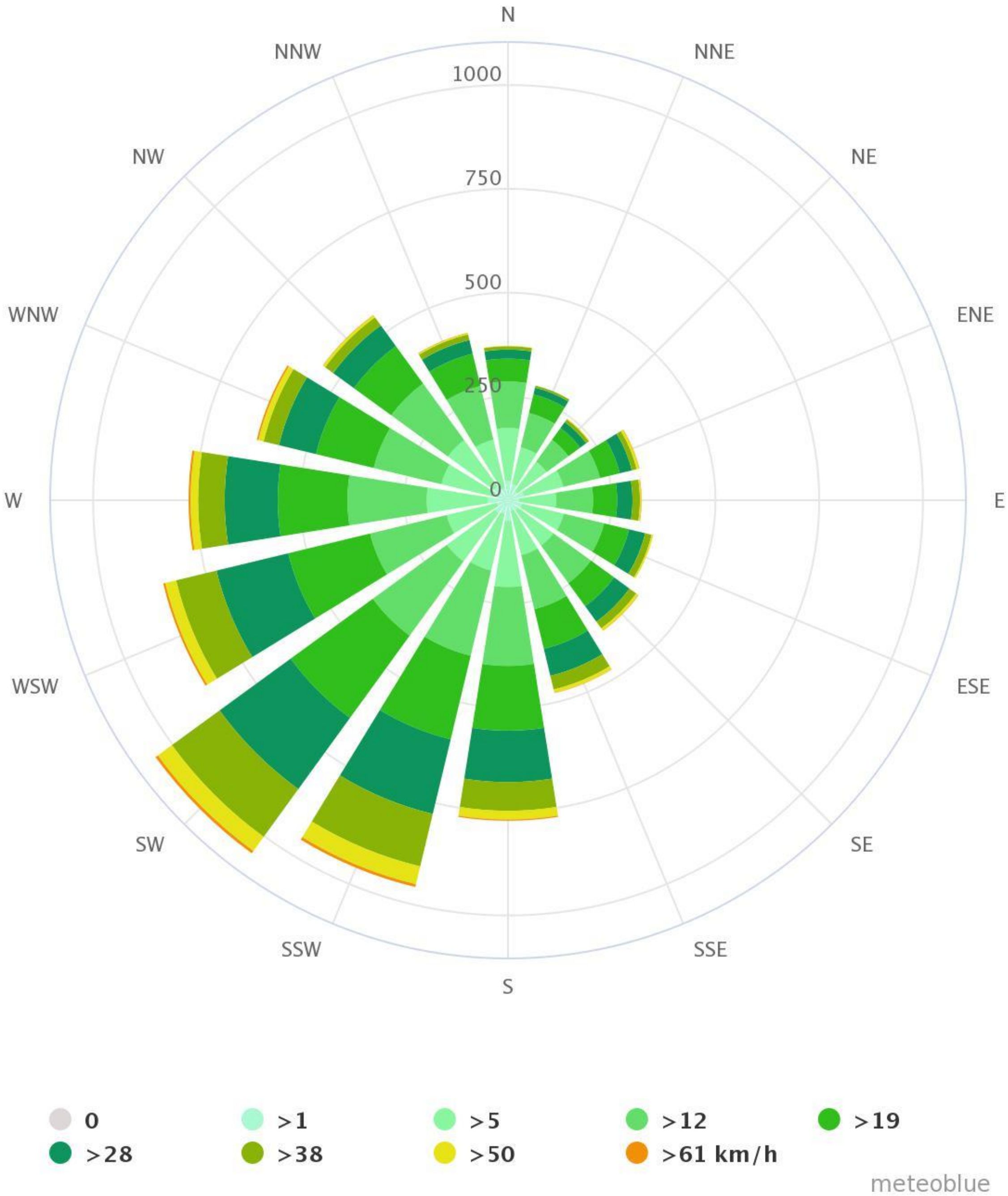
Appendix A – Apparent power load curve



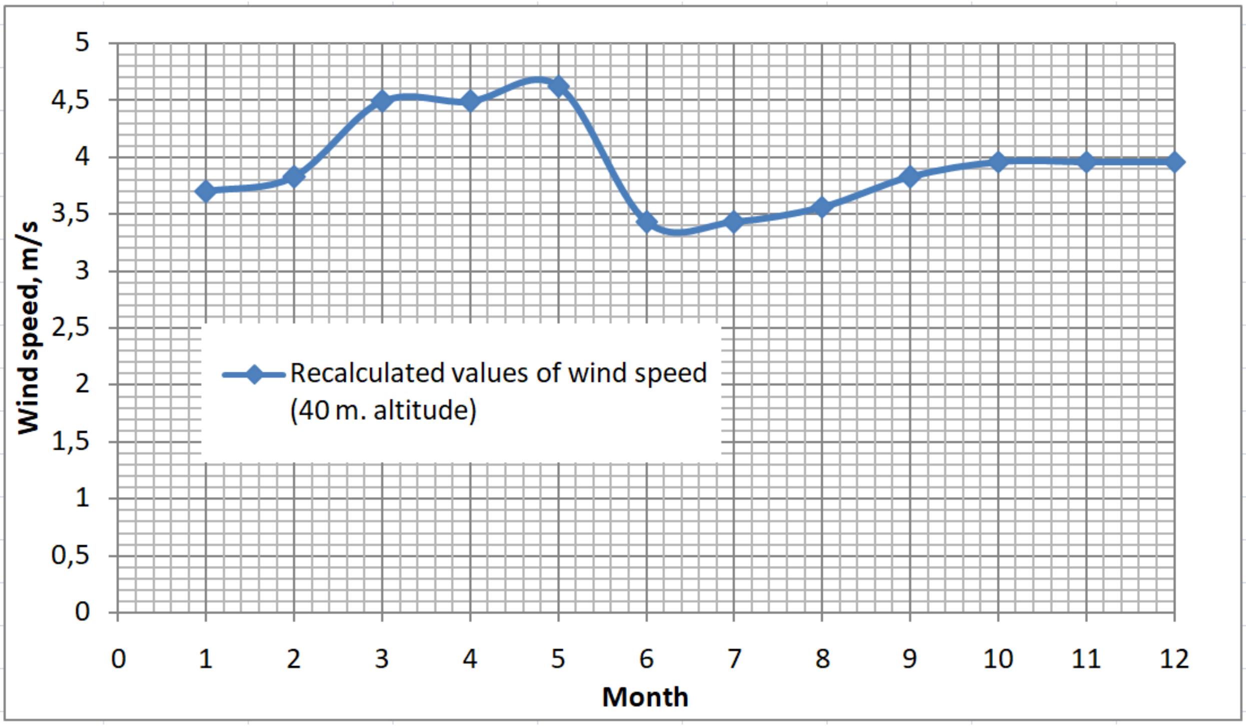
Appendix B – Passport data of 100-kW wind turbine generator produced by “EnergoStok”

Item	Value
Nominal power	100 kW
Output voltage	380V
Number of blades	3 units
Rotor diameter	21 m
Starting speed	2,5 m/s
Nominal wind speed	12 m/s
Maximum working wind speed	25 m/s
Generator	3 phase, asynchronous
Efficiency	90%
Turbine weight	3950 kg
Noise	no more than 70db
Internal temperature range	-40 to +60
Lifetime	25 years
Guarantee	2 years

Appendix C – Rose of Wind for the local area



Appendix D – Recalculated values of wind speed



Appendix E – Inflation rate in the Russian Federation during the last 10 years

Year	Inflation rate
2019	3,05%
2018	4,27%
2017	2,52%
2016	5,38%
2015	12,91%
2014	11,36%
2013	6,45%
2012	6,58%
2011	6,10%
2010	8,78%